



**ISRS'2021**  
INTERNATIONAL  
STEEL ROLLING  
SYMPOSIUM  
23 - 24 SEPTEMBER  
İSKENDERUN


ULUSLARARASI  
H A D D E  
SEMPOZYUMU



## Proceedings Book Bildiriler Kitabı

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**Proceedings Book**  
**Bildiriler Kitabı**

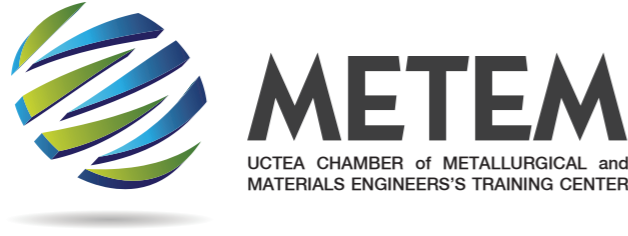


**METEM**

UCTEA CHAMBER of METALLURGICAL and  
MATERIALS ENGINEERS'S TRAINING CENTER

UCTEA CHAMBER OF METALLURGICAL AND MATERIALS ENGINEERS  
TMMOB METALURJİ VE MALZEME MÜHENDİSLERİ ODASI





## UCTEA CHAMBER OF METALLURGICAL AND MATERIAL ENGINEERS'S TRAINING CENTER

METEM (TMMOB Chamber of Metallurgical and Materials Engineers Training Center) gathers whole sector and cooperate for sustainable development and transformation of the sector. Also, it combines the qualified knowledge of industry, university and colleagues;

- Aims to be integrated to the world, with national and international symposiums, congresses, conferences, seminars,
- Provides highly qualified trainings and consultancy with scientific, technical and practical approach,
- Support sectoral and social developments with own projects,
- Acts as an powerful and active center by providing information, new aspects, relationships, and cooperation to create new opportunities.

METEM organizes many activities in order to reach the increasing knowledge accumulation, to share the experiences and to evaluate them in production processes.

Many such as the EFRS International Iron and Steel Symposium, IMMC International Metallurgy and Materials Congress, ISRS International Steel Rolling Symposium, ALUS International Aluminum Symposium, MCHTSE Mediterranean Heat Treatment and Surface Engineering Conference, congresses, conferences and symposium organization carries out.

In addition, it provides in-house training and consultancy services open to general participation. Engineers, scientists, researchers and production managers; in order to review and discuss new challenges, recent developments and issues.

For that purpose, by bringing together highly qualified and experienced experts from the university and industry, we are able to; technical, managerial and engineering knowledge to refresh, making business development related to the sector's problems, occupational health and safety in problem solving, quality and to increase awareness and thus aim to provide value-added training and events planning, engages.

METEM also demonstrates "researches of Turkish metallurgy industry and universities" to the world, by organizing "international congresses, conferences and symposiums".

METEM is at the service of our sector with its trust, diligence, beliefs and values for improvement.



## TMMOB METALURJİ VE MALZEME MÜHENDİSLERİ ODASI EĞİTİM MERKEZİ

METEM (TMMOB Metalurji ve Malzeme Mühendisleri Odası Eğitim Merkezi) tüm sektörü bir araya getirerek sektörün gelişimi ve dönüşümü için çalışmaktadır. Sanayi, üniversite ve meslektaşlarının nitelikli birikimlerini birleştiren METEM;

- Geliştirdiği ve planladığı tüm ulusal ve uluslararası sempozyum, kongre, konferans, seminer gibi organizasyonlarıyla dünyaya entegre olabilmek üzere çalışan,
- Bilimsel, teknik ve uygulamaya yönelik nitelikli eğitim ve danışmanlık hizmetleri veren,
- Sektörel ve toplumsal gelişimi planladığı projelerle destekleyen,
- Bilgi, yeni açılımlar, ilişkiler, fırsatlar yaratma konusunda işbirlikleri sağlama üzerinden hareket eden güçlü bir etkinlik merkezidir.

Artan bilgi birikimine hızla ulaşmak, edinilen deneyimleri paylaşmak ve bunları üretim süreçlerinde değerlendirmek üzere, METEM bünyesinde birçok etkinlik düzenlenmektedir.

EFRS Uluslararası Demir Çelik Sempozyumu, IMMC Uluslararası Metalurji ve Malzeme Kongresi, ISRS Uluslararası Hadde Sempozyumu, ALUS Uluslararası Alüminyum Sempozyumu, MCHTSE Akdeniz Isıl İşlem ve Yüzey Mühendisliği Konferansı gibi birçok; kongre, konferans ve sempozyum organizasyonları gerçekleştirmektedir.

Bunun yanı sıra genel katılıma açık, şirketçi eğitimler ve danışmanlık hizmetleri vermektedir. Mühendislere, bilim adamlarına, araştırmacılara ve üretim yöneticilerine; alanlarında yeni zorlukları, son gelişmeleri ve ortaya çıkan konuları gözden geçirip tartışabilecekleri ortamlar hazırlamaktadır.

Yine bu amaçla, üniversite ve sanayide yer alan, yüksek bilgi ve deneyime sahip uzmanları bir araya getirerek, sektöre ve sektör çalışanlarına yönelik; teknik, yönetsel ve mühendislik bilgilerini tazelemeyi, sektörün sorunlarına ilişkin iş geliştirmeler yapmayı, çalışan sağlığı ve güvenliğinde sorun çözmeyi, nitelik ve farkındalık kazandırmayı ve böylece katma değer sağlamayı hedefleyen, eğitimler ve etkinlikler planlayıp yürütmektedir.

METEM gerçekleştirdiği uluslararası etkinlikler ile Türkiye metalurji sektörünün ve akademik araştırmalarının dünyaya tanıtılmasına katkı sağlamaktadır.

METEM, güven, çalışkanlık, iyiye ve değişime olan inanç ve değerleriyle sektörümüzün hizmetindedir.



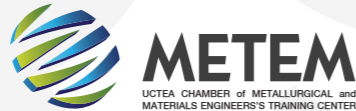
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## Organization Committee Organizasyon Komitesi



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## ORGANIZATION COMMITTEE

## YÜRÜTME KURULU



**Kadir KARA (Chairman)**  
Ekinciler Demir Çelik



**Özgür AKKANAT**  
Diler Demir Çelik



**Ayhan AYDIN**  
İskenderun Demir Çelik



**Andaç BİRİŞÇİ**  
Cares



**Yılmaz ÇAM**  
Noksel Çelik Boru



**Bahri İKİZ**  
Tosyalı Demir Çelik



**Mahmut KESKİNCİ**  
Çolakoğlu Metalurji



**Özgür NAL**  
Baştuğ Metalurji



**Ahmet Can ÖZDEMİRLER**  
Duferco



**Ö. Devrim ÖZSOY**  
İzmir Demir Çelik



**Ozan YAPICI**  
Yazıcı Demir Çelik





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SUPPORTING MANUFACTURERS

DESTEKLEYEN ÜRETİCİ FİRMALAR



**Çolakoğlu Metalurji**



İZMİR DEMİR ÇELİK  
SANAYİ A.Ş.



**KARDEMİR**



**NOKSEL**

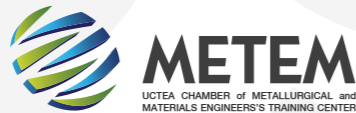


**TOSYALI**  
HOLDİNG



**YAZICI**

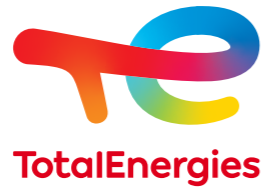
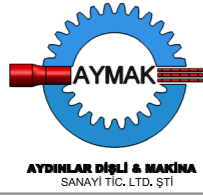
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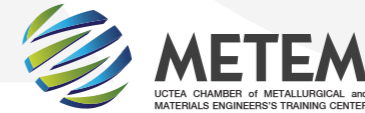
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Exhibitors  
Sergi Katılımcıları



UCTEA CHAMBER OF METALLURGICAL and  
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UCTEA CHAMBER OF METALLURGICAL and  
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**EXHIBITORS****SERGİ KATILIMCILARI**

Firm // Firma	Hall // Salon	Stand No
3-S MÜHENDİSLİK-QUAKER HOUGHTON	Terrace // Teras	<b>T-07</b>
AB INDUSTRIALS	Sea Side // Deniz	<b>DT-17</b>
AKM METALURJİ	Down Garden // Alt Bahçe	<b>B-04</b>
ALP MÜHENDİSLİK	Centro	<b>C-05</b>
ARC SU ARITMA	Sea Side // Deniz	<b>DT-04</b>
AYDINLAR DIŞLI	Sea Side // Deniz	<b>DT-01</b>
AYDINLAR REFRAKTER	Terrace // Teras	<b>T-02</b>
BAŞTUĞ METALURJİ	Terrace // Teras	<b>T-01</b>
BCS MÜHENDİSLİK	Sea Side // Deniz	<b>DT-13</b>
BLS MAKİNA	Sea Side // Deniz	<b>DT-15</b>
CASTROL	Terrace // Teras	<b>T-04</b>
DEMORA	Sea Side // Deniz	<b>DT-05</b>
EFES METALURJİ	Down Garden // Alt Bahçe	<b>B-01</b>
GERMAKSAN	Sea Side // Deniz	<b>DT-03</b>
GÜNEY ATEŞ REFRAKTER	Sea Side // Deniz	<b>DT-09</b>
GÜNEY HİDROPAR	Centro	<b>C-06</b>
HAKAN HİDROLİK	Centro	<b>C-02</b>

**EXHIBITORS****SERGİ KATILIMCILARI**

Firm // Firma	Hall // Salon	Stand No
HAMDİ KÜÇÜK	Sea Side // Deniz	<b>DT-10</b>
HİDROHAN HİDROLİK	Sea Side // Deniz	<b>DT-06</b>
HİSAR ÇELİK	Down Garden // Alt Bahçe	<b>B-03</b>
IHI DALGAKIRAN	Sea Side // Deniz	<b>DT-08</b>
KILTAŞ	Sea Side // Deniz	<b>DT-11</b>
KONUM MAKİNE	Sea Side // Deniz	<b>DT-12</b>
KORTEK	Sea Side // Deniz	<b>DT-14</b>
ORTATEPE-TIMKEN	Terrace // Teras	<b>T-06</b>
PETROFER	Terrace // Teras	<b>T-03</b>
PETROL OFİSİ	Centro	<b>C-03</b>
PRÜFTEKNİK	Terrace // Teras	<b>T-05</b>
SAĞLAM METAL	Sea Side // Deniz	<b>DT-07</b>
SAYGILI RULMAN	Sea Side // Deniz	<b>DT-02</b>
TEKNOMETALURJİ	Terrace // Teras	<b>T-08</b>
TOTAL	Centro	<b>C-04</b>
UFUK RULMAN EGS & KIS	Sea Side // Deniz	<b>DT-16</b>



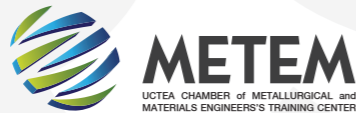
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## Symposium Programme Sempozyum Programı



### 23 September Thursday // 23 Eylül Perşembe

TIME/SAAT	Hall / Salon - ISSOS
09:00	<b>Registration // Kayıt</b>
09:55 - 10:30	<b>Opening Ceremony // Açılış Konuşmaları</b> <b>İrfan TÜRKKOLU</b> UCTEA MME Executive Board , Chair TMMOB MMMO Yönetim Kurulu Başkanı <b>Ata ÖZDEMİRLER</b> METEM Executive Board , Chair METEM Yürütme Kurulu Başkanı <b>Kadir KARA</b> ISRS2020 Organization Board, Chair ISRS2020 Sempozyum Yürütme Kurulu Başkanı
10:30 - 11:30	<b>Plaque Ceremony // Plaket Töreni</b>
11:30 - 12:50	<b>Plenary Panel // Açılış Paneli</b>
12:50 - 13:00	<b>Exhibition Opening // Stand Açılışı</b>
13:00 - 14:00	<b>Lunch Break // Öğle Yemeği</b>

### 23 September Thursday // 23 Eylül Perşembe

TIME/SAAT	Hall / Salon - ISSOS
14:00 - 14:20	<b>EHS- Paper of Safe and Sound Together Movement</b> ÇSG- Birlikte Sağ Salim Hareketi Bildirisi
14:20 - 15:40	<b>Industry 4.0/Digitalization &amp; Sustainability</b> Endüstri 4.0/Dijitalizasyon & Sürdürülebilirlik
15:40 - 16:10	<b>Coffee Break / with ALYORK</b> Çay /Kahve Arası ALYORK Sponsorluğunda
16:10 - 17:20	<b>High Quality Steel // Vasıflı Çelik</b>
19:00	<b>Stand Closing // Stand Kapanış</b>
19:30	<b>Gala Dinner / with CASTROL</b> Gala Yemeği CASTROL Sponsorluğunda



24 September Friday // 24 Eylül Cuma	
TIME/SAAT	Hall / Salon - ISSOS
09:30 - 10:50	<b>Long Products</b> // Uzun Ürünler
10:50 - 11:20	<b>Coffee Break</b> // Çay /Kahve Arası
11:20 - 12:20	<b>Thermomechanical Rolling</b> // Termomekanik Haddeleme
12:30 - 13:30	<b>Poster Control</b> // Poster Kontrol
12:20 - 13:20	<b>Lunch Break</b> // Öğle Yemeği
13:20 - 14:40	<b>Flat Products</b> // Yassı Ürünler
14:40 - 15:10	<b>Coffee Break</b> // Çay /Kahve Arası
15:10 - 16:10	<b>Lubricants</b> // Yağlama
16:10 - 16:40	<b>Coffee Break</b> // Çay /Kahve Arası
16:40 - 17:40	<b>Imaging &amp; Measuring Systems</b> Görüntüleme ve Ölçüm Sistemleri
18:30	<b>Symposium Closing and Cocktail Prolonge</b> Sempozyum Kapanışı ve Kokteyl Prolonge

## 23 September / Eylül 2021

Hall/Salon **Plenary Panel** // Açılış Paneli  
ISSOS

11:30 - 12:50



Panel Chairman / Panel Başkanı  
**Ata ÖZDEMİRLER - Kaptan Demir Çelik**

### Panelists / Panelistler



Osman GÖZÜKARA  
Yazıcı Demir Çelik



M. Fatih KESEROĞLU  
Ekinciler Demir Çelik



Suhat KORKMAZ  
Tosyalı Holding

14:00

14:20

### EHS- Paper of Safe and Sound Together Movement // ÇSG- Birlikte Sağ Salim Hareketi Bildirisi

**Zero Accident Target or Normal?  
Paradigm Exchange with Metallurgy Industry; "Safe and  
Sound Together Movement in Turkey"**  
"Sıfır Kaza Hedef mi? Normal mi?  
Türkiye'de Metalurji Sektöründe "Birlikte Sağ Salim Hareketi" İle  
Paradigma Değişimi"

**İdil Işık<sup>1</sup>, Elif Sungur<sup>2</sup>, Müzeyyen Gencer<sup>3</sup>, Murat Can Ocaktan<sup>3</sup>**  
<sup>1</sup>İSTANBUL BİLGİ ÜNİVERSİTESİ, <sup>2</sup>MALTEPE ÜNİVERSİTESİ, <sup>3</sup>METEM  
Türkiye

## 23 September / Eylül 2020

## 23 September / Eylül 2020

Hall/Salon  
ISSOS

### Industry 4.0/Digitalization & Sustainability

Endüstri 4.0 / Dijitalizasyon & Sürdürülebilirlik

Session Chairman / Oturum Başkanı

**Nuri GÜRKAN - İZMİR DEMİR ÇELİK**

14:20

#### Industry 4.0 - Proactive Quality Assurance – Automated Coil Release

Endüstri 4.0 – Proaktif Kalite Yönetimi ile Otomatik Bobin Değerlendirme

**Helga Evers, Sevda Sarova**

QUINLOGIC

Germany

14:40

#### Digital Transformation for the Reinforcing Steel Supply Chain

Yapı Çeliği Tedarik Zincirinde Dijital Dönüşüm

15:00

**Lee Brankley<sup>1</sup>, Ladin Camci<sup>1</sup>, Ayhan Tugrul<sup>1</sup>,  
Andac Birisci<sup>1</sup>, Andrew Woolnough<sup>2</sup>**

<sup>1</sup>CARES, <sup>2</sup>CARES Digital Partner / Constructive Group  
United Kingdom, U.A.E.

15:00

#### Rolling into the Future by Digitalization, Primetals Technologies Long Rolling Control System

Dijitalizasyon ile Geleceğe Doğru Haddeme

15:20

**R. Kirkwood-Azmat<sup>1</sup>, A. Papiez<sup>2</sup>**

<sup>1</sup>PRIMETALS TECHNOLOGIES USA,

<sup>2</sup>PRIMETALS TECHNOLOGIES POLAND

USA, Poland

15:20

#### Metal Endüstrisinde RPA (Robotic Process Automation) ile Maliyet Azaltma

Cost Reduction with RPA (Robotic Process Automation) in Metal Industry

15:40

**K. Mert Demirci, Burak Yılmaz**

CORPORATE SENSE

Türkiye

Hall/Salon  
ISSOS

### High Quality Steel

Vasıflı Çelik

Session Chairman / Oturum Başkanı

**Cevdet ÖZDURMUŞ - DİLER DEMİR ÇELİK**

16:10

#### Türkiye'de İlk Demiryolu Teker ve Ray Üretimi

First Railway Wheel and Rail Production in Turkey

16:40

**Hüseyin Erten, Serkan Atamer, Sait Hadutoğlu, Mücahit Sevim**

KARABÜK DEMİR ÇELİK

Türkiye

16:40

#### Oksitleyici Atmosferde Döküm Yolu ile Üretilen AISI 304 Kalite Östenitik Paslanmaz Çeliğin Sıcak ve Soğuk Haddeme Sonrasında Mekanik, Mikroyapı ve Korozyon Dayanımı Özelliklerinin İncelenmesi

Examining of Mechanical, Microstructural and Corrosion Resistant of Cold and Hot Rolled AISI 304 Grade Austenitic Stainless Steel Produced within Oxidising Atmosphere Casting Conditions

17:00

**Çetin Bağlan, Oğuz Işık, Sinan Aras, İbrahim Tozlu**

MATİL

Türkiye

17:00

#### Ferritic Grain Size Modeling with Rolling Process Parameters and Chemical Analysis Data

Haddeme Parametreleri ve Kimyasal Analiz Dataları ile Ferritik Tane Boyutu Modellemesi

17:20

**Cemre Keçeci**

İSKENDERUN DEMİR VE ÇELİK

Türkiye

## 24 September / Eylül 2020

## 24 September / Eylül 2020

Hall/Salon  
ISSOS

### Long Products

Uzun Ürünler

Session Chairman / Oturum Başkanı

**Tuna BEYDOĞAN - HABAŞ DEMİR ÇELİK**

09:30

#### Hadde Fırınlarında Rejeneratif Brülör Uygulamaları

Regenerative Burner Combustion System in Reheating Furnaces

09:50

**Aziz Kılıç, Hasan Yıldız**

BCS ENERJİ MÜHENDİSLİK

Türkiye

09:50

#### Latest Achievements on Rolling Mill Technology for the Production of Bars, Wire Rod and Profiles

Çubuk, Kangal ve Profil Haddehane Teknolojilerindeki Son Kazanımlar

10:10

**Andrea Diasparro**

DANIELI & C. OFF. MECC. S.P.A.

Italy

10:10

#### High Quality Wire Rod and Bar Production at YongXing Special Stainless Steel

YongXing de Yüksek Nitelikli Kangal ve Çubuk Üretimi

10:30

**J. Hsueh<sup>1</sup>, S.M. Shore<sup>2</sup>, R. Masini<sup>3</sup>**

<sup>1</sup>YONGXING SPECIAL STAINLESS STEEL, <sup>2</sup>PRIMETALS TECHNOLOGIES

USA, <sup>3</sup>PRIMETALS TECHNOLOGIES ITALY

PRC, USA, Italy

10:30

#### SAE 1080 Kangal Kalitesinde Soğutma Hızı, Kimyasal Analiz ve Çapın Mekanik Özellikler ve Mikroyapı Üzerine Etkisi

The Effect of Cooling Rate, Chemical Analysis and Diameter on the Mechanical Properties and Microstructure in SAE 1080 Wire Rod Grade

10:50

**Serdar Günbay, Cemre Keçeci, Erdi Gönülalan,**

**Ahmet Sağlam**

İSKENDERUN DEMİR VE ÇELİK

Türkiye

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ISSOS

### Thermomechanical Rolling

Termomekanik Haddeleme

Session Chairman / Oturum Başkanı

**Ceyhan KOZAK - KARDEMİR ÇELİK SANAYİ**

11:20

#### Tuning of Thermomechanical Rolling Model and Its Effects on Mechanical and Microstructure of Nb-Ti Alloy Steels

Nb – Ti Alaşımli Çeliklerde Termomekanik Haddeleme ve Mikroyapı İle Mekanik Özellikler Üzerindeki Etkileri

11:40

**Hasan Yıldırım, Cemre Keçeci**

İSKENDERUN DEMİR VE ÇELİK

Türkiye

11:40

#### Effect of Thermomechanical Rolling Process on the Mechanical Properties of Medium Carbon Microalloyed Steel

Termo-Mekanik Haddeleme Prosesinin Orta Karbonlu Mikroalaşımli Çeliklerin Mekanik Özelliklerine Etkisi

12:00

**Burcu Yılmaz<sup>1</sup>, Emre Temel<sup>1</sup>, Doğan Camli<sup>1</sup>, Mert Ülker<sup>1</sup>, Kenan Acar<sup>1</sup>, Arcan F. Dericioğlu<sup>1,2</sup>**

<sup>1</sup>ASİL ÇELİK, <sup>2</sup>MIDDLE EAST TECHNICAL UNIVERSITY

Türkiye

12:00

#### Optimization of Thermomechanical Processes for AISI 304 Stainless Steel Sheet Production

AISI 304 Kalite Paslanmaz Çeliklerin Üretiminde Termomekanik Proseslerin Optimizasyonu

12:20

**Hamdi Ekici, Onur Ay, Tuncay Yıldız, Erdem Güler, Bedirhan Güraydın, Eda Dağdelen**

TRINOX METAL

Türkiye

## 24 September / Eylül 2020

## 24 September / Eylül 2020

Hall/Salon  
ISSOS

### Flat Products

Yassı Ürünler

Session Chairman / Oturum Başkanı

**Sinan BOZKURT - EREĞLİ DEMİR VE ÇELİK**

13:20

13:40

#### Danieli Universal Endless (DUE®): The First-Ever Universal Solution for Flat Products is Now on Stream

Danieli Universal Endless (DUE®): Yassı Mamül Üretimi için İlk Üniversal Çözüm Artık Devreye Girdi

**Alessandro Pigani<sup>1</sup>, Mathias Knigge<sup>2</sup>**

<sup>1</sup>DANIELI & C. OFF. MECC. S.P.A., <sup>2</sup>DANIELI GERMANY  
Italy, Germany

13:40

14:00

#### Precise Profile Control and Concise Maintenance - Latest Evolution of Pair Cross Mill

Kusursuz Kesit Kontrolü ve Bakım – Sıcak Haddehanelerde Son Gelişmeler

**Longze He, Akira Sako, Toru Takeguchi, Jiro Hasai**

PRIMETALS TECHNOLOGIES JAPAN  
Japan

14:00

14:20

#### Optimisation of Roll Cooling and Descaling Processes at Erdemir 2. HSM

Ereğli Demir Çelik 2. Sıcak Haddehanesinde Merdane Soğutma ve Tufal Alma Optimizasyonu

**Kenan Acar<sup>1</sup>, Robert Wolff<sup>2</sup>, Abdullah Savaşçioğlu<sup>3</sup>**

<sup>1</sup>EREĞLİ DEMİR ÇELİK, <sup>2</sup>LECHLER GmbH, <sup>3</sup>METALFORM  
Türkiye, Germany

14:20

14:40

#### Affecting Factors on Gloss Value for Galvanized Cold Rolled Sheets

Soğuk Haddelenmiş Galvanizli Sac Parlaklığına Etki Eden Faktörler

**Özgür Karakaş<sup>1</sup>, Erdoğan Kanca<sup>2</sup>, İbrahim Göçer<sup>1</sup>, Alper Akün<sup>1</sup>, Erkan Püğe<sup>1</sup>, Güzin Müge Lüle<sup>1</sup>, Ali Doğan<sup>1</sup>, Ahmet Özdemir<sup>1</sup>**

<sup>1</sup>MMK METALURJİ, <sup>2</sup>ISKENDERUN TECHNICAL UNIVERSITY  
Türkiye

Hall/Salon  
ISSOS

### Lubricants

Yağlama

Session Chairman / Oturum Başkanı

**Murat DURUKAN - EKİNCİLER DEMİR VE ÇELİK**

15:10

15:30

#### A Ferrous Study Investigating the Film Thickness and Lubrication Behaviour of Steel Cold Rolling Oils

Soğuk Hadde Yağlarının Film Kalınlığı ve Yağlama Davranışını İnceleyen Araştırma Çalışması

**Emma Pates**

TOTAL LUBRIFIANTS  
United Kingdom

15:30

15:50

#### Energy Efficiency with Special Lubricants in Steel Industry

Çelik Endüstrisinde Özel Yağlayıcılar ile Enerji Verimliliği

**Irajá Ribeiro Junior**

KLÜBER LUBRICATION  
Brazil

15:50

16:10

#### Hot Rolling Roll Bite Lubrication (RBL)

Sıcak Haddelemede "Roll Gap" Yağlama

**Mike Cook**

QUAKER HOUGHTON  
Holland

24 September / Eylül 2020

Hall/Salon  
ISSOS

## Imaging & Measuring Systems

Görüntüleme ve Ölçüm Sistemleri

Session Chairman / Oturum Başkanı

**Eşref Bekir TURAN - BAŞTUĞ METALURJİ**

16:40

17:00

### Online Condition Monitoring System on Hot Rolling Mills

Sıcak Haddehane Tesisinde Online Durum İzleme Sistemi

**Özgün Yakar<sup>1</sup>, Murat Işık<sup>2</sup>**

<sup>1</sup>PRÜFTECHNIK PROAKTİF BAKIM,

<sup>2</sup>İSKENDERUN DEMİR VE ÇELİK

Türkiye

17:00

17:20

### Online Yüzey Kontrol Sistemi

Online Surface Control System

**Serkan Atamer, Sait Hadutoğlu, Mücahit Sevim,  
Hüseyin Ş. Soykan**

KARABÜK DEMİR ÇELİK

Türkiye

17:20

17:40

### Production Optimisation due to Real Time Information of Profile and Surface Defects on Rolling Products

Haddeleme Ürünlerinde Profil ve Yüzey Hatalarının Gerçek

Zamanlı Bilgiye Dayalı Üretim Optimizasyonu

**Johann Peters**

LAP LASER

Germany



STEEL  
ROLLING

**ISRS'2021**

INTERNATIONAL  
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SYMPOSIUM

23 - 24 SEPTEMBER

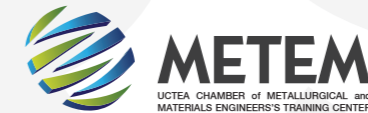
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ULUSLARARASI  
HADDE  
SEMPOZYUMU



**Poster Presentations  
Poster Sunumlar**

Poster Control // Poster Kontrol : 25 Sept./Eylül 2020 - 12:30 - 13:30





## Posters / Poster Sunumlar

### ISRS - P01

#### Integration of Laboratory Information Management Systems with SAP in an Iron-Steel Company

Demir Çelik Sektöründe Laboratuvar Veri Yönetim Sisteminin SAP ile Entegrasyonu

**İbrahim Göçer, Erdiñç Soylu, Özgür Karakaş, Pınar Özkan, Mesut Yılmaz**

MMK METALURJİ  
Türkiye

### ISRS - P02

#### Effect of Web Based Employee Suggestion System Software Application on System Performance:

##### MMK Metalurji Case

WEB tabanlı, Çalışan Öneri Sistemi Uygulamasının, Sistem Performansına Etkisi; MMK Metalurji Örneği

**Özgür Karakaş, Alper Akün**

MMK METALURJİ  
Türkiye

### ISRS - P03

#### Investigation of the Effects of Dry Film Thickness and Peak Metal Temperature on Surface Effect on Polyester Wrinkle Coil Coatings

Kuru Film Kalınlığının ve Pik Metal Sıcaklığının Polyester Kırışık Efektli Bobin Kaplamalarının Yüzeyi Üzerindeki Etkisinin Araştırılması

**Tuğçe Tunçbilek, Deniz Yıldırım, Adnan Kalkan, Hatice Arslan, Fahri Akça, Özgür Karakaş, Alper Akün**

MMK METALURJİ  
Türkiye

### ISRS - P04

#### Recent Hot Strip Mill Technology Highlights

**H. Longze, T. Takeguchi**

PRIMETALS TECHNOLOGIES JAPAN  
Japan

### ISRS - P05

#### Monitoring Technology for Downstream Processes on the Example of Hot Strip Camber, Strip Edge Inspection and Mechanical Properties Measurement

**Helmut Hlobil, Serkan Özdemir**

PRIMETALS TECHNOLOGIES AUSTRIA  
Austria

## Posters / Poster Sunumlar

### ISRS - P06

#### High Carbon High Speed Steel Rolls

Yüksek Karbonlu Yüksek Hız Çeliği Merdaneler

**Shifeng Liu**

QINGDAO YELONG  
China

### ISRS - P07

#### İstatistiksel Veri Analiz Teknikleri Kullanarak Sıcak Haddehane Proses Parametrelerinin Optimizasyonu Uygulaması

The Application of Hot Rolling Mill Plant Process Parameters Optimization Using Statistical Data Analysis Techniques

**Abdurrahman Mesud Çakır, Serdar Günbay, Muhammet Bilen, Burcu Soysal Atan, İlyas Açıkgöz**

İSKENDERUN DEMİR VE ÇELİK  
Türkiye

### ISRS - P08

#### Bor Alaşımli Orta Karbonlu Çeliklerde Göçüklük

Coil Slumping in Boron Alloy Medium Carbon Steels

**Koray Aray, Serdar Günbay**

İSKENDERUN DEMİR VE ÇELİK  
Türkiye

### ISRS - P09

#### Bobinlerde Baş Bölgelerde Sarılma Sıcaklığı Tutmayan Metrajın Kısaltılması

Improvement of Coiling Temperature Deviation at the Coil Head

**Turgut Arslan, Ahmet Mithat Avşar, Koray Aray, Rahmi Ülker, Erkan Dindaroğlu, Uğur Oktay,**

**Abdurrahman Mesud Çakır, İlyas Açıkgöz, Burcu Soysal Atan**

İSKENDERUN DEMİR VE ÇELİK  
Türkiye

### ISRS - P10

#### İsdemir Sıcak Haddehanede Seyyar Tezgâhlarla Yerinde İşleme Faaliyetleri

On-Site Machining Activities in Isdemir Hot Strip Mill

**Mustafa Ceyhun, Hakkı Emre Altundaş, Afşin Yavuz Çağlar, Hüseyin Olğun**

İSKENDERUN DEMİR VE ÇELİK  
Türkiye

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### Backup Roll Chamfer Design for İsdemir HSM

İsdemir Sıcak Haddehanesi İçin Destek Merdanelerinde PAH Dizaynı, Profili ve Sürdürülebilirliği

**M. Umut Kaya, Tolga Okuyucu, İskender Gök**  
İSKENDERUN DEMİR VE ÇELİK  
Türkiye

ISRS - P12

### Roll Grinding Optimization

Merdane Taşlama Optimizasyonu

**İskender Gök, M. Umut Kaya, Tolga Okuyucu**  
İSKENDERUN DEMİR VE ÇELİK  
Türkiye

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### Selection and Maintenance of Cold Roll

Soğuk Hadde Merdaneleri Seçim ve Bakımı

**Shifeng Liu**  
QINGDAO YELONG  
China

ISRS - P14

### Morphology and Surface Chemistry based Defects in Steel Cold Rolling

Soğuk Çelik Haddelemede Morfoloji ve Yüzey Kimyası Temelli Kusurlar

**Rob Smits, Bas Smeulders**  
QUAKER CHEMICAL  
Holland

ISRS - P15

### CERAN® - A Market Leading Grease Technology Reviewed

CERAN® - Pazar Lideri Gres Teknolojisi İncelemesi

**Franck Bardin, Raphael Brueggemann, Peter Leus, Olaf Kurtz**  
TOTAL MARKETING & SERVICES  
France

ISRS - P16

### Improvement of Work Safety and Reduction of Environmental Issues with Fire Resistant Lubricants in Steel Plants

Demir & Çelik Tesislerinde Ateşe Dayanıklı Hidrolik Sıvılar ile İş Güvenliğinin İyileştirilmesi ve Çevresel Sorunların Azaltılması

**Tim Mattern, Ronald Knecht**  
QUAKER HOUGHTON  
Holland

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Calcium Sulfonate Complex Greases in Iron and Steel Industry

**Tayfun Yılmaz<sup>1</sup>, Efsun Acar<sup>1</sup>, Oğuzhan Uğur<sup>2</sup>**  
<sup>1</sup>Vario Mühendislik, <sup>2</sup>Tosyalı Filmaşın ve İnşaat Demir Üretim  
Türkiye

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**Mehmet Mustafa Acemoğlu, Ozan Yapıcı**  
YAZICI DEMİR ÇELİK  
Türkiye

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Filtering in Hydraulic Systems

**Semih Tekin**  
HİDROHAN HİDROLİK  
Türkiye

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### Superior Cold Rolling Solutions of Primetals Technologies for the production of NGO Electrical Steels - MQL

NGO Elektrik Çeliği Üretimi için Primetals Technologies' in Soğuk Haddeleme Teknolojileri

**Toru Nakayama<sup>1</sup>, Konrad Krimpelstaetter<sup>2</sup>**  
<sup>1</sup>PRIMETALS TECHNOLOGIES JAPAN,  
<sup>2</sup>PRIMETALS TECHNOLOGIES AUSTRIA  
Japan, Austria

ISRS - P21

### HYPER UC-Mill - Superior Cold Rolling Solutions of Primetals Technologies for the Production of NGO Electrical Steels

**Toru Nakayama**  
PRIMETALS TECHNOLOGIES JAPAN  
Japan

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### ISRS - P22

#### Increasing the Hydrostatic Capacity of MORGOIL® Bearings in a Tandem Cold Mill

Thomas Wojtkowski, Peter Osgood, Ian Ward  
PRIMETALS TECHNOLOGIES USA  
USA

### ISRS - P23

#### Sıcak Haddelenme Sonrası Yapı Profillerinde Soğutma Parametrelerinin Mikroyapı ve Mekanik Özelliklere Etkisinin İncelenmesi

Examine of Effects to Microstructure and Mechanical Properties of Cooling Parameter in Building Profiles After Hot Rolling

Aytaç Bulut, Atakan İpekkan  
KARDEMİR HADDECİLİK  
Türkiye

### ISRS - P24

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Effects of Changes in the Guide System on Materials and Equipment Used to Hot Rolling Mill

Didem Kılıç, Orhan Akyol, Gencay Tosun  
KARDEMİR HADDECİLİK  
Türkiye

### ISRS - P25

#### Gel Bonded Cement Free Shotcrete

Jel Bağlı Çimentosuz Shotcrete Refrakter

Johnathan Nguyen<sup>1</sup>, Richard Volk<sup>1</sup>, James Caprio<sup>2</sup>  
<sup>1</sup>UNI-REF, INC, <sup>2</sup>UNITED REFRATORIES COMPANY  
USA

### ISRS - P26

#### The Use of Colloidal Silica Bonded Refractories in Reheat Furnaces

Tav Fırınlarında Kolloidal Silika Bağlı Refrakterlerin Kullanımı

Donald Park  
MAGNECO/METREL UK  
United Kingdom

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#### Slab Movement Optimisation by Automated Suggestion Modelling

Otomatik Öneri Modeli İle Slab Hareket Optimizasyonu

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Uğur Oktay, Halim Sade, Abdurrahman Mesud Çakır,  
Fatih Çelik  
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Türkiye

### ISRS - P28

#### INC718 Alaşımının Sıcak Dövme Prosesinin İncelenmesi

Investigation of Hot Forging Process of INC718

Merve Nur Çiftçi<sup>1,2</sup>, Batuhan Ceren<sup>1</sup>, Gökhan Coskun<sup>1</sup>, Tansel Kasar<sup>1</sup>  
<sup>1</sup>PARSAN MAKİNE PARÇALARI,  
<sup>2</sup>GEBZE TEKNİK ÜNİVERSİTESİ  
Türkiye

### ISRS - P29

#### Ti-6Al-4V Alaşımının Sıcak Dövme Prosesinin İncelenmesi

Investigation of Hot Forging Process of Ti-6Al-4V

Merve Nur Çiftçi<sup>1,2</sup>, Batuhan Ceren<sup>1</sup>, Gökhan Coskun<sup>1</sup>, Tansel Kasar<sup>1</sup>  
<sup>1</sup>PARSAN MAKİNE PARÇALARI,  
<sup>2</sup>GEBZE TEKNİK ÜNİVERSİTESİ  
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### ISRS - P30

#### ISRA VISION - Parsytec Inspection Systems

ISRA VISION - Parsytec Yüzey Muayene Sistemleri

Serkan Çakır, Jens Magenheimer  
ISRA PARSYTEC GmbH  
Germany

### ISRS - P31

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Sürekli Döküm ve Sıcak Haddelenmiş Ürünlerde Görüntüleme Tabanlı Yüzey Denetimi

Tzzy-Shuh Chang, Enrique Frixione, Howard Huang  
OG TECHNOLOGIES, INC.  
USA



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#### Through Process Optimization (TPO)

T. Pfatschbacher, C. Ergun, W. Oberaigner, K. Jax, A. Seyr  
PRIMETALS TECHNOLOGIES AUSTRIA  
Austria

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Investigation of Impact Resistances of DIN 1.2344, DIN 1.2367 and DIN 1.2367VAR Tool Steels Used in Rolling Mill Flying Shear Applications

Onur Özer<sup>1</sup>, Tuba Özeren<sup>1</sup>, Murat Arslan<sup>1</sup>,  
Aleattin Kulaklı<sup>1</sup>, Yunus Türen<sup>2</sup>, Hayrettin Ahlatçı<sup>2</sup>  
<sup>1</sup>SAĞLAM METAL, <sup>2</sup>KARABÜK ÜNİVERSİTESİ  
Türkiye

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SAĞLAM METAL  
Türkiye

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Potential of Energy Savings in Turkish Iron & Steel Plants

Uğur Cengiz, Oğuzhan Sakarya  
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Türkiye

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Onur Ay<sup>1</sup>, Hamdi Ekici<sup>1</sup>, Bedirhan Güraydın<sup>1</sup>,  
Erdem Güler<sup>1</sup>, Serhan Daniş<sup>2</sup>, Keziban Orman<sup>2</sup>  
<sup>1</sup>TRINOX METAL, <sup>2</sup>GALATASARAY ÜNİVERSİTESİ  
Türkiye

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Türkiye

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Türkiye

### ISRS - P39

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<sup>1</sup>İSTANBUL BİLGİ ÜNİVERSİTESİ, <sup>2</sup>MALTEPE ÜNİVERSİTESİ, <sup>3</sup>METEM • Türkiye

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<sup>1</sup>CARES, <sup>2</sup>CARES Digital Partner / Constructive Group • United Kingdom, U.A.E.

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<sup>1</sup>PRIMETALS TECHNOLOGIES USA, <sup>2</sup>PRIMETALS TECHNOLOGIES POLAND • USA, Poland

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<sup>1</sup>YONGXING SPECIAL STAINLESS STEEL, <sup>2</sup>PRIMETALS TECHNOLOGIES USA,

<sup>3</sup>PRIMETALS TECHNOLOGIES ITALY • PRC, USA, Italy

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<sup>1</sup>ASİL ÇELİK, <sup>2</sup>MIDDLE EAST TECHNICAL UNIVERSITY • Türkiye

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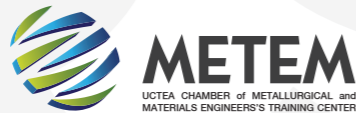
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**PROCEEDINGS  
BİLDİRİLER**

**EHS - Paper of Safe and Sound Together Movement  
ÇSG- Birlikte Sağ Salim Hareketi Bildirisi**



## Zero Accident Target or Normal? Paradigm Exchange with Metallurgy Industry: "Safe and Sound Together Movement in Turkey"

"Sıfır Kaza Hedef mi? Normal mi? Türkiye'de Metalurji Sektöründe "Birlikte Sağ Salim Hareketi" İle Paradigma Değişimi"

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<sup>1</sup>İSTANBUL BİLGİ ÜNİVERSİTESİ, <sup>2</sup>MALTEPE ÜNİVERSİTESİ, <sup>3</sup>METEM • Türkiye

### Abstract

Positive organizational culture is an approach that emphasizes business content, processes, relationship networks and opportunities that are suitable for human beings, in which employees feel valuable. In this perspective, it is of course the "normal" situation that is necessary to construct all these conditions in such a way as to ensure that the employee feels psychologically and physically healthy and to ensure a "zero accident". If occupational diseases, accidents and losses are experienced in an enterprise, there is a negative deviation from normal in this enterprise. Ideally, all proactive initiatives and activities will go beyond accident. This point of view has in fact been a paradigm shift for approaches that present accident-free as a goal.

We are trying to establish the view that "zero accident is not a vision, it is a natural condition that should be" for the metallurgy sector and to raise awareness that the effort for accident-free is a series of initiatives to reduce negative deviation.

In this study, based on the Positive Organizational Culture model, the structural features, theoretical background, basics and relationship between the model and ISO 45001 are presented and discussed for the project "Birlikte Sağ Salim Hareketi-Safe and Sound Together Movement in Turkey" which will reshape the approach to the health and safety of workers in the metallurgy sector.

### Özet

Pozitif örgüt kültürü, işletmelerde çalışanın kendini değerli hissettiği, insana yararlı iş içerikleri, süreçleri, ilişki ağları ve fırsatlarını öne çıkaran bir yaklaşımdır. Bu perspektifte, tüm bu koşulları çalışanın psikolojik ve fiziksel olarak

sağlıklı hissetmelerini sağlayacak, "sıfır kaza" oluşumunu garantileyecek şekilde kurgulamak zaten doğal olarak gereken "normal" durumdur. Eğer bir işletmede meslek hastalıkları, kazalar ve kayıplar yaşıyorsa bu işletmede normalden negatif yönde bir sapma var demektir. İdeal olan ise kazasızlığın ötesine geçecek proaktif tüm girişim ve çalışmalardır. İşte bu bakış açısı aslında yıllardır, kazasızlığı bir hedef olarak sunan yaklaşımlar için bir paradigma değişikliği niteliğindedir. Biz de metal sektörü için "sıfır kaza bir vizyon değil, olması gereken doğal durumdur" bakışını yerleştirmeye ve kazasızlık için gösterilen çabanın negatif sapmayı azaltmaya dair girişimler silsilesi olduğuna dair bir farkındalık yaratmaya çalışıyoruz. Bu çalışmada, Cameron'un (2012) Pozitif Örgüt Kültürü modelinden hareketle, metal sektöründe çalışan sağlığı ve güvenliğine yaklaşımı yeniden şekillendirecek "Birlikte Sağ Salim Hareketi" olarak isimlendirilen projenin yapısal özellikleri, teorik arka planı, dayanakları ve modelin ISO 45001 ile ilişkisi sunulmakta ve tartışmaya açılmaktadır.

### 1. Giriş

Bu çalışmada, Pozitif Örgüt Kültürü modelinden hareketle [1], metal sektöründeki işletmelerde çalışan sağlığı ve güvenliğine yaklaşımı yeniden şekillendirecek bir hareketin yapısal özellikleri ve teorik arka planı sunulacaktır. 2000'li yıllardan başlayarak psikoloji bilimi alanından araştırmacılar, insan davranışlarının, duyu ve düşünce süreçlerinin "yolunda giden" taraflarına odaklanmaya başladılar. Örneğin, psikolojik sağlık sorunlarının dinamiklerini anlamaya çalışan araştırmacılar, nasıl olup da aynı koşullar altında başka bir bireyin sağlıklı kalabildiğini sorguladılar. Bu yaklaşımı iş yaşamına yansıtacak olursak, performans ya da motivasyon düşüklüğünün nedenlerini anlama çabasının yanı sıra, yüksek performans ve

motivasyon ile çalışan kişilerin özellikleri ve bu olumlu durumu yaratan koşulları anlama çabası ön plana çıktı. Yaklaşımı daha da özelleştirip çalışan sağlığı ve güvenliği (ÇSG) alanına yaralayacak olursak, riskli iş davranışlarının nedenlerinden ziyade ya da bunlara ek olarak, güvenli davranışların dinamikleri, kaza deneyimi yaşamamış kişi ve kurumların özelliklerinin sistematik analizi altı çizilen bir konu oldu. Cameron [1] bu yaklaşımı araştırmalarına temel aldı ve pozitif örgüt kültürünü arzulan iş davranışlarının tetikleyicisi olarak tanımladı.

İşte bu yaklaşımdan hareketle, Metalurji Mühendisleri Odası Eğitim Merkezi (METEM) bünyesinde adını "Birlikte Sağ Salim Hareketi" olarak verdiğimiz bir seferberlik ile metal sektöründeki işletmelerde ÇSG alanında pozitif liderlik, pozitif iletişim ve pozitif davranış örüntülerini oluşturmak, dolayısıyla "pozitif örgüt kültürü"nü ÇSG için bir dayanak haline getirmek üzere yola koyulduk. "Ötesine geçmek" mottosu ile kurgulanan bu seferberlik, metal sektörü işletmelerindeki örgüt kültürünün pozitif ÇSG iletişimi, liderliği ve davranışları ile bezenmesi için bir model olarak sektöre paylaşılmaya başlandı. Bu bildiriye, bu modelin dayanakları ve modelin ISO 45001 ile ilişkisi sunulacak ve tartışmaya açılacaktır.

### 2. Türkiye Metalurji Sektörü Çalışan Sağlığı Ve Güvenliği Açısından Mevcut Durum Analizi

T.C.Sosyal Güvenlik Kurumu İstatistikleri, inşaat, nakliyat, madencilik ve metal sektörlerindeki ölümlü iş kazası oranlarının diğer sektörlerden yüksek olduğunu ortaya koymaktadır [2]. TMMOB tarafından her yıl yayınlanan İSG Oda Raporu 2018'de metalürji sektörüne ilişkin durum [3], SGK verilerine dayalı olarak çalışılmıştır. 2015 yılında gerçekleşen 241 bin 547 iş kazasının faaliyet gruplarına dağılımına göre, makine ve teçhizat hariç fabrikasyon metal ürünleri imalatı 19 bin 221 iş kazası ile birinci, bina inşaatı 15 bin 65 kaza ile ikinci, ana metal sanayii 12 bin 59 kaza ile üçüncü sırada yer almaktadır. 2016 yılında yaşanan iş kazalarının faaliyet gruplarına göre dağılımında birbiri ile ilişkili faaliyet gruplarının birleşik yorumlanması durumunda ise fabrikasyon metal ürünler ile ana metal sanayi 33 bin 697 kaza (% 11,77) ile ikinci sırada yer almaktadır. Diğer taraftan, Türkiye'de meslek hastalığı verileri ise aşırı sorunlu yapısını korumaktadır. SGK 2013, 2014, 2015, 2016 verilerinde meslek hastalıklarından dolayı hiç ölüm yoktur ancak bu bulguların gerçekle uyumlu olamayacağı değerlendirilmekte, metalürji sektöründe de risk içeren koşullara maruz kalmaya bağlı meslek hastalıkları riskleri bulunduğu bilinmektedir. Eurostat verilerine göre de Türkiye, ölümlü iş kazalarında Avrupa birincisidir [4].

Kamu politika belgelerinde metalürji sektörüne ilişkin büyük kaza sayılarıyla baş etmeye yönelik hedefler açıkça tanımlanmaktadır. Ulusal İş Sağlığı ve Güvenliği Konseyi tarafından hazırlanan III. Ulusal İş Sağlığı ve Güvenliği

Politika Belgesi ve Eylem Planı döneme ait işçi sağlığı ve iş güvenliği alanındaki politika önceliklerini, 2014–2018 dönemine yönelik hedefleri belirlemiştir [5]. Buna göre; risk değerlendirmesine dayalı önleyici yaklaşımın esas alınması, iş sağlığı ve güvenliği hizmetlerinin sayı sınırı olmaksızın tüm çalışanlara sunulması, çalışan temsilcisi kavramının getirilmesi ve mikro ölçekli işletmelere devletin destek sağlaması gibi ilkeler öne çıkmaktadır. Ayrıca, "metal, maden ve inşaat sektörlerinin her biri için iş kazası oranının azaltılması" ve "toplumda iş sağlığı ve güvenliği kültürünün yaygınlaştırılması" yedi hedef arasında belirtilmiştir.

Türkiye'deki işçi sağlığı ve iş güvenliği mevzuatında, sağlık hizmetleri dışındaki tüm hususlar mühendislik dallarını ilgilendirmektedir. İşçi sağlığı ve iş güvenliği ile ilgili teftiş görevini yürüten iş müfettişleri de büyük oranda mühendislerden oluşmaktadır. Yani mevzuatın denetim ve uygulayıcıları ağırlıklı olarak mühendislerdir. Bu nedenle, Metalurji sektöründeki iş kazalarının engellenmesi için en önemli aktör, bu sektörde çalışan Metalurji Mühendisleri ve bu meslek grubunun temsilcisi olan Metalurji ve Malzeme Mühendisleri Odası'dır. Türk Mühendis ve Mimar Odaları Birliği'ne (TMMOB) bağlı olarak ilgili yasa hükümlerine uygun şekilde 1970 yılında kurulmuştur ve Anayasanın 135. maddesinde belirtilen kamu kurumu niteliğinde bir meslek kuruluşudur. TMMOB Metalurji ve Malzeme Mühendisleri Odasının 4.100 üyesi, İstanbul'da bir şubesi, dört il temsilciliği ve tüm yurttaki yaklaşık 30 işyeri temsilciliği vardır. İlgili yasa gereği; mühendislik mesleği mensuplarının ortak gereksinmelerini karşılamak, mesleki etkinlikleri kolaylaştırmak, mesleğin genel yararlarına uygun olarak gelişmesini sağlamak, meslek mensuplarının birbirleriyle ve halkla olan ilişkilerinde dürüstlüğü ve güveni hakim kılmak üzere, meslek disiplinini ve ahlakını korumak; kamunun ve ülkenin çıkarlarının korunmasında, yurdun doğal kaynaklarının bulunmasında, korunmasında ve işletilmesinde, çevre ve tarihi değerlerin ve kültürel mirasın korunmasında, tarımsal ve sınai üretimin artırılmasında, ülkenin sanatsal ve teknik kalkınmasında gerekli gördüğü tüm girişim ve etkinliklerde bulunmak amaçlarını gütmektedir [6].

### 3. Çalışan Sağlığı Ve Güvenliğine Pozitif Psikoloji Perspektifinden Bakış

Türkiye'de ölümcül iş kazalarının gerçekleştiği sektörlerden biri olan metalürji sektöründe ÇSG'nin güvence altına alınması, güvenlik kültürünün yaygınlaştırılması, iş kazalarının ve olumsuz sonuçlarının ortadan kaldırılması, pozitif liderlik bakışını kılavuz alan, sadece kazasızlığı sağlamakla kalmayıp "ötesine geçen", çalışanlarını odağa koyan ve çalışanlarını kendi iş yaşamlarının öznesi kılan çalışmalarla sağlanabilir. Kural odaklı ÇSG'den insan odaklı ÇSG'ye geçişte özellikle metalürji sektöründe görev alan mühendislerin kolaylaştırıcılık yapacağı çalışmaların tüm sektörde topyekûn bir iyileşmenin ve sürdürülebilir ÇSG'nin



anahtar olduğunu öngörmekteyiz, bu nedenle “Birlikte Sağ Salim Hareketi” adını verdiğimiz çalışmayı METEM bünyesinde yürütmekteyiz. Giriş kısmında bahsettiğimiz Cameron [1] tarafından önerilen yaklaşımda öne çıkan önemli bir husus, bireysel, kolektif ya da örgütsel ölçekteki çıktılar için “normal” tanımı ile normalden “negatif sapma” ve “pozitif sapma” tanımlamalarıdır (Tablo 1).

	Olumsuz Sapma	Normal	Olumlu Sapma
<b>BİREY</b>			
<b>Fiziksel</b>	Hastalık	Sağlık	Zindelik/Canlılık
<b>Psikolojik</b>	Hastalık/ Fonksiyon kaybı	Sağlık/ Fonksiyon el	Akışa geçmiş
	<b>ÖRGÜT</b>		
<b>Çalışan Güvenliği</b>	Reaktif	«0 Kaza»	Proaktif
<b>Ekonomi</b>	Kârsız	Kârlı	Zengin/Cömert
<b>Etkililik (Amaçları gerçekleştirmek)</b>	Netice vermeyen	Etkili	Mükemmel
<b>Verimlilik (Kaynak kullanımı)</b>	Verimsiz	Verimli	Olağanüstü
<b>Kalite</b>	Hataya açık	Tutarlı	Mükemmel
<b>Etik</b>	Etik dışı	Etik	Yardımsaver/Müşfik
<b>İlişkiler</b>	Zedeleyici	Yardıma hazır	Onurlandıran/ Saygınlığı kuvvetlendiren
	<b>Uyum</b>	Tehditkâr-Katı	Başa çıkabilen

**Tablo 1.** Cameron'un perspektifinden işletme süreçlerinde normal ve normalden pozitif-negatif sapma tanımları [1]

Tablo 1'de de görülebildiği gibi örneğin, bu modele göre “psikolojik sağlık” zaten insanlar için doğal ve normal olandır; hastalık “negatif sapma”dır; daha az hasta olmak ya da bir hastalığın şiddetinin az olması bu sapma düzeyini kabul edilebilir yani “normal” kılmaz; “enerjik ve zinde olmak” ise “pozitif sapma”dır. Başka bir örnekle, bir iş sürecinin “kârlı” olması pozitif sapma değil “normal”dir; aslında hiçbir iş süreci sadece “baş baş” noktası için yürütülmez; zaten normal durum “karlılık”tır; eğer “zarar” varsa bu negatif sapmadır; pozitif sapma ise “bolluk” ve “gelirlerin cömertçe kullanılabilir olacak ölçüde çıkmış” olmasıdır. Bu yaklaşım verimlilik, kalite, etik, sosyal ilişkiler ve uyum gibi birçok iş çıktısına uyarlanırken “çalışan güvenliği” konusunda bir yorumlama yapılmamıştır. İşte, Metalurji Mühendisleri Odası Eğitim

Merkezi (METEM) bünyesinde son iki yıldır sektörün ÇSG açısından durum analizini yapmak üzere çalışırken, Cameron'un modelini [1] ÇSG'ye uyarlamaya karar verdik. Bu sektörde yaşanan kazaların azalma eğiliminde olsa dahi kurumun aslında “negatif sapma” içinde olduğuna dikkat çekmek, “sıfır kazanın hedef değil, zaten olması gereken normal durum” olduğuna dair paradigma değişikliği başlatmak ve yöneticilerin zamanlarını proaktif yaklaşımlarla “pozitif sapma” yaratmak için odaklanmalarını sağlamak üzere kolları sıvadık. “ÇSG alanının normali nedir? Normalden pozitif ve negatif sapma nasıl tanımlanır?” sorularının cevaplarını bulma çabası içine girdik. Cevap “sıfır kaza hedef değil, normaldir” oldu. Yani yıllardır, ÇSG alanındaki hem teorik hem de uygulamalı çalışmalarda “hedef sıfır kaza” sloganı aslında sorgulanması gereken bir söylemdir. “Sıfır kaza” iş süreçlerinde zaten olması gereken doğal ve normal durumdur. İş kazaları normalden negatif sapmadır ve ister bir tane, ister onlarca olsun negatif tarafta yer alır.

Bu bakış açısının, ÇSG alanı için bir paradigma değişimini içinde barındırdığını düşünüyoruz. İş sağlığı ve güvenliği profesyonellerinin sıklıkla tekrarladığı “etik nedenlerle zaten bu yıl örneğin iki kaza hedefimiz var diyemeyiz; hedef sıfır kazadır” söylemi, bu alanın profesyonellerinin bakış açısının da getirdiği bir kısıta işaret eder. “Sıfır kaza” hiçbir zaman erişilemeyecek bir soyutlama haline gelmekte, geçmiş yıllara göre kaza sayısının azalması pozitif bir sapmanın göstergesi kabul edilmektedir. Oysaki kazaların yaşanması “reaktif bir tutum”u beraberinde getiren “negatif sapma”dır; “sıfır kaza” doğal/normal koşuldur; hedef ise “sıfır kazanın ötesine geçmek”tir, yani, pozitif sapma “proaktif yaklaşım”dır. Cameron [1] modelini kurgularken aslında yöneticilerin şu iç görüyü geliştirmesini istiyor: “Acaba yöneticiler, zamanlarının ne kadarını normal korumak, ne kadarını negatif sapmalarla mücadele etmek, ne kadarını pozitif sapma yaratmak adına gerçekten liderlik davranışları göstermek için kullanıyor?”

#### 4. Örgütlerde Çalışan Sağlığı Ve Güvenliği Kültürü Ve “Sıfır Kaza”

Güvenlik kültürünün bir zemin yaratarak, çalışanların tutumlarını ve dolayısıyla davranışlarını etkilediği, çalışan sağlığı güvenliğini uygulamalarının sonuçlarından yönetimin sorumlu olduğu ve önleyici yaklaşımların içselleştirilmesinin önemi endüstri çevrelerinde gündem oluşturan konuların başında gelmektedir. İşyerinde bütün kazaların önlenilebileceğine olan inanç ve bu vizyona uygun çalışmalar, güvenlik kültürünün evrensel boyutlarının yerel ve işyerine özgü farklılıklarıyla araştırılması ve uygulama örneklerinin incelenmesini gerektirir, ama hepsinden önce “sıfır kaza” paradigması üzerinde düşünmeye ve kazanın bir negatif sapma olduğunun kabulüne ihtiyaç vardır.

Güvenlik kültürü kavramı ilk kez Uluslararası Atom Enerjisi Kurumunun (IAEA) Nükleer Güvenlik Danışma Grubunun

(INSAG) Çernobil faciasıyla ilgili 1989'da hazırladığı raporda yer almıştır. INSAG kavramı tanımlarken; "Organizasyonlarda ve bireylerde, kesin bir öncelik olarak, nükleer tesisin güvenliği ile ilgili önemli konuların, spesifik özelliklerin ve önleyici yaklaşımların bütünüdür" der, ve "güvenlik kültürünün yapısal olduğu kadar yaklaşımlarla da ilgili olduğunu" belirtir [7]. Aynı grup 1992'de "Çernobil kazası sadece Çernobil reaktöründen değil, güvenlik kültürünün yetersizliğinden dolayı cereyan etmiştir. Güvenlik kültürü, nükleer güç reaktöründe çalışma ve geliştirmede söz sahibi olan yönetici tutumlarından başlayarak toptan bir adanmışlık gerektirmektedir." ifadesine yer vermiştir [8]. Tanımlar ve bilinen büyük endüstriyel kazaların arka planları incelendiğinde güvenlik kültürü kavramı bütün açıklığıyla ortaya çıkmaktadır. Kültür, "hem organizasyonlara hem de bireylere ilişkin"dir. Bireyler, sadece çalışanlar da değildir, aynı zamanda yöneticilerdir. Kültürün bireylere ilişkin kısmı, yönetici ve çalışanların güvenlik kültürünün göstergesi olan davranışlarında ortaya çıkar. Sağlık ve güvenliği etkileyen davranışlar, işyerinde güvenlik kültürünün görünen yüzüdür. Bir sonuç olan güvenli davranış, sağlık ve güvenlik kültürünün pozitif olduğu ortamlarda sağlanabilir. Dolayısıyla davranış odaklı güvenlik, sağlık ve güvenlik kültürünün bir parçası ve sonucudur. Davranışların oluşumuna etki eden faktörleri National Examination Board of Occupational Safety and Health'in (NEBOSH) genel İSG sertifika programı kitapçığında [9] ele alındığı biçimiyle aktarabiliriz: "Organizasyonel etkenler birey ve grup davranışlarında en fazla etkiye sahiptir. İş güvenliği kültürüne olumlu etkisi olan etkenler, yönetim elementleridir. Bunlar; planlama, organize etme, kontrol, izleme, gözden geçirme ve denetimdir." Bu açıklama, davranışların oluştuğu düzleme ve ortama yönetim fonksiyonunun etkileri olduğuna dikkat çekiyor, sağlık ve güvenlik kültürünün bireylere ilişkin olmasının yanında organizasyona ilişkin oluşumu açıklıyor. Bu söylem Cameron [1]'un liderlerin sayısal sıfır kaza hedefinin yani "normal" durumun ötesine geçen "proaktif" çalışmalara zaman ayırmaya başlaması için de bir itici güç oluşturmaktadır.

İşte bu noktada, sıfır kaza vizyonu ve sıfır kazanın ötesine geçilip geçilemeyeceğini tartışmak gerekmektedir. 2018'de İstanbul'da gerçekleştirilen İSG Yerel Sempozyumuna katılan DİSK Genel Başkanı Çerkezoğlu, 6331 sayılı İş Sağlığı ve Güvenliği Yasası hakkında değerlendirmelerde bulunarak Çalışma Bakanlığı'nın 2016 yılında hayata geçirdiği 'Sıfır Kaza, Sıfır Ölüm' hedefinin hiçbir gerçekliği olmadığını belirtmiştir [10]. Kamu söylemi açısından sıfır kaza, 13 Mayıs 2017'de dönemin Çalışma Bakanının katılımıyla imzalanan 'İş Sağlığı ve Güvenliği Hedef Sıfır Deklarasyonu'nda ortaya çıkmıştır. Eksenini inşaat sektörünün oluşturduğu ve dört aylık sıfır kaza kampanyası boyunca işyeri ziyaretleri yaparak işçi ve işverene iş sağlığı ve güvenliği konusunda bilgilendirme ve rehberlik yapılacağı, sonraki aşamalarda, uyarılara rağmen önlem

almayanlara yaptırım uygulanacağı vurgulanmıştır. Kampanya döneminde inşaat iş konusunda kazaların azalması belirtilmektedir [11]. İşçi Sağlığı ve İş Güvenliği Meclisi, bu bildirgenin üzerinden geçen dört aylık sürede 753 işçinin hayatını kaybettiğini açıklamıştır [12]. Kampanya hakkında Çalışma ve Sosyal Güvenlik Bakanlığı resmi web sayfasından ve yeni yapısıyla Aile, Sosyal Hizmetler ve Çalışma Bakanlığı web sitesinden de herhangi içeriğe ulaşamamıştır [13].

Güvenlik literatüründe kaza (accident), olay (incident) ve harm (zarar) terimlerinin birbirinden farklı olduğu ve taşıdıkları anlam iyi bilinmektedir. Bu nedenle, sadece kaza, ya da olay sayısı ve sıklığının takip edilmesi kuruluşun "sıfır zarar" performansı hakkında bilgi vermez. "Sıfır zarar" kavramı pratikte her türlü yaralanmanın kabul edilmediği ve yaralanmaları önlemek için mümkün tüm önlemlerin alındığı bir ortamın yaratılmaya çalışılması anlamına gelmektedir. Bu anlayış, güvenlik aktivitelерinin ve alınan önlemlerin yeniden düşünülmesini, gelişimin ve elde edilen başarının iyi izlenmesini ve her seviyede çalışanın mutlak katılımını gerektirir.

Kazasız bir işyeri oluşturma azmi ile hesap verilebilir bir "sıfır kaza hedefi" genellikle karıştırılmaktadır. Sıfır kaza hedefi birçok kişi tarafından "gerçekçi" ve "ulaşılabilir" olmadığı gerekçesi ile eleştirilmektedir. Bunların arasında ÇSG profesyonelleri de vardır. Onlara göre üretim olan yerde kaza mutlaka olur. Ancak, "sıfır kaza vizyonu"nun yenilikçi bir yönü olduğunu da unutmamalıyız. Günümüzde, güvenlik stratejilerinin çoğunda risklerin kontrolü anlayışı yaygındır. Güvenlik konularında ortaya çıkan problemler çözümlenince yönetimin taahhüdünün yerine getirildiği varsayılır. Bu durum, gelecekte yeni kazaların önlenmesine yetmez. Sıfır kaza hedefi, bir sürat koşusu değil, bir maraton gibidir. Bu kültürde sürekli iyileştirme ve küçük ama önemli adımlar, gösteri ya da reklam/pazarlama amacıyla yapılan iyileştirmelerden çok daha önemlidir. Deniz'e göre "tüm kazalar önenebilir" ve "sıfır kaza vizyonu" bir hayal değildir. Kurulmuş sıfır zarar/kaza kültürünün oluşturulması için "küçük şeyler" yapmaya devam edilmelidir [14]. Koivupalo ve arkadaşları [15] küresel bir çelik şirkette güvenlik yönetiminin tüm kazaları önlemeyi taahhüt ettiğini, kurumsal güvenlik vizyonunun "Önce Güvenlik" teması etrafında tanımlandığını ve hedeflenenin tüm kazaların önenebilir olduğu bir güvenlik kültürü oluşturmak olduğunu tespit etmiştir. Güvenlik sistemleri ve süreçlerine büyük önem verilmiş, çalışanların konuyu sahiplenmesi ve güvenlik liderliği, yönetim taahhüdü, emniyet iyileştirme sürecinde önemli faktörler olarak görülmüştür ve bu yaklaşım "sıfır kaza vizyonu"nun bir göstergesi olarak kabul edilmektedir.

Zwetsloot ve arkadaşları [16] sıfır kaza hedefiyle çalışan ve bunu değerleri arasında yerleştiren şirketlerin, kaza ve olaylarla başa çıkmak, kazaların nedenleri belirlemek için araştırmak (suçlu kişiler değil) ve kaza mağdurlarına yapıcı

davranmak için gereken “adil” bir kültüre büyük ölçüde sahip olduğunu, güvenliği arttırmak için yenilikçi yollar aradıklarını gözlemlediğini raporlamaktadır. Diğer taraftan, pozitif hedeflerin öneminin vurgulandığı, zaman zaman sıfır kaza vizyonunun “sadece olumsuzları önlemek” olarak görüldüğü belirtilmektedir. Zwetsloot ve arkadaşları [16] olumlu hedeflerin önemine inanıyor ve araştırma yaptıkları şirketlerde bu vizyonun ‘olumsuzluktan kaçınma’ ve aynı anda “olumlu gelişme” için de kullanıldığını belirtiyorlar. Araştırmacıların bu vurgusu, pozitif örgüt kültürü ile bağ kurması açısından ÇSG alanına yenilikçi ve proaktif bir gelişme olarak girdi sunmaktadır.

### 5. ISO 45001- Örgüt Kültürü İlişkisi Ve Birlikte Sağ Salim Hareketi

Günümüzde örgütler süreçlerini sistematik yaklaşımlarla yönetmek için farklı yönetim sistemi modellerini uygulamaktadır. Çalışan sağlığı ve güvenliği de işletmelerin ana süreçlerinden birisi olarak kabul edildiği için birçok işletme formal/informal iş sağlığı yönetim sistemi kurmuştur. Yirminci yüzyılın sonlarında İngiltere’de yayınlanan OHSAS 18001 standardı “İş Sağlığı ve Güvenliği Yönetim Sistemi” günümüzde birçok işletmenin kullandığı bir sistemdir ve kazalara yönelik önleyicilik açısından bu standart yararlı bir rehber görevi görmüştür. Ancak işletmeler standartları ayrı ayrı yönetmekten, Entegre Yönetim Sistemi (EYS) yaklaşımına yani bütüncül bir yaklaşıma ihtiyaç duymaktadır. ÇSG süreci genellikle çevre ve kalite süreçleri ile beraber yönetildiğinden, Nisan 2018’de Uluslararası Standart Kurumu (ISO) ISO 45001 “İş Sağlığı ve Güvenliği Yönetim Sistemi”ni yayınlayarak ISO 9001 “Kalite Yönetim Sistemi” ve ISO 14001 “Çevre Yönetim Sistemi”ne daha uyumlu bir ÇSG yönetim sistemi standardı oluşturmuştur.

ISO 45001 standardı amacını “iş sağlığı ve güvenliği risk ve fırsatlarını yönetecek çerçeveyi sağlamaktır” şeklinde açıklar [17]. ISO 45001, OHSAS 18001’den farklı olarak kuruluşun bağlamını en önemli girdilerden birisi olarak kabul ettiği için amacında aslında doğru yapı kurgulanırsa riskin bir fırsata çevrilebileceğini de ifade etmektedir. ISO 45001 amacını daha detaylı açıklarken “Bir iş sağlığı ve güvenliği yönetim sistemi iş sağlığı ve güvenliği performansını artıracak fırsatlar karşısında erken faaliyete geçebiliyorsa daha etkili ve verimli olur” demektedir. Standartın en çarpıcı yanları ise “örgütsel bağlam”dan söz ederek tüm ÇSG sonuçlarının işletme yönetimiyle ilgisini kurması ve liderlik ile çalışan katılımını merkeze alan yapısıdır.

Birlikte Sağ Salim Hareketi, ISO 45001’deki örgütsel bağlam vurgusunu çerçeve alarak, metal sektöründeki işletmeler için pozitif liderlik, pozitif iletişim ve pozitif davranış örüntülerinin oluşturulmasını ve ÇSG için pozitif bir bağlam yaratmayı hedeflemektedir. Pozitif liderlik, üst yönetimin ÇSG taahhüdü, çalışanın esenliği ve psikolojik

sağlığı, çalışanın ÇSG süreçlerine katılımını sağlayan yaklaşımları ve ortak hedeflere sahip topluluklar haline gelmeyi içeren bir süreçtir. Pozitif iletişimden kast edilenler; olumlu dil ve kişileri etiketleme, kötü muameleye sıfır tolerans, hatalardan öğrenme ve takdir kullanımınıdır. Pozitif davranış örüntüleri ise çalışanın ÇSG açısından güçlü yönlerini ödüllendirme/pekiştirme, yapıcı, davranışa odaklı geribildirim verme/alma ve destekleyici iletişim kurabilme yetkinliklerini içermektedir. Pozitif liderlik, iletişim ve davranıştan hareketle ISO 45001 yönetim modelini de destekleyebilecek ilkelerle aşağıdaki hedefleri benimsemekte ve sektörel olarak yaygınlaştırmaya odaklanmaktadır:

- ÇSG’yi «kurum kültürünün temel bir bileşeni» haline getirmek,
- ÇSG’yi kurumsal süreçlerde «pozitif kurum kültürü» değerleri ile işleyen bir sistematige dönüştürmek,
- Sektörel iş yapış biçimlerinde «modern yönetim ve liderlik» ilkelerini yerleştirmek,
- Yöneticilere «insana yaraşır iş ve çalışma ortamı» yapılandırılmalarını sağlayacak araçlar sunmak,
- Kurumsal yapı içinde ÇSG alanında çalışan profesyoneller ve uzmanların «güçlendirilmesini» sağlayacak eğitim programları ve araçlar geliştirmek,
- Uzun soluklu sektörel ÇSG seferberliği, bir hareket başlatmak.

### 6. “Sıfır Kaza” Söylemine Dair Paradigma Değişimi İçin Öneriler

Theboud-Mony, sarsıcı eseri “Çalışmak Sağlığa Zararlıdır”da çalışanların sağlığının ekonomik bir akılcılık meselesine dönüştürüldüğünü belirtir. Yazara göre “sıfır kaza diye bir şey yoktur” veya “yumurtayı kırmadan omlet yapamazsın” gibi yaklaşımlarla ekonomik büyümenin doğal bir sonucu olarak sunulan iş kazaları toplumsal olarak kabul edilir bir biçime sokulmaya çalışılmaktadır [18].

Oysaki iş süreçlerinden ya da çalışma eyleminin kendisinden kaynaklı kaza yaşanmaması, kaza olasılıklarının yönetim sistemleri yoluyla ortadan kaldırılması normal/doğal durum kabul edilmelidir. Çalışanların sağlık ve güvenliği iş yaşamının diğer ekonomik birimleri ve hedefleriyle aynı kefedede değerlendirilmelidir; işte bu toplumsal bir paradigma değişimi önerisidir. Örneğin, Soma felaketi sonrası haber kanallarında canlı olarak izlediğimiz bir sahne gözümüzün önünden gitmez: Kazadan yaralı kurtulan bir maden işçisi sedyeye ile ambulansa taşındığı sırada “Çizmelerimi çıkarayım mı?” diye sorar. Bu örnekteki işçinin kendisini kurtarmak için orada olan ambulansın sedyesinin beyaz örtüsünün kendisinden daha değerli olduğunu düşündüğünü söyleyebilir miyiz? Çalışan insanın paradigmatması, çalışırken başına bir şey gelebileceği, bir nevi öğrenilmiş çaresizlik midir? Bunu besleyen düşünce yöneticilerin reaktif şekilde

“kaza ve ölüm bu işin fitratında var” demeleri, demeseler bile bunu sezdirmeleri olabilir mi? Mühendislik hesaplamalarında “kaç insanın öleceği” hesaplanabilir mi? Kazaların %98’i önlenemez demek ne anlama gelmektedir?

İş kazası olmamasının “normal”, çalışırken zarar görmemenin “çalışan hakkı” olduğunu, insana yaraşır işin ancak böyle sağlanabileceğini düşünmekteyiz. Bu paradigma değişimi ve başarının ne şekilde sağlanacağı ÇSG alanının en önemli tartışma konumundadır. Eduardo Blanco-Munoz, 2015 yılında başkanlığını yürüttüğü Uluslararası Davranış Odaklı Güvenlik Konferansının (Behavioral Based Safety-BBS) ardından kaleme aldığı yazısında, konferansta ele alınan konuların “davranış odaklı güvenlik yönetimi sonrası” (Post-BBS) söylemler içerdiğini belirtmiştir. Artık ödül-cezadan oluşan klasik davranışsal örüntüleri takip etmeyerek liderleri güvenlik kültürü ve değerleri ile donatma zamanı geldiğine vurgu yapmıştır [19]. “Birlikte Sağ Salim Hareketi” benzer şekilde, pozitif liderlik, pozitif iletişim ve pozitif davranış kültürü konularında işletme yönetiminin sağlık ve güvenlik kültürüne ilişkin taahhüdünü ön koşul almaktadır. Çalışanların işin öznesi olabileceği bir çalışma ortamında, sadece rakamlara odaklanmayan, sağlık ve güvenlik için süreklilik ve sürdürülebilirlik içeren bir çabayı garantileyen bir yaklaşım önermektedir.

Bunun sağlanabilmesi için; güvenlik iletişimi organizasyonun tüm seviyelerinde özgürce gerçekleşmelidir. Açık, kısa ve öz olmalıdır. Çalışanların, kendi sorumluluklarını anlaması, bir güvenlik endişeleri varsa bunu ifade etmek veya iyileştirme önerilerini iletmek için farkındalık ve özgüven kazanmaları sağlanmalıdır. Bu süreç hantal ve yavaş olamaz. Çalışanların fikirlerini toparlamak için ÇSG personeli ile güvene dayalı, çift yönlü ilişki kurmalarını sağlamak gerekir. Böyle bir ilişki geliştirmenin yolu, düzenli şekilde etkileşime açık iletişim kurmaktır [20]. Çalışanları duymak ve sözlerini söyleyebilmeleri için onları güçlendirmek gerekmektedir.

Paradigma değişimi örgüt kültürünün değişimi ile gerçekleşebilir. Kültür değişimi programlarında, kampanyalar yoluyla yönetimin destek ve kararlılığı diğer paydaşlar, çalışanlar ve kamuoyu ile paylaşılabilir. Kampanyalar, bir dizi iletişim etkinliklerinden oluşur ve içeriklerin kültüre uyumlu oluşturulması gerekir. Bu iletişim içeriklerinin hazırlanmasında yönetimin çalışanları “duyması” bu tip çalışmaların başarılı olması açısından önemlidir. Bu görüşü benimseyenler için sıfır kazanın zaten olması gereken doğal durum olarak düşünüldüğü paradigma değişiminde liderlik çok önemli potansiyeline sahiptir. Sonuç olarak, aslında iş esnasında kaza olmaması “normal” durumdur, ancak önemli olan şudur; bizler bunu kabul edebilecek ve bunun için liderlik edebilecek miyiz? Zamanımızı negatif sapmaları düzeltmek yerine, “olumlu sapmalar” yaratmak için, ÇSG’yi çalışma kültürümüzün içine proaktif şekilde yerleştirmek için ayıracak mıyız?

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**Industry 4.0/Digitalization & Sustainability**  
**Endüstri 4.0 / Dijitalizasyon & Sürdürülebilirlik**



## Industry 4.0 - Proactive Quality Assurance – Automated Coil Release

Endüstri 4.0 – Proaktif Kalite Yönetimi ile Otomatik Bobin Değerlendirme

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### Abstract

Smart factory, high flexibility, short time to market in an industrial scale are the key words of Industry 4.0. Digitalization and growing quality requirements for high-end products are at the same time an enormous challenge, which is often in competition with efficiency targets and market driven cost-cutting measures.

This paper describes the implementation experience of an Expert-system and the achieved benefits of an innovative new Industry 4.0 technology.

It opens the chance for a new way of using all the available experience inside a mill to improve the work flow and increase efficiency. In principle this technology helps all production lines in all grades but it has the highest impact in challenging grades for high-end markets like automotive and aerospace.

The new solution has an embedded automatic improvement cycle, which makes sure that needed modifications and adaptations to new market requirements are taken care of instantly. Speed of adaptation as well as reliability of the delivered quality will be the differentiator in the upcoming years.

### 1. Introduction

In recent decades, huge amounts of quality data were collected due to the continuous and regular monitoring of processing lines in the steel industry. Now is the time to take additional advantage of the investments in precise quality measuring equipment by opening up and integrating data. The Aachen-based company QuinLogic has been supporting steel companies worldwide with their quality assurance solution QES - Quality Execution System for more than 10 years. On the basis of fully integrated process and quality data, the combination of the applications Automatic Coil Grading / Release and DataCorrelator enable untapped improvement potential to be tapped.

Any anomalous or divergent quality data found during the production process of a coil require an action to be taken by the monitoring personnel. This action may be repairing, rerouting or in the worst case scenario, scrapping a coil resulting in losses. A huge amount of time and effort is

typically invested in pinpointing the exact cause of the defect(s).

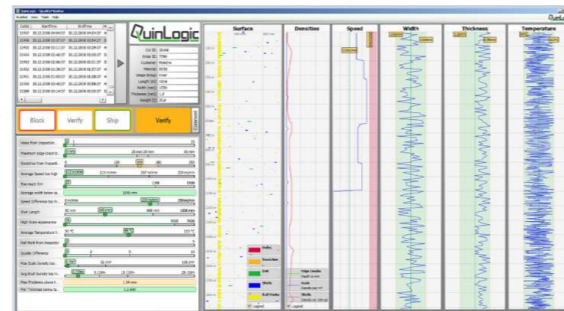


Figure 1. Automatic coil grading and release in QES

The vision of the QES is to pull out and analyze available data which was hidden or unused yet, in order to continuously improve automatic grading of product quality in a first step, and to search for previously invisible correlations in a second step using classification algorithms. Relevant correlations are displayed in relational decision trees which can then be converted into new rules. If these rules are then implemented, they immediately help in the prediction and detection of errors and defects, and ideally at a very early stage on the processing line.

The newly inducted rules thus help in making automatic coil grading and release more reliable and producing coils of a better quality. The newly generated and more precise data are again fed to the data correlator, which in turn comes up with newer and better correlations, which can be converted into even more intelligent rules based on a great deal of past experience as well as current, improved data (see Fig. 2). These rules continue to improve the quality of the output coils, while at the same time allowing for an easier and earlier root cause analysis of a quality problem. The feedback-based system contributes to bettering itself, thereby resulting in continuous quality improvement.

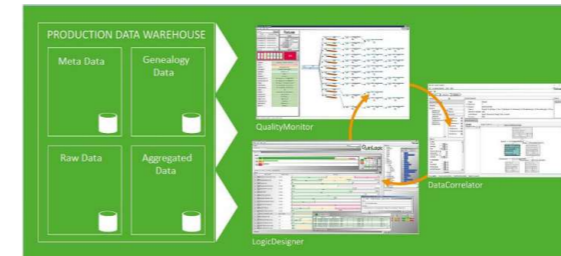


Figure 2. Continuous improvement process Correlation - Rule creation - Coil grading

### 2. Automatic coil grading and release support

In many rolling mills, quality assessment is still not an automated process. A lot of time and effort is invested in quality monitoring by experts, whereby the total effort required and the quality of the monitoring often depend on the skills and experience of individual operators.

In order to minimize the ensuing variations and deviations and their consequences and to reduce the effort for quality assessment in quality management, the QES is already an important component in many steel plants. The automatic grading system uses comprehensive process, product and quality data to assess the quality - from level 1 to level 4. These data are collected and processed centrally in the Production Data Warehouse (PDW) (see Fig. 4). The raw and aggregated data contained in the PDW offer enormous potential if these data are made available for immediate, continuous evaluation and then used for the automatic coil quality grading.

The added capability to analyze data on demand enables further optimization potential to be identified at any time when fine-tuning coil grading and release. For example, a quality rule can be defined that allows a certain number of light scratches on a coil to pass without sending the coil to be reviewed or without blocking the coil. However, if the system detects a critical number of these scratches in a very small area, it automatically recommends a further check or blocks the coil, depending on the density with which the scratches appear.

Another very important aspect of automated coil grading and release is that it frees up quality experts to concentrate on solving and maintaining real issues.

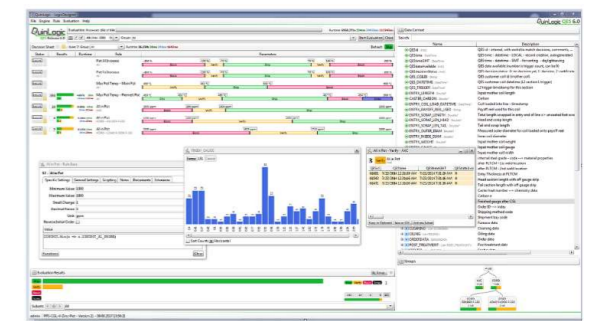


Figure 3. Rule creation and grading with the LogicDesigner

### 3. QES system components

In order to achieve continuously improved quality supervision and therefore, higher quality products, various components work in sync with one another in the QES for automatic coil grading / release. Thereby various concepts and principles are interconnected:

- **data integration** - making available and integrating all data on all past and current coils
- **quality rule translation, modification and definition** - translation of existing quality rules into the new rule set for automatic coil grading / release and introduction of new precise, logical quality rules to define desired quality standard (see Fig. 3)
- **automated quality monitoring** - allows reliable, automatic quality supervision
- **genealogy** - storing and maintaining every possible traceable data on a coil
- **correlating data and feedback** - identification of patterns in process and quality status in a given set of products which are converted into suggestions for changes in existing rules or addition of brand new quality rules
- **quality improvement** - prevention of bad coil production by using the feedback from experts

Once the suggested rule modifications are adapted or the newly suggested rules are inducted into the system, the performance of the system (automatically) goes up. Within the parameters of the quality rules, the system grades the coils flawlessly and leaves operators with more time to concentrate on deviations in a detailed manner rather than going through every single coil. All this while the system continues to perform the functions stated above in a continuous loop.

### 3.1. Data integration

There are two main aspects to consider when integrating data:

When observing various process steps together through the evaluation of diverse measuring systems, often only an incomplete overview of the current data landscape of the overall process is possible. The reasons for this often lie in the growing IT and automation structures which are not compatible with one another due to the lack of interfaces and inconsistent technologies, and access protocols. The integration of all data via the PDW closes this gap, i.e. the data can now be placed side by side, combined and put into new contexts.

The second aspect of data integration allows the user to view all of the past data, so far unused, in addition to current, continuously incoming data. These data are now connected to and brought together in a way that enables all previous and current process and quality status data to interact with each other.

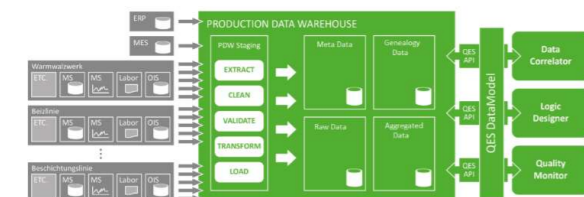


Figure 4. Production Data Warehouse (PDW)

The key advantage of the integration lies in the possibility of being used as a large data pool with which previous behavioral patterns can also be examined. If suitable methods are used, these data make it possible to trace the sequence of problematic coils and to find common factors that are responsible for the reduced product quality.

### 3.2. Quality rule translation, modification and definition

Using integrated data, all of the existing quality (logical) rules can be translated into the new system with ease. Existing complex rules can be simplified and/or modified to make them more efficient. The fact that all data is now available for interaction makes it possible to define new quality rules that are far more superior and complex than their forefathers. Better rules help catch problems before they turn hazardous and thus, contribute to continuous quality improvement.

### 3.3. Genealogy

Data integration into PDW achieves the purpose for the first time to actually connect the user with all company-wide available data. However, analyses of problems can become a challenge when dealing with a very large volume of data and this is where the concept of genealogy comes to the rescue. A complete, meticulous record of every single coil is stored and maintained in the system,

right from its perception or in other words, the roots of every single coil are traced back to its origins and a digital twin of the coil is created, stored and maintained (to reflect any further changes) in the system (see Fig. 5).

This means that a full track record of all the raw material that went into the making of this coil and including every single process that each section of a daughter coil underwent, possibly made up of parts from different mother coils, is stored and maintained in the system. This includes records of all intermediate processes that were applied to the material from the point it was introduced. Eventually, this makes possible a quick and precise analysis of the cause of a problem.

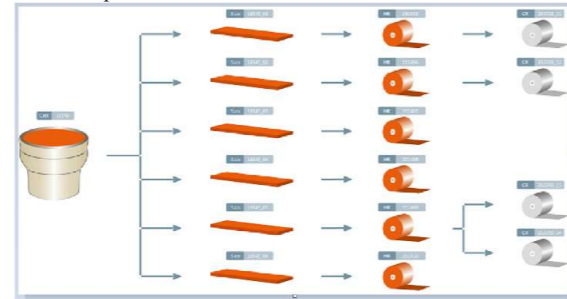


Figure 5. Genealogy

### 3.4. Correlating data and feedback

Using genealogy for every coil, different algorithms can be put to work in DataCorrelator to track behavioral patterns and find different correlations in the material and processes of coils with the same output quality (see Fig. 6). The results of such correlations can help spot trends in parameter values measured that were, for instance, within tolerance limits but nevertheless affected the quality of coils at a later stage. Once such behavior is made available descriptively or visually, it is very easy to fix the problem by modifying an existing rule with greater than acceptable tolerances or to introduce new rules altogether. The results of the correlation analyses work on creating and proposing such rules that can be directly taken over. This means that it is no more required from the personnel that they spend time and thought into actually creating a new rule and feeding it into the system – they can simply take over the suggestion.



Figure 6. Correlation analysis with the DataCorrelator

### 3.5. Quality Improvement

The correlation and feedback system continues to work with past and incoming data to further figure out how to continuously further improve the quality of already acceptable coils. Proactive quality supervision allows deviations in process lines to show up (and therefore, to be rectified) before they can affect the quality of a coil at a later point.

### 4. Conclusion

Automatic coil grading / release with QuinLogic's Quality Execution System has become a well-established standard. Through its introduction, processing effort by quality experts has been demonstrably reduced, while the coil grading / release itself has become more valuable. By integrating data in the Production Data Warehouse, all data is easily accessible and comparable. By organizing this integrated data on the basis of its entire life cycle (genealogy), this large volume of data can be wisely accessed through analysis. Correlating data using powerful algorithms helps to spot common behaviors and trends in the production process and to identify the root causes of problems that can lead to a defective coil.

The goal here is not only to avoid delivery of one or more bad products to the customer, but more importantly to ensure that such defects do not occur at all by making certain that conditions leading up to defective production are identified and eliminated. What is also important to note here is that such a system greatly reduces the downtime in a plant, thereby not only contributing to continuously improving quality, but also to production volume and therefore, revenue.



## Digital Transformation for the Reinforcing Steel Supply Chain

Yapı Çeliği Tedarik Zincirinde Dijital Dönüşüm

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### Abstract

Organisations are geared to an intensification of competitiveness in the context of globalisation; the volatility of market demands; shortened innovation spans; and reduced product life cycles, as well as the increasing complexity around products and processes.

Digitalisation is not a simple transfer from analogue to digital data and documents, but represents a fundamental transformation in core business process networks, the creation of efficient interfaces and fully integrated data exchange and management [1].

The future of construction and steel industries is digital. It follows that digital transformation is one of the core elements of this ongoing industrial revolution.

This paper describes the CARES Digital Transformation approach covering all stages in the reinforcing steel supply chain from receipt of raw materials, on to the manufacture and processing of steel products through to delivery to the end user. CARES digital solutions are being developed in support of the construction and steel industries drive towards greater traceability, safety and sustainability. These solutions also provide reliable, easily accessible product information and evidence of assurance.

### 1. Introduction and Background

The drive towards digitalisation is a central topic across all industries, revolutionising the design, production and organisation of the global value chain. Digital technologies promote new processes implementation along the entire value chain, through manufacturing and sales to services, concerning the use of a product, performed by research and development activities. For this reason, digitalisation should be considered a holistic approach that covers all areas and functions of an organisation in order to exploit digital potentials and analyse each stage of its value chain.

Digital transformation is one of the core elements of the ongoing industrial revolution. Digitalisation requires significant investment in people, processes and technology.

**People:** A culture change has to start with people. A digital transformation will only happen if the right people are involved in the process, and if everyone is on board including Top Management with the changes that will happen across the business.

**Process:** A digital transformation process is about getting stakeholders to think and work more effectively, make smarter decisions, and use the right tools for the business. It's an opportunity for the organisation to see what processes can be automated and take a deeper look at the data to gain greater insight into the way the business runs and how to meet stakeholder needs more effectively.

**Technology:** Technology helps to enable process transformation. The organisation should define the right technology infrastructure to enable the future plans to ensure the growth and success. For example, Cloud is not a new technology and there are a wide variety of Cloud configurations available for businesses. Cloud architectures should be flexible, adaptable to changing regulations and business requirements.

The future of construction and steel industries is digital.

The construction industry accounts for 6% of the national economy and hires as many as 2.4 million workers in the UK – roughly 8% of the whole workforce. Yet, despite its national and indeed global importance, it has yet to undergo any significant digitalisation.

Increasingly, there is recognition across HMG that delivering the stated priorities of infrastructure investment requires a shift in thinking – with digitalisation holding the key. In a recent foreword to Flourishing Systems, an academic paper on the impact of climate change on current economic and social priorities Fergus Harradence, Deputy Director for Construction at BEIS, wrote [2]:

“The UK government has made clear that it places infrastructure at the centre of its vision for the nation – investing in infrastructure to level up prosperity and wellbeing across the country. Digitalisation, built on secure, resilient data sharing, has an important role to play in achieving this. As we emerge from the Covid-19 pandemic,

it could be that digitalisation has reached a tipping point. The lockdown has required us to adapt quickly to digital ways of working, proven the robustness of telecommunications systems globally, and shown the need for improved data.”

Investment in digital solutions is already beginning to have a positive impact, according to the recent survey [3]. It found 54% of organisations that had already adopted integrated digital practices had seen an increase in workforce productivity; 43% said business win rates had improved; and 56% had cut operating costs.

### 2. Digitalisation of CARES' operations and the reinforcing steel supply chain

Trust in safety critical products has been hit by fake data scandals and major disasters. Finding the truth of a product's provenance is never more needed than now – and reinforcing steel is one of the most safety critical elements in any project.

The CARES Cloud digital solution is being developed to address and solve this urgent issue, bringing simplicity to a complex supply chain (Figure 1) while restoring trust where it's missing. By working collaboratively with stakeholders, the CARES Cloud tracks each batch of reinforcing steel from its point of origin to the construction site providing compliance and carbon footprint data plus sustainability credentials to achieve credits in BREEAM, LEED and/or CEEQUAL (Figure 2).

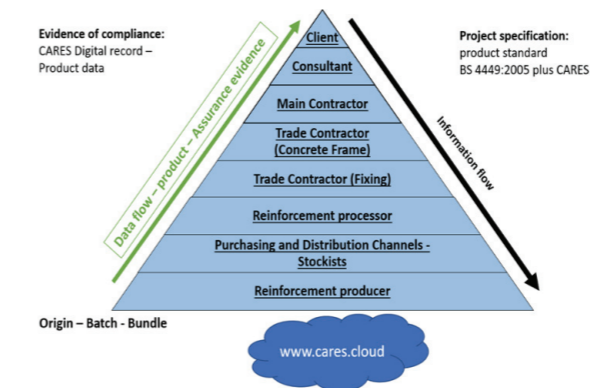


Figure 1. CARES assured reinforcing steel supply chain

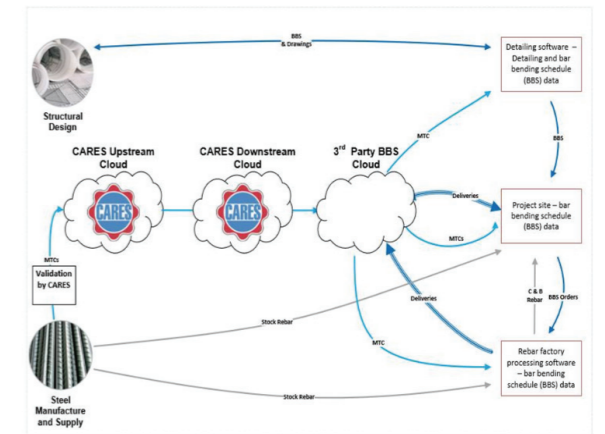


Figure 2. CARES digital supply chain

CARES is aiming:

- To make the CARES assured reinforcing steel supply chain the safest, most effective, efficient, digital and sustainable in the World.
- To ensure all reinforcing steel products are quality assured, responsibly sourced and evidenced by a CARES Digital Record.

Making sure products are effectively tested, marketed and traced complements CARES' independent assurance of product compliance from the CARES assured supply chain, including manufacturers and processors of reinforcing steels. The CARES Cloud enables real-time analysis of the manufacturing origin of the reinforcing steel and an accurate carbon footprint value for each tonne of reinforcing steel delivered.

### 3. CARES digital products

#### 3.1. CARES Cloud

The CARES Cloud [4] ecosystem started development in 2016 to digitise a complex supply chain. The product test data for each cast of reinforcement produced is securely stored on the Microsoft Azure platform and provides real-time access to the product test data uploaded by the CARES approved manufactures.

This digital platform is built through an 'agile' development process, using a suite of Apps which allow online and hand-held scanners and smartphones to trace what has been produced, fabricated, delivered and installed in real-time.

It replaces existing manual paper-based processes which are labour intensive and prone to leaving significant gaps in assurance trails. The CARES Cloud will also enable a value-based procurement approach and provide a reliable digital twin.

The start of the journey from product testing to creation of the Dynamic QR Code is the uploading of product test data by the mills to the CARES Cloud as an XML file. The data requirements and format of the XML file is set out in the CARES Cloud Data Transfer Specification.

Two GUIDs namely “Test GUID” and “Digital Record GUID” are used to help identify data that is on the CARES Cloud. The “Test GUID” is simply a unique identifier for each of the test lines uploaded. The “Digital Record GUID” is used to create the Dynamic QR Code, which is printed on each label attached to every product bundle.

For each combination of Cast, Standard and Diameter, the CARES approved manufacture creates a Digital Record GUID. This acts as a reference that the manufacturer may, if required, store in their own systems to record the Digital Records created.

If required a Cast, Standard and Diameter combination can be split into multiple digital records. In Figure 3, all of Cast no “1000000001”, Standard “BS4449:2005+A3:2016 Grade B500B”, Diameter 32mm, has been put into one digital record, so all 4 testing records have the same “Digital Record GUID”. Cast “1000000002”, Standard “BS4449:2005+A3:2016 Grade B500C”, Diameter 20mm, has been electively split into two sets of tests, stored on separate digital records, before upload.

CARES Digital Record No.	Digital Record GUID	Cast Number	Standard	DiamNo	Test Line	TestGUID
145725	85408731-27A8-41E6-82FC-DC3938456578	1000000001	BS 4449 2005 + A3:2016 Grade B500B	32	1	85408731-2B25-479B-94BD-2A4104045106
145726	85408731-27A8-41E6-82FC-DC3938456578	1000000001	BS 4449 2005 + A3:2016 Grade B500B	32	2	85408731-2734-4631-8C39-8C94F10D1F84E8
145727	85408731-27A8-41E6-82FC-DC3938456578	1000000001	BS 4449 2005 + A3:2016 Grade B500B	32	3	85408731-2734-4631-8C39-8C94F10D1F84E8
145728	85408731-27A8-41E6-82FC-DC3938456578	1000000001	BS 4449 2005 + A3:2016 Grade B500B	32	4	85408731-2734-4631-8C39-8C94F10D1F84E8
1519120	85408731-27A8-41E6-82FC-DC3938456578	1000000002	BS 4449 2005 + A3:2016 Grade B500C	20	1	85408731-2734-4631-8C39-8C94F10D1F84E8
1519121	85408731-27A8-41E6-82FC-DC3938456578	1000000002	BS 4449 2005 + A3:2016 Grade B500C	20	2	85408731-2734-4631-8C39-8C94F10D1F84E8



Figure 3. CARES “Digital Record GUID”

3.2. CARES Apps

A suite of CARES Apps have been developed and made available for use for a number of users groups, including internal users and external users. They contribute to improve the effectiveness and efficiency of audits, including with the audits of reinforcement manufacturers, traders, agents and processors.

CARES Cloud App was developed in 2019 and is available from the App Store for iOS device [5] and Google Play for Android device [6]. The App is capable to search CARES

approved companies product markings, referred to as bar marks, report a concern for CARES approved companies and scan the static QR Code on the CARES certificate of approval to confirm the validity and scope of approval on the certificate.

CARES Auditor App was developed to help CARES auditors to report issues arising from CARES audits. The App has the same functionality as the CARES Cloud App and additional CARES Audit Functionality and is also used to scan the CARES dynamic QR Code on labels.

CARES Upstream App was developed to help processors and contractors in the supply chain to confirm the validity and scope of approval on the certificate; and to scan the CARES Static QR Code on labels/delivery notes to validate the Origin and Standard of Material used

Further Apps are being developed to provide increased levels of traceability and record the flow of CARES approved Material used on projects

3.3. Industry standard QR bar codes

3.3.1. Static QR Codes

CARES Static QR Codes (Figure 4) provide evidence that the reinforcing steel was sourced from a CARES approved manufacturer with a valid approval to the relevant product standard. The information from the Static QR codes can only be retrieved by third parties (stockists, traders, processors, contractors, designers and clients) by using CARES Cloud App.



Figure 4. Scanning CARES Approved Company static QR code

3.3.2. Dynamic QR Codes

CARES Dynamic QR Code provides a link directly to the uploaded XML product test data by the manufacturers on the CARES Cloud. The data requirements and format of the XML file is set out in the CARES Cloud Data Transfer Specification

CARES Dynamic QR Codes (Figure 5) allow permitted third parties to retrieve an online digital record of the traceability, chemical composition and mechanical properties of the reinforcing steel. The information from the Dynamic QR codes can only be retrieved by permitted third parties (stockists, traders, processors, contractors, designers and clients) by using CARES Supply Chain Apps



Figure 5. Scanning CARES Manufacturer Dynamic QR code

3.4. Evidence of product compliance

Assurance of product quality - The digital portal enables a CARES Digital Record of each batch of reinforcing steel to be available in real-time as evidence of compliance to the reinforcing steel product standard and sustainability credentials, such as the carbon footprint. The CARES certificates of approval for all companies in the supply chain are available via a customised dashboard.

Sustainability credentials - The CARES sustainability certificates of approval and Environmental Product Declarations (EPD), including carbon footprint data, for all companies in the supply chain are available via a customised dashboard. It provides independent, reliable and verified carbon footprint data for each batch of steel reinforcement to enable carbon accounting.

CARES Digital record – enable digital compliance checking and provide a reliable digital twin.

Material Compliance Report (MCR) – Clients, such as Network Rail, require a Material Compliance Report which includes the sources of all materials, certification of all suppliers and product information at the batch level.

3.5. Enable value-based procurement

CARES Cloud enables a value-based procurement approach which will contribute to high level national / governmental strategic objectives:

- a) Supporting delivery of overarching economic, social and environmental goals

- b) Addressing the challenges of climate change in the built environment
- c) Supporting the transition of the steel sector to lower environmental impact and resource efficiency, in turn enabling the transition to the circular economy
- d) Encouraging and facilitating innovation and achieving the maximum benefit from long-term infrastructure investment.

Conclusion

CARES Digital Transformation Strategy represents a truly visionary solution at a time of critical global transformation in a core economic sector – construction – which has resisted change for too long. Through its bold, ambitious and timely scope, CARES goals deliver on the objectives and commitments detailed in the UK Government’s Construction Sector Deal [7] and supports the objectives of complementary digitalisation policies in the construction industry [8] [9].

CARES seeks to embed its digital transformation initiative as a core part of its Strategy and Action Plan. CARES’ vision is to:

- Implement new technologies and systems which will transform the steel supply chain (Digital product traceability, compliance checking, BIM) and
- Continue setting the pace in collaborating with stakeholders including digital partners.

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 [7] GOV.UK - Policy paper - Construction Sector Deal (July 2019) <https://www.gov.uk/government/publications/construction-sector-deal/construction-sector-deal> Date: 28.07.2020.

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<<https://www.gov.uk/government/publications/uk-construction-industry-digital-technology>> Date: 28.07.2020.

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<<https://www.gov.uk/guidance/creating-a-digital-built-britain-what-you-need-to-know>> Date: 28.07.2020.

## Rolling into the Future by Digitalization, Primetals Technologies Long Rolling Control System

Dijitalizasyon ile Geleceğe Doğru Haddeleme

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### Abstract

Today's steel producers face the dual challenge of ensuring on-time delivery and ever demanding product requirements, while also running a lean operation. Every day the management of a long rolling plant requires continuous optimization of both operating and business practices. Imagine a long rolling facility, where individual pieces of equipment communicate with each other, where sensor information can be used not only for control purposes but to also monitor the condition of the equipment, where models are used to verify the process is within working limits and the equipment raises alerts to operators when it requires maintenance. Utilizing the ongoing evolution in technology through data collection, communication, internet of things, control techniques and smart sensors, there is now more information available than ever before. The collection and analysis of this information will both advance control and monitoring of plant performance; revolutionizing long rolling mill plants worldwide and optimizing the entire value chain, along with improved and more flexible production.

### 1. Introduction

“You cannot manage what you do not measure” - to reach the goals for future market requirements it is imperative to fully understand the operation of a long rolling facility. With the ongoing technological evolution, it is ever easier to collect, manage and collate data at all levels within the mill, to understand and improve processes, operations and maintenance requirements.

New concepts are being developed to improve the operational management of the critical areas within a long rolling mill. Using existing installed technology, combined with smart sensors such as non-contact measurement devices, vision systems, intelligent temperature measurement, RFID for product tracking, additional real time data will become accessible. Utilizing the powerful

computational and network systems now available, this data can be collected, collated, analysed and reported; allowing operators to make rapid, educated decisions on the mill floor and providing a higher level of automation within long rolling mills.

These concepts alone will lead to improvements in Product Quality, Rolling Process, Rolling Flexibility, Operating Costs, Maintenance costs, Operation setup, Operator Intervention, Product Storage and Logistics

With the growth in plant digitalization, the increase in data available for collection, utilization, analysis and distribution, along with intelligent models (or process based systems) used for production planning, product quality, mill and equipment maintenance, a revolution in long rolling mill control systems is occurring.

### 2. Approach to digital transformation

Primetals Technologies continuously develops new technological functions and packages for long rolling to improve quality, mill flexibility, mill efficiency and increase overall productivity. These packages are based on the latest technologies, business trends and close cooperation with key customers, to understand and meet the challenges of customers, in order to provide tools to support customers for the growth in technology and requirements for the future long rolling plant requirements.

It should be understood that Industry 4.0 IS NOT a PRODUCT, but a group of technological, process and maintenance packages to support the transition of a long rolling plant to meet the future requirements of plant digitalization.

Today we have the traditional horizontal and vertical integration of the mill control and supervisory systems, as can be seen in Figure 1. With the change in technology we will, in future, be able to communicate on one plane,



allowing long rolling customers to collect data and communicate to all sensors, machines and processors within a plant. The internet of things (IoT) becomes a major pathway for sensors and systems to collect and communicate data.

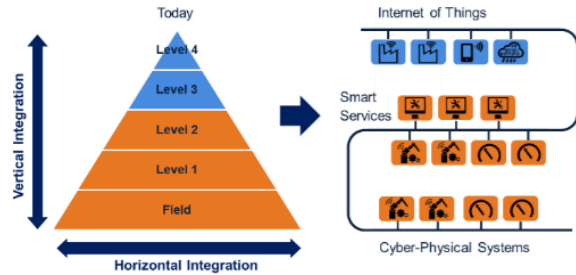


Figure 1. Mill control system hierarchy today vs tomorrow.

Primetals Technologies have developed packages to support the future trend to digitalize long rolling plants; these packages are designed in such a manner that equipment can be added to existing plants, in a phased approach, to help support the long term future requirements of long rolling customers (see Figure 2).



Figure 2. Approach to reach future requirements of long rolling customers.

Future requirements will dictate the following within a long rolling plant;

- Equipment: Intelligence (both process and maintenance), High plant availability
- Production: High Flexibility, High Efficiency
- Quality: High Product Quality, Product Flexibility,

Understanding the requirements of the equipment, processes and control within a long rolling mill has allowed Primetals Technologies to design and implement packages to meet the future demands of the industry.

2.1. Equipment

Every customer is aiming for high plant availability. With the addition data from devices such as smart sensors, advances in predictive maintenance and condition monitoring systems, this goal can be achieved. By adding these concepts and utilizing the vast amount of data now available, intelligence can be added for each piece of equipment.

Imagine Stand #1 informing stand #2 what is happening to the product, and what is required from stand #2 based on the rolling condition of stand #1 - or the roughing mill communicating with the intermediate mill! Although this seems highly visionary today, based on the level of control within a long rolling mill, this type of control is coming.

A good example of this is an image sensor (smart sensor) added between two stands. This can provide both actual real-time speed and the product dimensions, improving not only the process, but also mill safety, by eliminating the necessity for operators to take actual physical measurements of the product. This single, simple illustration shows the true benefits to customers of developing such sensors; a small, but important piece of meeting customers' future requirements. Figure 3 shows an example of an in-line product dimension measurement.

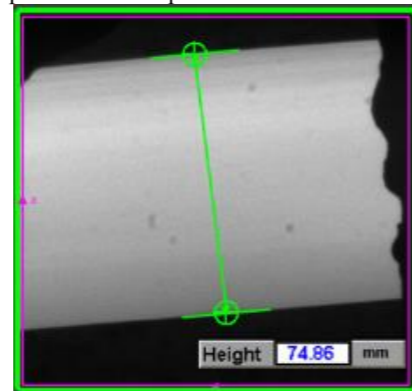


Figure 3. HMI view of product height being measured dynamically in a roughing mill.

Table 1 below shows the benefits to customers of adding small technological packages into a wire rod mill in order to enhance the overall control of the rolling process.

Table 1. Benefits of technological packages to mill operations.

FURNACE	RM	IM	FM	STEMOR COOLING	COIL HANDLING	RESULT	Pre-cond Sensor
	Height and width measurement	Height and width measurement				STOCK CONTROL IN RMILL / BMILL CONSTANCY IN MTC AND MILL SETUP PREDICTIVE COOLING	Vision / Non Contact Laser
	Product Speed measurement	Product Speed measurement	Product Speed measurement			YIELD IMPROVEMENT (SHEAR CONTROL) MASS FLOW CALC MTC BETWEEN FINISHING BLOCKS (IMPROVE PRODUCT TOLERANCE) DYNAMIC MILL SET UP PINCH ROLL CONTROL LAYING HEAD CONTROL	Non Contact Laser
			Auto coil Position			IMPROVE QUALITY	Vision System
				Temperature Control		IMPROVE QUALITY, DEFINE PRODUCT TRANSFORMATION POINT	Thermal scan
			Auto coil shape control			COIL PACKAGE IMPROVEMENT	Vision
			Intelli Coil			LOGISTICS IMPROVEMENT IN COIL YARD	Wireless TAG

2.2. Smart sensors for long rolling

A 'smart' sensor is defined as that which is able to measure and/or monitor the process with a degree of 'internal processing', or 'intelligence'. It provides information that up until now has often been unavailable; particularly in real-time. Smart sensors either directly measure physical values, or use existing measurements, to indirectly calculate additional information. These are the enablers for the implementation of advanced automatic functions, process models, as well as condition monitoring. Such devices provide continuous information on state of the processes, enabling ever more sophisticated monitoring and control of the entire plant.

Installing packages that have been developed around smart sensors provides new and improved process metrics, leading to a more intelligent rolling process. By reducing mill setup time and implementing condition monitoring and predictive maintenance, overall plant operation can be significantly improved – seen by an increase in quality, yield and flexibility.

Figure 4 lists some of the smart sensors available and their application in the long rolling process.



Figure 4. A sample of SMART sensors developed for long rolling applications.

2.3. Production

Every customer is aiming for flexibility and high efficiency in their production cycle. As discussed earlier, with advancements in software and powerful network systems, we now have the tools to collect, sort and analyze large amounts of data. Utilizing these tools in Cyber Physical Systems (CPS) allows the production performance to be monitored, analyzed and measured against Key Performance Indicators (KPIs) to ensure the planned production is being followed.

A CPS is a virtual model of the REAL PHYSICAL plant or process and is used to verify the consequences of changing the plant conditions. The model is formed from integrations of computation, networking, and physical processes (see Figure 5). Embedded computers and networks monitor and control the physical processes with

feedback loops, where physical processes affect computations and vice versa.

A CPS can be a model of an individual process; such as cooling model to calculate the temperature equalization in a rail mill, water box set up in a conventional rod or bar mill, or mill set up and the roll pass calculations. By utilizing CPS in the future, mill operators and supervisors will be able to understand the effects of a change in set up of a certain process or piece of equipment BEFORE the change is made.

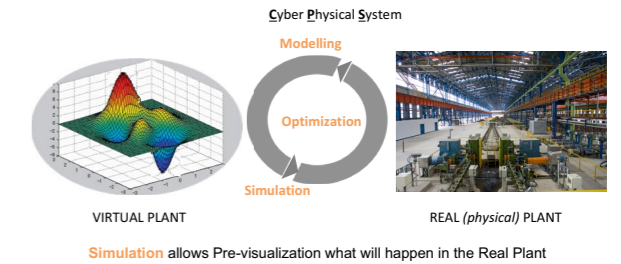


Figure 5. Cyber Physical System.

2.4. Quality – Through Process Quality Control, Through Process Optimization (TPOpt)

TPOpt provides knowhow-based identification of non-conformities, determines the related root cause and provides corrective and compensational actions throughout the entire production chain. It effectively helps to achieve the intended product specifications and support quality management.

This system integrates the quality knowhow of a product with the real-time process. A rule-based system checks the resultant data at each process event. A decision is made based on these rubrics as to whether the product quality is within the defined limits. The system then determines corrective dynamic adjustments to the processes both upstream and downstream, relative to the event position. This will consequently enhance the overall product quality by both preventing further quality issues from occurring and rectifying those detected. Figure 6 shows an example of the rules-based system. This is a dynamic quality control system, updating the process requirements of the product as it is being made. Although Fig. 6 shows only a long rolling plant section, Primetals Technologies' TPQC system monitors quality throughout the entire process from the liquid phase to the finished product.

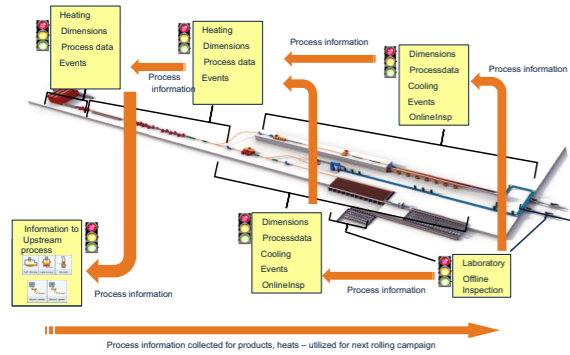


Figure 6. Rules-based Through Process Quality Control system.

2.5. Process Expert

Primetals Technologies Process Expert monitors and collects data from the raw material stage through to the finished product. Its domain extends from the enterprise resource planning (ERP), through Manufacturing Execution Systems (MES), to control systems and right down to level 1 devices. The system delivers valuable mill reports to the operator staff and management so they can easily assess a plant's performance and optimize production. Defined Key Performance Indicators (KPI's) help to assess a plants performance; the system is not limited to one plant but can enable plant to plant performance at corporate level.

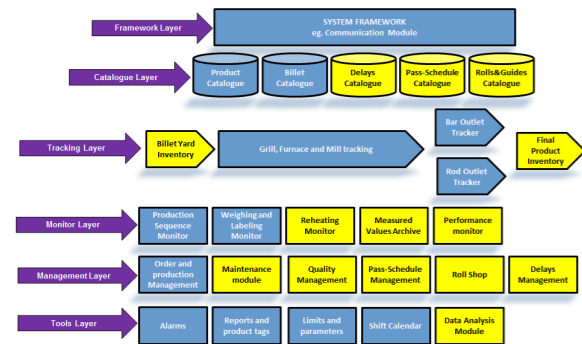


Figure 7. Process Expert modules overview.

The basic technological modules, based on extensive experience in the long rolling industry, include:

- Production sequencing
- Heat data management
- Raw material assignment
- Automatic mill setup data management and control
- Material tracking
- Data processing/archiving
- Plant monitoring
- Pass Scheduling

- Weighing and tagging
- Analysis and report manager
- Delay management
- Online system help
- User-friendly integrated HMI
- Definition of KPIs
- Genealogy module
- QUALITY on line monitor

Optional modules of Process Expert:

- Interface to MES – Manufacturing Execution System (L3) and other IT systems
- Production program optimization
- Roll and guide management
- Melt shop interface
- Maintenance tracking and guide manager
- Offline sample & laboratory interface generation of QA certificates
- Billets and final product yards inventory

2.6. Condition monitoring

Primetals Technologies utilizes mechanical and electrical knowledge of the equipment and the process to monitor the condition of the equipment - not only in the rolling mill, but also upstream and downstream components, thus guaranteeing all elements contributing to plant operation are monitored. This ensures that planned downtime and shutdowns are optimized; to be as minimal and efficient as possible, throughout the complete process. Fig. 8 shows an example of a comprehensive condition monitoring system.

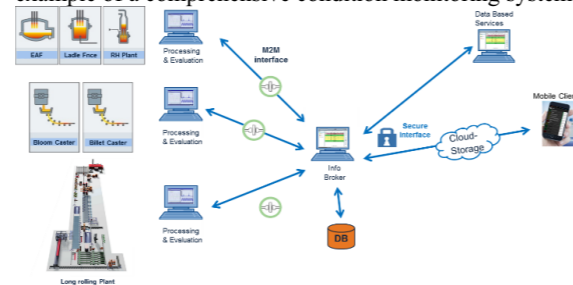


Figure 8. Condition Monitoring System

Equipment condition data is acquired at each plant level, then processed and evaluated against known operating standards and reported back at the plant level. Utilizing the equipment knowledge within Primetals Technologies, the system can process the data and alert when maintenance is required. By knowing the status of the equipment throughout the full process line, downtime for maintenance can be optimized at the plant level.

Work instructions for maintenance personnel (including any spares required) will be produced automatically, along with any additional information required for the maintenance project - including those obtained through 3-D

interactive models on tablets; further minimizing downtime.

3. Summary and benefits

Along with the systems described in this paper, Primetals Technologies is also working on improved automated equipment and robotics to help increase productivity and reduce downtime. From an equipment standpoint, the goal is to replace the fluids-driven equipment with electrical and servo-controlled devices that offer more information on both the equipment and feedback of the process itself. An example of this is the patented Morgan Intelligent Pinch Roll, where the pinch control of the roll, originally done pneumatically, has been replaced by electric servo motor control. This provides high speed, accurate and repeatable control and feedback of the pinch roll pressure and opening throughout the different stages of rolling process.

Primetals Technologies is working on robotic applications with the goal of replacing heavy, dangerous manual maintenance functions and repetitive operations - for instance; laying head pipe change, roll change, shear blade change. Robotic control systems will be supported by fully-automated mechatronic solutions, allowing operators more time to focus on the essential tasks of the process and the plant.

Table 2 below represents the true digitalization of long rolling, using a wire rod mill example. The same results can be gained for any long rolling facility. By developing systems that can be introduced into long rolling mills in a phased approach, it allows customers to utilize the tools provided to ensure their target for digitalization can be achieved in a cost-effective manner.

Table 2. Long rolling mill digitalization.

Digitalization of a Long Rolling Mill (WRM)							
Through Process Control	FURNACE	RM	IM	FM	STEMMOR COOLING	COIL HANDLING	Pre-cond Sensor
THROUGH PROCESS QUALITY CONTROL							
Height and width measurement	Height and width measurement						IMPROVED PRODUCT, DYNAMIC SCHEDULING
							STOCK CONTROL IN RM/ML / IM/ML, CONSISTENCY IN MFC AND MILL SETUP, PREDICTIVE COOLING
Product Speed measurement	Product Speed measurement	Product Speed measurement					YIELD IMPROVEMENT (SHEAR CONTROL), MASS FLOW CALC, MFC BETWEEN FINISHING BLOCKS IMPROVE PRODUCT TOLERANCE, DYNAMIC MILL SET UP, PINCH ROLL CONTROL, LAYING HEAD CONTROL
				Auto coil Position			IMPROVE QUALITY
					Temperature Control		IMPROVE QUALITY, DEFINE PRODUCT TRANSFORMATION POINT
						Auto coil shape control	COIL PACKAGE IMPROVEMENT
						Intelli Coil	LOGISTICS IMPROVEMENT IN COIL YARD
							INCREASED EFFICIENCY OF MAINTENANCE AND REDUCED DOWNTIME
	CONDITION MONITORING (CMS)						

The benefits of these systems are numerous. They can be aligned to meet customers' short-term goals, be an integral part of a long-term strategy for process digitalization, and help meet the challenges that long rolling plants will face in

the future to achieve the ever demanding requirements of the market.

4. Conclusion

The advantages of the Primetals Technologies approach to digitalization (Industry 4.0) are:

- The solution is not "OFF THE SHELF", but tailored to each individual mill's requirement
- Technological packages that can be introduced in phases to existing and new facilities with IMMEDIATE customer value and return of investment
- Developments in all directions, - Quality, Productivity and Flexibility
- Each long rolling customer must, with the assistance of Primetals Technologies, define their own particular implementation strategy for Industry 4.0 readiness
- Primetals Technologies will actively assist long rolling customers in the digital transformation of their production plants with portfolio elements and services

This approach to the digitalization of the long rolling industry will enable customers to set both their short and long term goals in a phased approach. Strategically planned investment to meet the future requirements of the industry will allow optimized implementation of these ever-evolving technologies and harness the full power Industry 4.0.



## Metal Endüstrisinde RPA (Robotic Process Automation) ile Maliyet Azaltma

Cost Reduction with RPA (Robotic Process Automation) in Metal Industry

K. Mert Demirci, Burak Yılmaz

CORPORATE SENSE • Türkiye

### Abstract

Developing technology changes many ways of doing business every single day. Especially growing companies are challenging small companies with the cost advantage they gain thanks to the economies of scale. RPA (Robotic process automation), which has come into our lives in recent years as a new technological development, has already begun to multiply the cost advantage of big companies. In this paper, RPA applications in the sales department of a company which is in the metal industry and the benefits of the cost reduction with this project will be explained.

### Özet

Hızla gelişen teknoloji birçok iş yapış şeklini değiştiriyor. Özellikle büyüyen şirketler ölçek ekonomisinin yarattığı maliyet avantajı ile küçük şirketlere yaşama şansı bırakmıyor. Yeni bir teknolojik gelişme olarak son yıllarda hayatımıza giren RPA (Robotik süreç otomasyonları) 'de yine büyük şirketlerin maliyet avantajını katlayıcı bir etki yaratmaya başladı bile. Bu bildiride metal endüstrisinde faaliyet gösteren bir firmanın satış departmanında RPA uygulamaları ile maliyet düşürme projesinden elde edilen faydalar anlatılacaktır.

### 1. Giriş

İlk sanayileşmiş ülkelerde endüstriyel değer yaratma, şu anda Sanayi 4.0 olarak adlandırılan sanayileşmenin dördüncü aşamasına doğru gelişme ile şekillenmektedir. Bu gelişme 1970'lerin başında başlayan ve imalatta yüksek düzeyde otomasyon gerçekleştirmek için elektronik ve bilgi teknolojilerine dayanan üçüncü sanayi devrimini takip etmektedir (Acatech 2013).

Endüstri 4.0'a yönelik gelişim günümüzde imalat sanayii üzerinde önemli bir etkiye sahiptir. Akıllı fabrikaların, akıllı ürünlerin ve endüstriyel internet olarak da adlandırılan şeylerin ve hizmetlerin internetine yerleştirilmiş akıllı hizmetlerin kurulmasına dayanmaktadır (Kagermann, H.; Lukas, W.; Wahlster, W: Abschotten). Ayrıca, bu Endüstri 4.0 unsurları etrafında yeni iş modelleri gelişmektedir. Endüstri 4.0'a yönelik bu gelişme, her yerde bulunan bilgi ve iletişim teknolojisi (BİT)

altyapısını kullanarak sürdürülebilir üretimin gerçekleştirilmesi için büyük fırsatlar sunmaktadır (Prinz, C., Morlock, F., Freith, S., Kreggenfeld, N., Kreimeier, D., & Kuhlenkötter, B. 2016).

Endüstri 4.0 ile endüstri alanındaki bu ilerleme teknoloji alanında kat ettiğimiz yol ile daha sağlam adımlarla ilerlemektedir. Teknolojik ilerleme sonucunda dünyamızda çok büyük boyutlarda veri üretmeye ve bu verileri depolama ve işleme kabiliyetlerimizi ilerletmeye başladık. Bu ilerleme bağlamında veri bilimi, yapay zeka, büyük veri, makine öğrenmesi ve RPA gibi bir çok alan oluşmuştur. Tüm bu gelişim habitatında şirket ve sanayi süreçlerimizde değişime uğramaya başlamıştır. Gelişen bu teknolojiler arasında RPA en dikkat çekici alanlardan bir tanesi olarak göze çarpmaktadır (Jardim-Goncalves, R., Romero, D., & Grilo, A. 2017).

Robotic Process Automation (RPA) konusunda İşletme ve Bilgi Sistemleri Mühendisliği (Business and Information Systems Engineering) tarafından sorulan çok temel bir soru bulunmaktadır. Bu soru "Hangi iş süreçleri otomatize edilmeli ve insanlar tarafından hangi süreçler yürütülmelidir." Bu soru yakın tarihimizde sıkça duyduğumuz ve teknolojik gelişmeler ışığında duymaya devam edeceğimiz bir soru olarak karşımıza çıkmaktadır (Le Clair C 2017). Veri bilimi, makine öğrenimi ve yapay zeka alanındaki gelişmeler bizi bu soruyu sürekli olarak tekrar gözden geçirmeye zorluyor. Robotik Proses Otomasyonu (RPA) bu gelişmelerden biridir.

### 2. RPA Nedir? Ne Amaçla Kullanılır?

RPA, bir insanın gün içerisinde bilgisayar üzerinde yani elektronik ortamda yaptığı tekrarlı işleri yerine getirme amacıyla kullanılmaktadır. Bilgisayar sistemlerinin kullanıcı ara yüzünde çalışan araçlar için kullanılan bir sistemdir (Tornbohm 2017). Bir RPA aracı, yazılım robotunun izleyeceği RPA aracı dilinde bir işlemi eşleştirerek çalışır ve komut dosyasını bir kontrol paneli tarafından yürütmek için çalışma zamanı ayrılır. " (Tornbohm 2017). Bu nedenle, RPA araçları çalışanlar üzerinde

tekrarlayan, basit görevlerin yükünü azaltmayı amaçlamaktadır (Aguirre ve Rodriguez 2017).



Şekil 1. RPA Robotik Proses Automation

"Robotik Proses Otomasyonu" (RPA) terimi, insan görevlerini yerine getiren ofis işlemleri etrafında teşekkül eden bir vizyonlarını ifade etse de, RPA, çoğunlukla e-posta ve Kurumsal Kaynak Planlama (ERP) ve Müşteri İlişkileri Yönetimi (CRM) sistemleri gibi kayıt sistemleri ile entegre bir şekilde çalışabilmektedir. Ayrıca bu sistemlerin kullandığı ara yüzler üzerinde elektronik tablolar ekleme gibi bir çok süreci yerine getirilmektedir. CRM üzerinde bu işlemleri yerine getirebilmesi için RPA bir oturma açma kimliği ve şifresi atanır ve görevleri tıpkı bir insanın yaptığı gibi yürütür (Le Clair 2017; Tornbohm 2017).

"Otomasyon çekirdek sistemlerde hiçbir şeyi değiştirmez, sadece sahip olduğumuz şeyleri kullanır." Örneğin, "robot" e bir e-ticaret sisteminde oturum açma ve kredi başvurusundan bir sosyal güvenlik numarası çıkarma, oturumu kapatma, tüketici kredisi raporlama sistemine giriş yapma, bir kredi puanı almak için sosyal güvenlik numarasını girme, oturumu kapatma talimatı verilebilir. Bir kredi onay sistemine giriş yapın, kredi puanınızı girin, faiz oranını alın, krediyi önceden onaylamak için kurallar uygulayın, ardından müşteriye bir onay bildirimini gönderin, vb. Birçok işlem RPA tarafından sıfır hata ile yürütülebilir (van der Aalst and van Hee 2002; Chandler et al. 2017; Le Clair 2017; Kirchmer 2017; Tornbohm 2017).

2000'li yılların ortalarında RPA ile deney yapan ilk birkaç firma, işletmelerinin en küçük bölümlerin üzerinde RPA denemeleri yaptılar. İlk birkaç yıl boyunca bir avuç robot kullanan ve artık var olmayan işlemleri otomatikleştirdi. 2008 yılına gelindiğinde RPA ilk ciddi başarısı gerçekleşti. Konut sektöründe çalışan milyonlarca müşterisi olan bu firma birçok dağıtık sisteme sahipti ve süreçlerini manuel olarak yönetmekteydi. 2008 hedefleri teknolojinin nasıl kullanılacağını ve süreçlerine nasıl dahil edebileceklerini bulmak ve oldukça fazla paraya mal olan birkaç iş vakasını otomatikleştirmekti. İlgili firma işlemlerini otomatikleştirmek için bir RPA sağlayıcısından 10 robot lisanslayarak, küçük bir ekip ile dağınık olan sistemleri üzerinde zorlu süreçleri

otomatikleştirerek RPA teknolojinin işe yaradığını kanıtladı. Günümüzde dev kuruluşların RPA deneyimleri bulunmaktadır. RPA gelişimi evresinde ilgili firmalar otomasyon için süreçleri veya alt süreçleri daha iyi tanımlamayı, bazen bir sürecin sadece bir kısmını otomatikleştirilmesi gerektiğini, otomasyon için ideal olan alt süreçlerin açık ve net kurallara sahip olduğunu, sınırlı istisna yönetimi gerektirdiğini, yüksek ve öngörülebilir hacimlere sahip olduğunu ve istikrarlı bir ortamda çalıştığını göstermiştir (van der Aalst 2016; Kerremans 2018).

Günümüzde her firmanın maaş idaresi, emeklilik, personel, eğitim, araştırma, projeler, finans vb. için bilgi sistemleri vardır. Bir kişinin herhangi bir firmadan ayrıldığında yada işe girdiğinde ilgili kişinin özlük, sigorta bilgilerinin girilmesi için bilgi sistemlerine veri girişleri yapılmaktadır. Bu işlemlerin her seferinde işe giren yada çıkan çalışanlar için tekrarlandığını ve bilgi eklenmesi, kaldırılması veya değiştirilmesi gerekmektedir. Sektör gözetmeksizin dev kuruluşlar her yıl yüzlerce yeni personel işe almaktadır ve bu kişilerin bilgilerini farklı sistemlere girmektedir. Tüm çalışan bilgilerini tek bir sisteme entegre etmek çok zor ve maliyetlidir. Örneğin ERP'ler genellikle üretim, finans ve muhasebe işlemleri için kullanılır ve CRM'ler satış ve pazarlama yönetim sistemi olarak kullanılır, ancak bu iki sistemin bağlantısı çoğu zaman yoktur. Bu süreçleri yerine getirecek insanların birden fazla sisteme bilgi girmesi ve tutarlılığı korumaya çalışması gerekir. Ancak veri girişi gibi basit ve çok fazla hata yapılan işlemleri RPA, farklı bilgi sistemleriyle etkileşime girerek sıfır hata ile yerine getirmektedir. Bu bağlamda RPA firmalara yüksek düzeyde hatasız süreç yönetimi imkanı sunmaktadır.

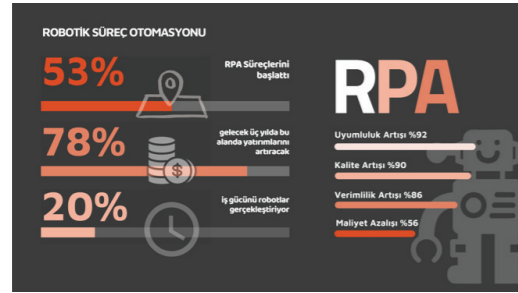
RPA iki önemli stratejik sonucu vardır: işletme maliyetlerini düşürmek, azaltmak ve müşteri hizmetlerini iyileştirmek. RPA uygulaması yapmış olan bir firma elde ettiği kazanımları şöyle özetliyor. "Ticari işletme maliyetleri ile ilgili olarak, RPA projesi ortalama olarak manuel sürece kıyasla maliyetlerde yüzde 200'e varan azalmalar sağlamıştır. Müşteri hizmetleri iyileştirmeleri ile ilgili olarak, RPA, müşterilerin ilk etapta yardım istemelerinin nedenlerini çözmeye ya da önlemeye yardımcı oldu. 2014 yılına kadar müşteri hizmetleri bazı alanlarda önemli ölçüde iyileştirdi." RPA, talep edilen çalışmanın birikimini azaltmak ve maliyet engelleyici veya insanlar tarafından gerçekleştirildiğinde çok yavaş olacak ek müşteri özellikleri eklemek için kullanıldı. Örneğin, müşteri şikayetlerinin kaydedilmesini hızlandırmak için RPA kullanıldı, böylece çalışanlar sorunlarını çözmek için daha fazla zaman harcayabiliyor. (van der Aalst and van Hee 2002; ter Hofstede et al. 2010).



### 3. RPA Kullanım ve Kazanım Oranları

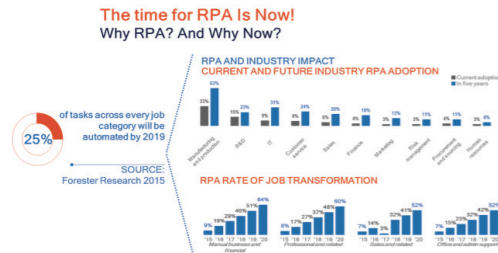
Deloitte'un 2018 yılı Amerika Birleşik Devletlerinin en büyük ilk 1000 firmasında yapmış olduğu RPA araştırmasına göre firmaların %53'ü RPA süreçlerini başlatmış durumda. Yine ilk 1000 firmanın %78'i gelecek üç yıl içerisinde PRA 'e yatırım yapmaya başlayacak ve yatırımlarını artıracak. Şu an hali hazırda ise bu firmaların mevcut iş yükünün %20'si RPA robotları tarafından gerçekleştiriliyor. Firmaların RPA sonrasında elde ettikleri kazanımlar ise şu şekilde;

- %92 Uyumluluk Artışı,
- %90 Kalite Artışı,
- %86 Verimlilik Artışı,
- %56 Maliyet Azalışı



Şekil 2. Deloitte 2018 RPA Raporu

2015 yılında Forester 'ın araştırmasına göre ise RPA'nın üretim endüstrisinde 2015 yılı kullanım oranı %33 iken bu oranın beş yıl içerisinde %63'e çıkması beklenmektedir. Tüm iş birimlerinde ise bu oranın toplam iş yükünün %25'ine ulaşması beklenmektedir.



Şekil 3. 2015 Forester Research

### 4. Deneysel Çalışma

Metal endüstrisinde 60 yıldan fazla süredir faaliyet gösteren yaklaşık 300 çalışanı olan bir firmada

yapmış olduğumuz deneysel çalışmamızda, satış departmanı 10'dan fazla sistem ve web sitesi üzerinden yürüttükleri işler ve müşteri ziyaretlerine vakit ayırmakta zorlanmaları sebebi ile pilot bölüm seçilmiş ve RPA uygulamalarının iş yüküne katkısı analiz edilmiştir.

Çalışma öncesi istatistikler;

Satış departmanında müdür, yönetici, uzman ve destek personeli olmak üzere 4 farklı ünvana ait görev tanımı yer almaktadı. Bu süreçte satış uzmanı, yönetici ve müdürlerin süreçleri ortak ele alınmış, Satış destek personeli için ise ayrı bir çalışma yürütülmüştür. Bu çalışmada anlatılacak olan müdür, yönetici ve uzman personelin RPA öncesi ve sonrası iş yükü analizlerine dayanmaktadır.

Personelin sorumlu olduğu süreç sayısı: 69

Süreç adımı sayısı: 352

Analizde kullanılan program ve web sitesi sayısı: 10

Yıllık satış miktarı: 40.000 ton

Personel sayısı: 1 Müdür, 2 Yönetici, 5 Uzman



Şekil 4. RPA projesi süresinde kullanılan farklı programlar

Çalışanların her biri için yıllık çalışma süresi saat cinsinden belirlenmiş ve izin kullanımları çalışmada ihmal edilmiştir. Her bir çalışan için standart çalışma süresi 97.200 saat olarak belirlenmiştir.

Deneysel çalışmanın ilk aşamasında personelin sorumlu olduğu süreçler çıkarılmış ve her bir süreç adımı için satış personeli ile birlikte bir iş analisti süreçlerin standart sürelerinin ölçülmesini yapmıştır. Her bir süreç adımının bağlı olduğu değişkenler tanımlanmıştır. Örneğin siparişlerin ERP sistemine girilmesinde sipariş satırı değişken seçilmiş ve her bir satır sipariş için harcanan süre dakika cinsinden hesaplanmıştır. Ardından bir yıl içerisinde her bir personelin ne kadar sipariş aldığı ERP sisteminden çekilerek her çalışan için siparişlerin ERP sistemine girilmesinden kaynaklanan iş yükü tespit edilmiştir.

Satış personelinin sorumlu olduğu 352 farklı iş süreci adımının her birinin 1 yıllık çalışma sürecinde sorumlu olduğu ve gerçekleştirdiği tüm işler ile çarpılması sonucunda mevcuttaki iş yükleri çıkarılmıştır. Aşağıdaki Tablo.1 'de her çalışmada aynı bir iş yükü dağılımı olduğu görülmektedir. Bazı personellerin iş yüklerinin az olmasının yanında genelinde fazla bir iş yüküne sahip oldukları görülmektedir.

Tablo.1 Satış Personeli İş Yükü Analizi

Uzman	Uzman 1	Uzman 2	Uzman 3	Uzman 4	Uzman 5	Uzman 6	Uzman 7	Uzman 8	Ortalama
İş Yükü	13%	22%	30%	17%	19%	17%	34%	34%	23%

Fazla iş yükünün yarattığı problemlerden bazıları şu şekilde özetlenebilir ;

- Personelde motivasyon kaybı,
- Hatalı işlemlerden kaynaklanan müşteri şikayetleri,
- Hatalı işlemlerden kaynaklanan ilave zaman kayıpları,
- Yetiştirilemeyen işler sebebi ile yaşanan riskler (limit aşmaları, alacak takibinde aksamlar,)
- Şirket içi çatışma ortamı (bölümler arası ek görevleri üstlenmeme tartışmaları)
- Personelin ana işlerine odaklanmasında yaşanan sorunlar sebebi ile ana hedeflerden uzaklaşma ve performans kayıpları.

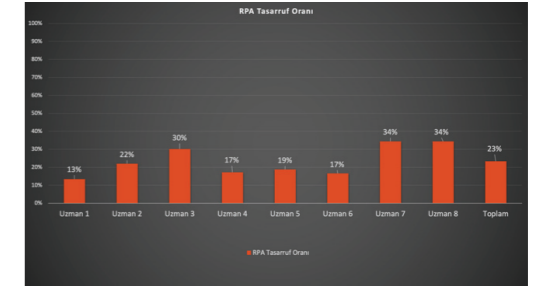
#### 4.1. RPA Uygulanacak Süreçlerin Belirlenmesi

RPA uygulanacak süreçlerin belirlenmesi her bir süreç adımının tekrarlanan türden olması, değişikliklerin minimumda olması, yüksek tekrarlanma sıklığına sahip olması, uzun zaman alıyor olmasına göre belirlenmiştir.

Bazı değişkenlik gösteren süreçler için pareto çalışmaları yapılmış ve en fazla sipariş veren %20'lik dilimdeki müşterilerin siparişlerinin otomatize edilmesi süreçlerine odaklanılmıştır. Tüm bu çalışmalar neticesinde personel üzerindeki iş yükünde aşağıdaki kazanımlar sağlanmıştır.

Tablo 2. Satış Personeli RPA sonrası tasarruf edilen süre (dakika/yıl)

Uzman	Uzman 1	Uzman 2	Uzman 3	Uzman 4	Uzman 5	Uzman 6	Uzman 7	Uzman 8	Ortalama
Tasarruf	13%	22%	30%	17%	19%	17%	34%	34%	23%



Şekil 5. RPA Projesi Sonrasında Personel Başına Elde Edilen Zamanın Toplam Çalışma Süresine Oranı

PRA projesi sonrasında genel itibarı ile bakıldığında personel başına ortalama %23'lük bir zaman kazanımı sağlanmaktadır.

#### 4.2. Projenin Ekonomik Kazanımları

RPA projesi sırasında mevcut firmanın gerçekleştirdiği 40.000 birim üretim ve satışa bağlı personel durumu ile birlikte bir sonraki yıl hedefi olan 60.000 birim üretim ve satış hedefi mevcut iş yükü ve bütçelenen iş yükü olarak analiz edildi. Buna göre 60.000 birime çıkıldığında personel iş yükünü kaldırabilir durumda olmayacaktır ve iki adet satış personeli ihtiyacı ortaya çıkmaktadır. Ancak RPA ile elde edilen zaman tasarrufu ile mevcut 8 kişilik satış personeli koruma imkanı sağlanmaktadır.

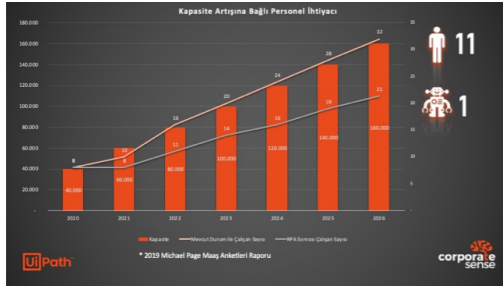
Aynı senaryo ile büyüme modeli 6 yıl boyunca sabit tutularak ilave iş yükleri ve personel ihtiyaçları RPA projesi ile (RPA Sonrası) ve RPA projesi yapılmadan (Mevcut Durum) simüle edilmiştir. Buna göre elde edilen sonuçlar aşağıdaki gibidir.

#### Mevcut Durum (RPA Yok)

2020 Çalışan Sayısı: 8  
2020 Satış: 40.000 birim  
2026 Çalışan Sayısı: 32  
2026 Satış: 160.000 birim

#### RPA Sonrası

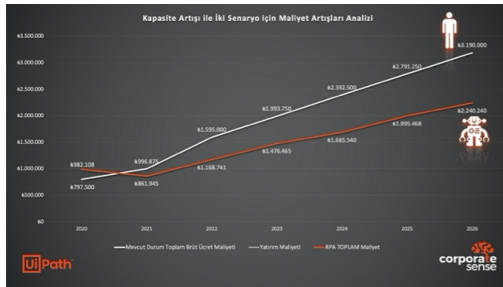
2020 Çalışan Sayısı: 8  
2020 Satış: 40.000 birim  
2026 Çalışan Sayısı: 21  
2026 Satış: 160.000 birim



Şekil 6. İki Senaryo için Satış Miktarları ve Personel İhtiyaçları Analizi

İki senaryo karşılaştırıldığında artan satış ve üretim rakamlarına bağlı olarak 6 yıl içerisinde RPA yapılmadığı durumda firmanın fazladan 11 personel işe alması gerekirken RPA yapılarak bir robot ile 11 kişinin iş yükünü yönetebilmektedir.

Her iki senaryo için de firmanın karşılaşacağı maliyetler aşağıdaki tabloda verilmiştir. Personel maliyetleri için Michael Page'in 2019 yılı Satış ve Pazarlama Brüt Ücretler Raporu verilerinin ortalaması kullanılmıştır. Yıllık olarak ücretler %8 zam yapılacağı ve RPA bakım maliyetlerinde de %12 artış olacağı varsayılmıştır.



Şekil 7. Kapasite Artışı ile İki Senaryo için Maliyet Artışları Analizi

## 5. Sonuç

RPA projesi ile ve RPA yapılmadan gerçekleştirilen büyüme senaryolarının maliyet analizleri karşılaştırıldığında 6 yıl içerisinde artan kapasiteye bağlı olarak artacak maliyetler ile RPA ile toplamda 3.346.369 ₺'lik bir tasarruf sağlanacağı görülmektedir. Bu durum firmadan firmaya farklılıklar gösterebileceği gibi çalışan sayısının fazla olduğu şirketlerde çok daha büyük tasarrufların sağlanmasını da sağlamaktadır.

	2020	2021	2022	2023	2024	2025	2026	TOPLAM
Mevcut Durum Toplam Brüt Ücret Maliyeti	4.797.500	4.986.475	5.196.000	5.423.750	5.679.500	5.964.250	6.278.000	41.349.025
RPA Toplam Maliyeti	4.882.328	4.981.345	5.108.741	5.276.465	5.485.540	5.735.468	6.024.240	41.413.028
RPA ile Tasarruf	85.172	105.130	187.259	147.285	193.960	228.782	253.760	635.000
Personel Maliyeti	4.807.156	4.876.215	4.921.492	5.079.280	5.281.580	5.535.782	5.824.240	40.778.028
RPA ile Tasarruf	85.172	105.130	187.259	147.285	193.960	228.782	253.760	635.000
TOPLAM	4.892.328	4.986.475	5.108.741	5.276.465	5.485.540	5.735.468	6.024.240	41.413.028

Tablo 3. İki Senaryo için Detaylı Maliyet Karşılaştırması Tablosu

RPA maliyetleri içerisinde lisans, bakım ve ilk yatırım maliyetleri kullanılan program, tercih edilen yazılım şirketine göre farklılıklar gösterebilir. Ancak RPA projeleri geneli itibarı ile bir yıldan kısa bir süre içerisinde kendisini geri ödeyebilen, büyüme hedefi olan ve çalışan sayısı hızla artan firmaların öncelikli olarak tercih etmesi gereken yatırımlar olarak hayatımızda yerini hızla almaktadır.

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## Türkiye'de İlk Demiryolu Teker ve Ray Üretimi

First Railway Wheel and Rail Production in Turkey

Hüseyin Erten, Serkan Atamer, Sait Hadutoğlu, Mücahit Sevim

KARABÜK DEMİR ÇELİK • Türkiye

### Abstract

Transportation is essential part of our daily life; it has an irreplaceable impact on society economically and socially. Railway is one of the major ways of transportation. Railway transportation is considered the largest environmental friendly form of public transport. In order to strengthen the role of railway transport, which will have significant impact on Turkey's independence and development; there is a need to establish a liberal, competitive, economic and socially sustainable railway sector. Railway investments continue with an increasing momentum worldwide, reducing regional economic and social development disparities. For railway transportation sector, first wheel production facility and first railroad rail facility was established within Kardemir. In this study, the production of the first railway wheel and rail in Kardemir, the first integrated iron and steel factory producing ore, is explained. Kardemir meets the wheel and rail requirements of the sector with a quality understanding, thanks to the newly established railway wheel production facility and rail rolling mill. It will continue to have a say in terms of the future of the wheel and rail in the regional sense and will meet the country's need.

### Özet

Günlük hayatımızın vazgeçilmez bir parçası olarak görülen ulaştırma sistemi; ekonomik ve sosyal girdileriyle toplum üzerinde önemli bir etkiye sahiptir. Ulaşım sisteminin en önemli öğelerinden biri de demiryollarıdır. Demiryolu taşımacılığı, çevre dostu en büyük toplu taşıma şekli olarak kabul edilmektedir. Türkiye'nin kalkınmasında ve bağımsızlığında belirleyici olan demiryollarının yeniden canlandırılması ve taşımacılıktaki rolünün güçlendirilmesi için; serbest, rekabetçi, ekonomik ve sosyal açılarından sürdürülebilir demiryolu sektörünün oluşturulmasına ihtiyaç vardır. Demiryolu yatırımları bölgesel, ekonomik ve sosyal gelişmişlik farklılıklarını azaltacak yönde dünya genelinde artan bir ivme ile devam etmektedir. Bu doğrultuda, Türkiye'nin demiryolu sektörüne yönelik ilk ray üretim tesisinden sonra ilk demiryolu tekeri üretim tesisi de Kardemir'de kurulmuştur. Bu çalışmada, cevherden üretim yapan ilk entegre demir çelik fabrikası

Kardemir'de ilk demiryolu tekeri ve ray üretimi anlatılmaktadır. Kardemir A.Ş. sektörün tekerlek ve ray gereksinimlerini kalite anlayışıyla karşılamaktadır. Kurulan demiryolu teker üretim tesisi ve ray haddehanesi sayesinde de bölgesel anlamda tekerleğin ve rayın geleceği açısından söz sahibi olmaya ve ülke ihtiyacını karşılamaya devam edecektir.

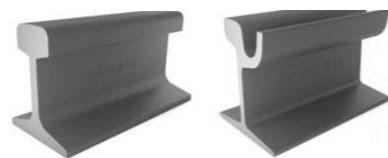
### 1. Giriş

Kardemir A.Ş. 150 Milyon \$ harcamayla 2019 yılında yatırımlarını tamamladığı Demiryolu Teker Üretim Tesisi ile sadece Türkiye'nin değil dünyanın 16 üreticisi arasına girmeyi başarmıştır. Tesis, yıllık 200.000 adet tekerlek üretim kapasitesine sahiptir (Çizelge 1). Ülkemizde tekerlek ihtiyacını tek başına karşılayacak olan Kardemir büyük bölümü Almanya, Avusturya, Polonya, Slovakya, Bulgaristan, Fransa gibi başta Avrupa ülkeleri olmak üzere Ortadoğu ve Afrika'nın farklı ülkelerine pazarlamayı planlamaktadır.

Çizelge 1. Kardemir yıllık üretim kapasitesi.

Tekerlek Tipi	Çap (mm)	Miktar (adet)
Yük Treni Tekerleği	Ø 920	120.000
Yolcu Treni Tekerleği	Ø 920	40.000
Hafif Raylı Sistem Araç Tekerleği	Ø 840	20.000
Lokomotif Tekerleği	Ø 1016 Ø 1100	20.000
Toplam (Adet)		200.000

2007 yılında 400.000 ton/yıl kurulu kapasitesiyle yatırımları gerçekleşen Ray-Profil haddehanesi ile demiryolu rayı üretiminde yurtiçi ve yurtdışı pazarına açılan Kardemir A.Ş. ülkemizdeki tek ray üreticisidir. Bünyesindeki mantarı sertleştirilmiş ray üretim tesisi ile de dünyadaki sayılı ray üreticilerinden biri haline gelmiştir.

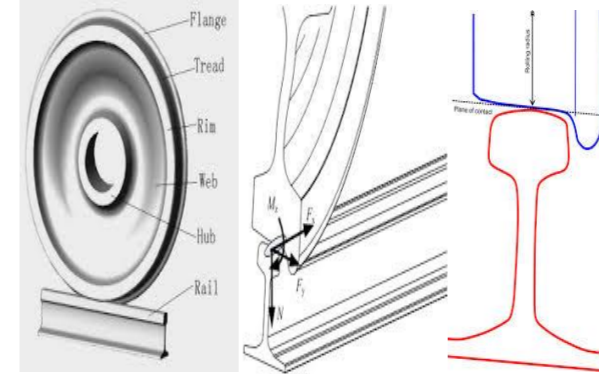


Şekil 1. Kardemir'de üretilen ray tipleri

## 2. Teker Üretimi

### 2.1 Tekerleğin tanımı ve özellikleri

Demiryolu tekeri, trenin raylar üzerinde hareket etmesini ve gövde yapısı ile uyumlu geçişleri sağlayan yapı elemanıdır.



Şekil 2. Demiryolu tekerinin kısımları ve ray ile teması.

Yüksek verim elde etmek için tekerlekte ihtiyaç duyulan özellikler arasında ağırlık, web yorulma dayanımı ve aşınma direnci yer almaktadır.

Ağırlık; sürüş konforu ve boji parçaları üzerindeki etkileri nedeniyle önemlidir. Bu faktör özellikle yüksek hızlı araçlar tasarlanırken dikkate alınır.

Web yorulma dayanımı; web tren gövde ağırlığının neden olduğu döngüsel mekanik strese dayanacak mukavemete sahip olmalıdır.

Aşınma direnci; tekerleğin kenar bölgesi ray ile sürekli temas halindedir. Bu yüzden aşınma direnci yüksek olmalıdır.

### 2.2 Tekerlek standartları

Tren tekerleği, düşük alaşımlı ve C'lu çeliklerden uluslararası standartlara göre üretilmekte ve kullanım alanına göre ölçüleri farklılıklar göstermektedir.

Tekerlek üretim metotları arasında dövme ve döküm yöntemleri kullanılmaktadır.

Çizelge 2. Standartlara göre çelik kaliteleri.

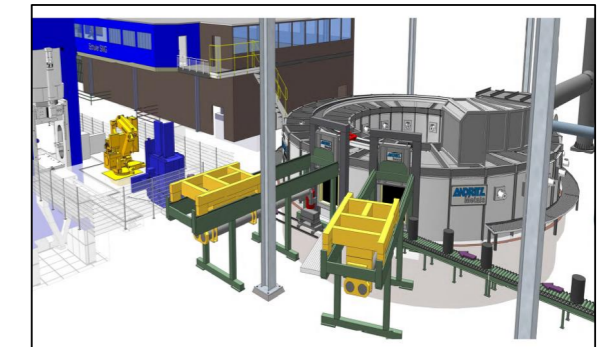
Bölge	Standart	Çelik Kalitesi	Karbon Miktarı	Sertlik
			%	HB
Avrupa	EN 13262	ER6	≤ 0.48	234-270
		ER7	≤ 0.52	247-282
		ER8	≤ 0.56	258-296
		ER9	≤ 0.60	300-350
Kuzey Amerika	AAR M-107/M-208	Class L	≤ 0.47	197-277
		Class A	0.47-0.57	255-321
		Class B	0.57-0.67	302-341
		Class C	0.67-	321-363
		Class D	0.77	341-415
Japonya	JIS E 5402-1	SSW	QS	246-307
			QR	311-363
			QRH	295-347

### 2.3 Kardemir'de tekerlek üretimi

Devreye alınan demiryolu teker üretim tesisimizde, sürekli döküm yöntemiyle 380 mm çapında üretilen kalın yuvarlak malzemeler, yarı mamul olarak kullanılmaktadır. Uygun boyalara göre kesilen kalın yuvarlak malzemeler, tavlama, dövme ve haddeleme, ısıl işlem, CNC işleme, test ve muayene işlemlerinden geçirilerek tekerlek üretimi gerçekleştirilmektedir.

#### 2.3.1 Yarı mamullerin tavllanması

Sahaya gelen yarı mamuller kesme işleminden sonra, soğuk şarj alınarak östenitik bölgeye kadar tavlanamaktadır. Döner tip tavlama fırını bulunmaktadır. Yakıt olarak doğal gaz kullanılmaktadır.



Şekil 3. Döner tip tav fırını.

Beş adet ısıtma bölgesi bulunan fırında, homojen tavlamanın sağlanması amacıyla fırın içi ısı rejimi, tavlama süresi, fırın iç basıncı, fırın içi atmosfer oksijen seviyesi gibi parametreler sürekli olarak sensörler ve



otomasyon sistemleri vasıtası ile personeller tarafından takip edilmektedir. Ayrıca malzemelerin fırına şarj ve deşarj edilmesi, tamamen yükleyici robot kolları ile yapılmaktadır.

### 2.3.2 Tufal giderme süreci

Fırından yaklaşık 1250°C sıcaklıkta çıkan yarı mamuller konveyör ve robotlar vasıtası ile tufal giderme ünitesine gönderilir. Bu üniteye 320 bar basınçlı su ile yarı mamul yüzeyinde bulunan tufal giderilir. Temizlenen tavlınmış kalın yuvarlak malzemeler, robot aracılığıyla sıcak pres ünitesine gönderilir.

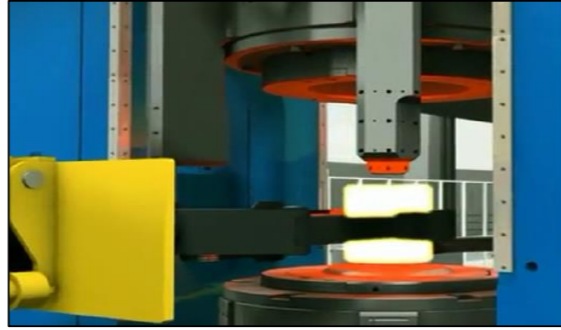


Şekil 4. Tufal giderme ünitesi.

### 2.3.3 Tekerleğin şekillendirme süreci

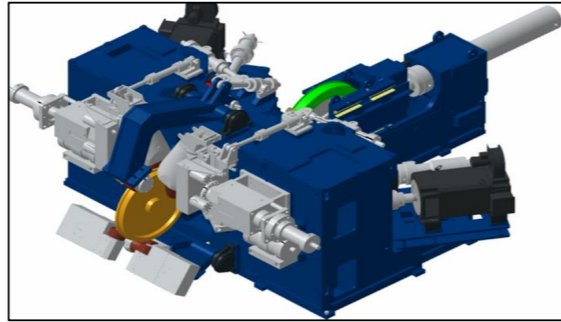
Yukarıda belirtilen işlemler sonrasında kalın yuvarlak malzeme, dövme ve haddeleme prosesine sevk edilir. Demiryolu Teker Üretim Tesisi pres hattı bir adet 10 bin ton pres (10.000 kN), bir adet 3 eksenli haddeleme ünitesi ve bir adet 5 bin ton presten (5.000 kN) oluşmaktadır.

Tufal giderme ünitesinden 10 bin ton presin OP1 kalıbına konulan yarı mamul, önce OP1 presleme işleminden geçirilir. Manipülâtör ile OP2 kalıbına taşınan yarı mamul, burada ikinci presleme operasyonundan geçirilerek teker yarı taslağı elde edilir, böylelikle ön şekillendirme tamamlanmış olur. Bu süreç sırasında teker ve kalıplara su-grafit bazlı bir solüsyon püskürtülerek kalıbın sıcaklığı düzenlenip sıcak mamulün kalıba yapışması engellenir.



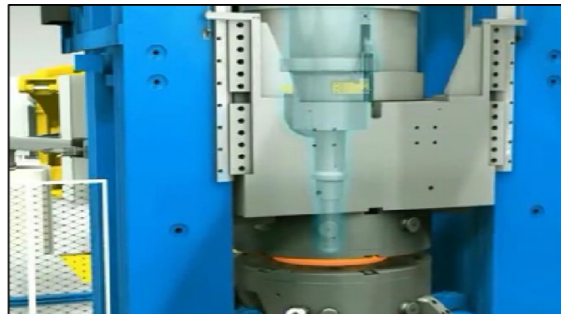
Şekil 5. 10 bin tonluk pres.

10 bin ton pres ünitesinden robot vasıtası ile 3 eksenli haddeleme ünitesine yüklenen teker taslağının web ve rim bölgesi haddelenerek şekillendirilir ve istenilen çapa getirilir.



Şekil 6. 3 eksenli haddeleme ünitesi.

Haddeleme işlemi sonrası Şekil 8'deki yükleyici robot sistemi ile 5 bin ton pres ünitesinden delik delme ve teker taslağına son şekil verme işlemi yapılır. Burada da aynı şekilde, teker ve kalıplara su-grafit bazlı bir solüsyon püskürtülerek kalıbın sıcaklığı düzenlenip sıcak mamulün kalıba yapışması engellenir.



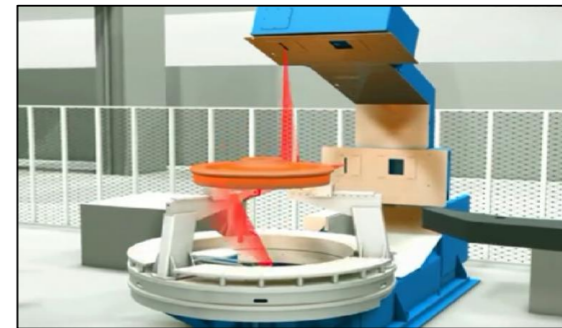
Şekil 7. 5 bin tonluk pres.



Şekil 8. Yükleyici robot sistemi.

### 2.3.4 Tekerleğin lazer ile boyut kontrolü

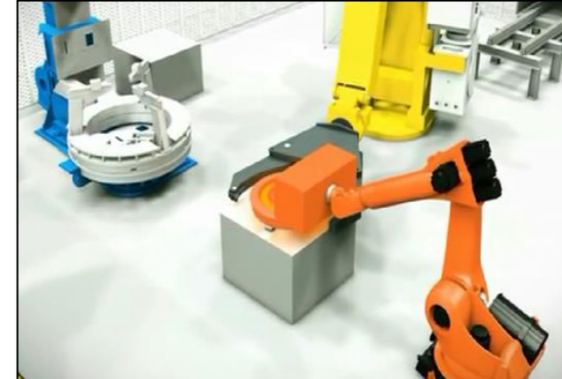
Son şekli verilen tekerlek, robot ile lazer ölçüm cihazına yüklenir, referans ölçüleri ile kontrol edilerek ürünün tolerans dahilinde olup olmadığı tespit edilir.



Şekil 9. Lazer boyut kontrol sistemi.

### 2.3.5 Tekerleğin markalanması

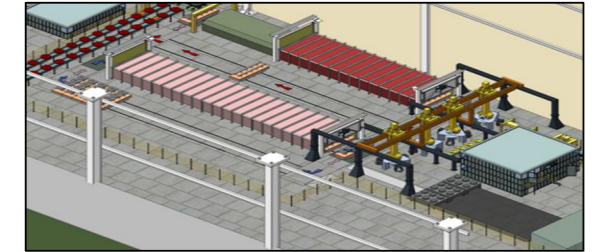
Boyutsal olarak uygun olan teker, markalama ünitesinde noktalı vuruş yapan pnömötik sistem ile markalanır. Böylece, tekerin kimliği yüzeye işlenmiş ve işlem tescillenmiş olur.



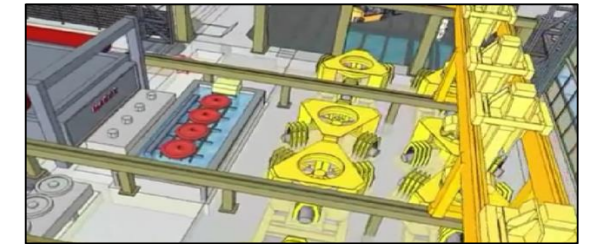
Şekil 10. Markalama ünitesi.

### 2.3.6 Tekerleğin ısıtılması

Isıl işlem hattına konveyör ile transfer edilen ham teker, 4 teker kapasiteli araçlara yüklenir. Araçlar, önce HTO fırınına girer. Burada 830°C sıcaklıkta yaklaşık 2 saat kalır, sonrasında robot vasıtasıyla su verme ünitesine alınır. Basınçlı su ve hava üflenerek rim bölgesi yüzeyi sertleştirilen ve temizlenen tekerlekler tekrar robot vasıtası ile araçlara yüklenir. Tekerlere, NTO fırınında ikinci ısıl işlem uygulanır. Burada, 520°C sıcaklıkta yaklaşık 3 saat kalan tekerleklerin, sertleştirme işleminde ortaya çıkan kalıntı gerilmeleri giderilir.



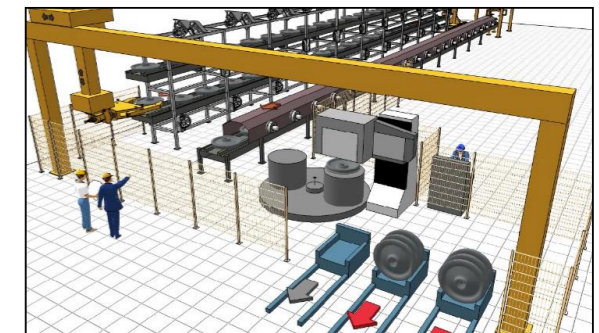
Şekil 11. Isıl işlem fırınları.



Şekil 12. Isıl işlem su verme ünitesi.

### 2.3.7 Tekerleğin sertlik ölçümü

Sertlik ölçüm cihazına robot ve konveyör vasıtasıyla getirilip yüklenen tekerleklerin, yüzey sertlikleri ölçülür, uygulanan ısıl işlemin kontrolü yapılır.

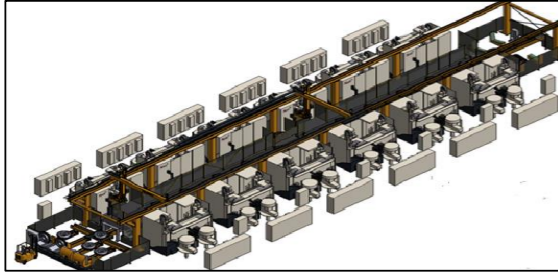


Şekil 13. Sertlik ölçüm ünitesi.



### 2.3.8 Tekerleğin işlenmesi

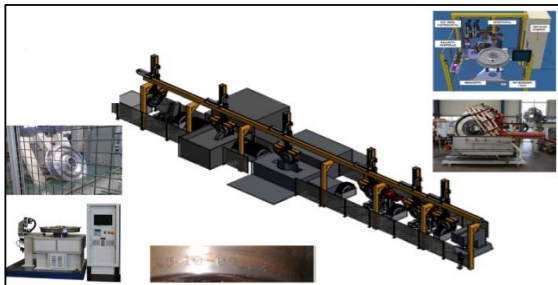
Ham haldeki tekerlekler, konveyör ve robotlar aracılığıyla 12 adet olan CNC ünitelerine yüklenir. CNC'lerin 10 adeti kaba işleme, 2 adeti ise final işleme ve yağ deliği delme işlemi için kullanılır. Sırasıyla, kaba işleme ve son işleme cihazlarında tekerin nihai ölçülere göre şekillendirilmesi tamamlanır.



Şekil 14. CNC işleme ünitesi.

### 2.3.9 Tekerleğin kalite kontrolü

Nihai ölçülere getirilen tekerlekler, önce yıkama ünitesine alınıp sıcak su ile yıkanarak, CNC ünitesinden gelen talaş ve soğutma sıvısından arındırılır ve kurutulur. Temizlenmiş tekerlek, soğuk lazer ölçüm ünitesine konulur. Pres hattındaki daha büyük ve hassas olan bu ünite, tekerleklerin son halinin fiziksel boyut ölçümünü detaylıca yapar. Fiziki ölçümü tamamlayan tekerlek, ultrasonik ölçüm cihazına alınarak içyapı kusurları incelenir. Robot ile manyetik partikül test cihazına alınır ve yüzeyde çatlak kontrolü yapılır. Ardından robot vasıtasıyla balans ölçüm ünitesine taşınır. Belirli bir devirde döndürülerek tekerlek balansının istenen toleransta olup olmadığı tespit edilir. Standartta belirtilen değerler üzerindeki tekerlekler, hat dışındaki diğer üniteye vinç ile transfer edilir. Balansı, standartlar dahiline getirilir. Ardından, tekerlekler markalama makinasında ID numarası, üretim tarihi, üretici kodu vb. bilgilerin yer aldığı marka vurulur. Uygun balanstaki tekerlekler ise hattın devamındaki markalama işleminden sonra üretimi tamamlanır.



Şekil 15. Tekerlek kontrol ünitesi.

## 3. Ray Üretimi

### 3.1 Ray standartları

Kardemir bünyesinde üretimi gerçekleştirilen ray tipleri ve ilgili standartlar Çizelge 3'de verilmiştir.

Çizelge 3. Üretimi gerçekleştirilen ray tipleri ve standartlar.

Standart	Ray Tipi	Kalite
EN 13674-4	33E1	R260
EN 13674-1	46E2	R260
	49E1	R260, R350HT
	50E4	R260
	54E4	R260, R350HT
	54E1	R260, R350HT
	60E1	R260, R350HT
	60E2	R260, R350HT
UIC 860	UIC49	900A
	UIC50	900A
	UIC54	900A
	UIC60	900A
GOST R 51685	R50, P50	
EN 14811	59R2	R220G1, R260
	60R1	R220G1, R260
	60R2	R220G1, R260

### 3.2 Kardemir'de ray üretimi

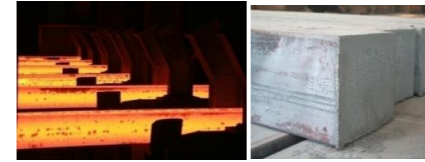
Ray-Profil Haddehanesin'de ray üretimi sürekli döküm teknikleri ile dökülen 260x360mm ve 320x420mm kesitli yarı mamulün tavlama, haddeleme, ray sertleştirme (R350HT kalite için), soğutma, doğrultma, tahribatsız muayene, gag pres, boy kesim ve kalite kontrol adımları izlenerek gerçekleştirilmektedir.

#### 3.2.1 Ray yarı mamulünün tavlama

Ray üretiminde ray tipine göre istenilen boy ve kalitede sahaya gelen yarı mamuller kok gazı ile ısıtılan, yürüyen kırıli fırında 1200-1250°C'de tavlanaarak haddelemeye hazır hale getirilir. Fırın girişinde izlenebilirliği sağlamak amacıyla yarı mamul üzerindeki döküm numarası otomatik okunarak mamulün tavlama son ürün aşamasına kadar takibi sağlanır.



Şekil 16. Tav fırını ve descaler.



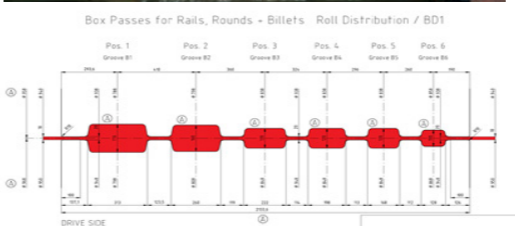
Şekil 17. Ray yarı mamulü.

#### 3.2.2 Tufal Giderme

Ray üretiminde 180 bar basınçla malzeme üzerindeki tufal kaldırılarak temiz bir yüzey elde edilir.

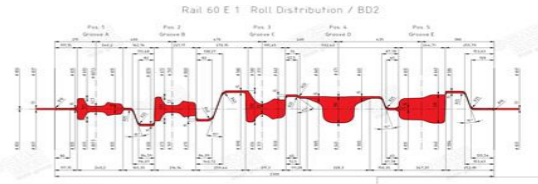
#### 3.2.3 Haddeleme

Tavlı malzeme öncelikle BD1 kaba haddesinde haddeleme reçetelerine uygun olarak 1100-1200°C aralığında birincil şekillendirme (ön haddeleme) gerçekleştirilir.



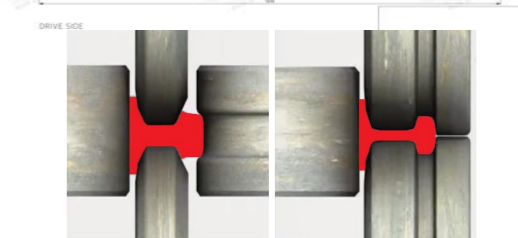
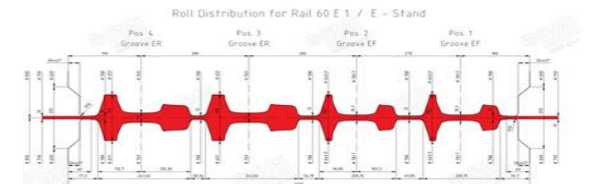
Şekil 18. BD1 Kaba Haddesi ve kalibre düzeni.

Ön şekillendirmenin ardından BD2 ara haddesinde 1100-1000°C'de ikincil haddeleme yapılır.



Şekil 19. BD2 ara haddesi ve kalibre düzeni.

Son olarak Tandem haddehanesinde nihai haddeleme işlemi gerçekleştirilir. 2 adet üniversal ve 1 adet duo tip haddenin senkronize bir şekilde çalışmasıyla son ürün elde edilir. Burada hadde giriş ve çıkışında mantar bölgesini temizlemek ve kaliteli yüzey elde etmek amacıyla 180bar basınçla çalışan descaler bulunmaktadır.

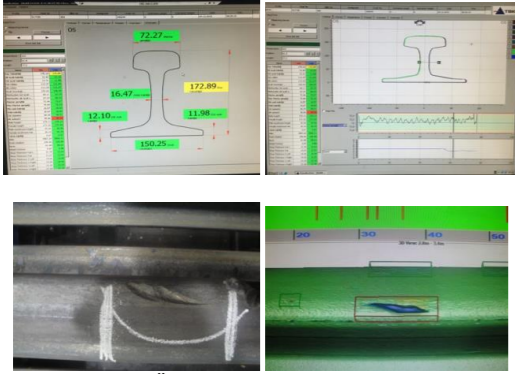


Şekil 20. Tandem nihai haddesi ve kalibre düzeni.



### 3.2.4 Ölçü ve Yüzey Kontrolü

Haddeme işleminin ardından online ölçü ve yüzey kontrol sistemlerinden ürün kontrol edilir. Bu sayede ürün kalitesi güvence altına alınmış olur.



Şekil 21. Ölçü ve yüzey kontrol cihazları.

Yaklaşık 900°C sıcaklıktaki malzeme R350HT kalite olarak talep edilen siparişler için Ray sertleştirme tesisine alınır. Bunun dışında kalan kaliteler doğrudan soğutma ızgarasına transfer edilir.

### 3.2.5 Ray Sertleştirme

Bu tesiste sıcak haddeme işleminin ardından online olarak yeniden bir ısıtma olmaksızın hava ve pulverize suyun belirli reçeteler dahilinde püskürtülerek rayın soğutulması ile ince perlitik bir mikroyapı elde edilir. Hava-su karışımının istenilen miktar ve sürede uyarlanabilir olması sayesinde yüksek sertlik ve homojen sertlik dağılımı elde edilir. Minimum 350HBW sertliğe sahip olan mantarı sertleştirilmiş raylar görece daha yüksek bir aşınma direncine ve ömre sahiptir.



Şekil 22. Ray sertleştirme tesisi.

### 3.2.6 Soğutma-Doğrultma

Haddeme ve sertleştirme işlemlerinin ardından soğutma ızgarasında fanlar yardımıyla 50°C civarına soğutulan ray dikey ve yatay doğrultma tezgahlarına alınır. Bu sayede iç gerilmeler homojenize edilir, ray standartın talep ettiği gövdesel doğruluk ölçülerine getirilir.



Şekil 23. Dikey ve yatay doğrultma üniteleri.

### 3.2.6 Tahribatsız Muayene

Tesis Lazer doğruluk ölçüm cihazı, Eddy current yüzey hatası kontrol cihazı ve içyapı kusurlarını tespit edebilmek için ultrasonik muayene cihazından oluşmaktadır. Bu tesiste her raya %100 oranında tahribatsız muayene uygulanır.



Şekil 24. Tahribatsız muayene (Eddy Current Cihazı).

### 3.2.7 Gag Pres, Delme Kesme, Nihai kontrol

Tahribatsız muayeneden sonra raylar uç doğruluğunun sağlanması amacıyla gag-pres tezgahına ardından boy kesimi ve talebe göre cebire deliği için delme-kesme ünitelerine, nihai master kontrolü için ray kontrol ızgarasına sevk edilir.



Şekil 25. Delme-Kesme ünitesi.



Şekil 26. Gag pres.



Şekil 27. Ray kontrol ızgarası

## 4. Sonuç

Türkiye'nin ve yakın pazarın ray ihtiyacını sağlayan Kardemir, Demiryolu Teker Üretim Tesisi'nin devreye girmesiyle, ülkemizin ihtiyacını karşılamaya başlamıştır. Kardemir'in üretim planlamasında, önümüzdeki iki yıl içinde, 150 bin adedi ihracata yönelecek yıllık 200 bin adet demiryolu tekeri üretimi bulunmaktadır.

Şirketimiz son yıllarda artan üretim kapasitesini katma değeri yüksek ürünlere yönlendirmiştir. Cevherden

üretim yapmanın avantajıyla yerli ve milli tekerlekleri rekabet ortamına sunmaktadır. Bu yaklaşım, ülkemize yapılan ithalatın önünü keserken ihracatı da körükleyecektir. Tesisimizde, mevcut durumda yük treni tekerleklerinin üretimi yapılmaktadır. İlerleyen dönemde, Yüksek Hızlı Tren tekerine kadar, yerli ve milli marka olarak tüm raylı sistemin ihtiyacı olan tekerlek tipleri de üretilecektir.

Kardemir AŞ köklü tecrübesini 2007 yılında yeni Ray-Profil Haddehanesi ile taçlandırarak Türkiye'nin ve bölgemizin demiryolu rayına olan ihtiyacını tek başına karşılar hale gelerek önemli bir misyon yüklenmiştir. Özellikle sertleştirilmiş ray üretim tesisinin devreye alınması ile ithal ikameci üretim anlayışına yeni bir soluk getirmiştir. Önümüzdeki yıllarda bu benzeri yeni ürünleri geliştirme yolunda ülkemizin ekonomisine katkıda bulunmaya ve katma değerli üretim anlayışıyla kendisini geliştirmeyi sürdürecektir.

## Teşekkür

Türkiye'de ilk defa demiryolu tekerleği üretimi yapan bir tesisin kurulmasına öncülük yapmanın gururunu yaşatan, imkanları sağlayan Devletimize, Kardemir A.Ş. Yönetim Kurulumuza, üst yönetimimize ve emeği geçen tüm çalışanlarımıza teşekkür ederiz.

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## Oksitleyici Atmosferde Döküm Yolu ile Üretilen AISI 304 Kalite Östenitik Paslanmaz Çeliğin Sıcak ve Soğuk Haddelene Sonrasında Mekanik, Mikroyapı ve Korozyon Dayanımı Özelliklerinin İncelenmesi

Examining of Mechanical, Microstructural and Corrosion Resistant of Cold and Hot Rolled AISI 304 Grade Austenitic Stainless Steel Produced within Oxidising Atmosphere Casting Conditions

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MATİL • Türkiye

### Abstract

Corrosion resistance is among the most important parameters that determine the lifetimes of steel. The chemical composition of the AISI 304 austenitic stainless steel group is chromium, and it creates an oxide film layer on the chrome steel surface. This layer provides superior corrosion resistance. Along with other alloy elements such as nickel and manganese in the composition, austenitic structure can be obtained even at room temperature and cold deformation can be made by rolling. Stainless steel production is carried out in 2 ways by melting in a vacuum or inert gas environment. Even though our country is in the 8th place in steel production in the world, it has to import the stainless steel that it needs, since there is no investment in the production of stainless steel with high economic value. At the same time, stainless scrap in our country is exported abroad without being recycled and this situation causes economic losses. In this study, melting processes were carried out in induction furnaces operating in oxidizing medium without using vacuum melting furnaces and stainless AISI 304 steel was produced. In this way, companies casting with induction furnace have been encouraged for casting of AISI 304 austenitic stainless steel with high economic value and it has been shown that production can be done within the targets in oxidizing environment.

In the study, casting processes of AISI304 stainless steels with induction furnace and oxidizing medium with a thickness of 20 mm were made and then it was reduced to 8 mm by hot rolling. In the final flat roll production was produced by rolling it to a thickness of 1.66 mm using the cold rolling method. AISI 304 stainless steel reference samples, which are produced in the induction furnace and cold rolled

AISI 304 stainless quality steel, have been tested by making chemical, microstructure, mechanical and corrosion tests.

The test results obtained were evaluated according to the reference sample and it was demonstrated that the firms that are already casting in the market can produce stainless steel with high economic value. A supportive study has been carried out for companies wishing to work in this area.

### Özet

Korozyon dayanımı çelik kullanım ömrünü belirleyen en önemli parametreler arasında yer almaktadır. AISI 304 kalite östenitik paslanmaz çelik gurubunun kimyasal bileşiminde krom bulunur ve krom çelik yüzeyinde oksit film tabaka oluşturur. Bu tabakaya sahip çelikler üstün korozyon dayanımı gösterirler. Bu grubun bileşimde bulunan nikel ve mangan gibi diğer alaşım elementleri sayesinde oda sıcaklığında bile östenitik yapıya sahip olması, soğuk deformasyona uğratarak haddelene yapılmasına olanak sağlamaktadır. Paslanmaz çelik üretimi vakum ya da inert gazlı ortamda ergitme işlemleri yapılarak 2 şekilde gerçekleştirilmektedir. Ülkemiz çelik üretiminde dünyada tonaj olarak 8. sırada olsa da ekonomik değeri yüksek olan paslanmaz kalite çelik üretimi için yatırım yapılmadığından ihtiyacı olan paslanmaz çeliği ithal etmek durumunda kalmıştır. Aynı zamanda ülkemizde paslanmaz hurdaları geri dönüşümlü olarak değerlendirilmeden yurt dışına ihraç yapılmakta ve ekonomik kayıplara neden olmaktadır. Yapılan çalışmada vakum ergitme ocakları kullanılmadan, oksitleyici ortamda çalışan indüksiyon ocaklarında ergitme işlemleri gerçekleştirilip, paslanmaz AISI 304 kalite çelik üretimi gerçekleştirilmiştir. Çalışma bu yönüyle

indüksiyon ocağı ile döküm yapan firmaları, ekonomik değeri yüksek olan AISI 304 kalite östenitik paslanmaz çelik dökümü için teşvik edecek niteliktedir.

Yapılan çalışmada AISI304 kalite paslanmaz çelikleri indüksiyon ocağında oksitleyici ortamda 20 mm kalınlığa dökülmüş, sonrasında önce sıcak haddelene ile 8 mm'ye ve takiben soğuk haddelene yöntemi ile 1,66 mm kalınlığa haddelenerek yassı lama üretimi gerçekleştirilmiştir. İndüksiyon ocağında üretimi gerçekleştirilen ve soğuk haddelenen AISI 304 paslanmaz kalite çelik numunelerine kimyasal, mekanik testler ve mikroyapı, korozyon testleri yapılarak piyasada kullanılan AISI 304 kalite paslanmaz çelik referans numuneleri ile karşılaştırmalar yapılmıştır.

Alınan test sonuçları referans numuneye göre değerlendirilmiş ve piyasada hali hazırda döküm işlemleri yapan firmaların ekonomik değeri yüksek olan paslanmaz kalite çelik üretimini yapabileceği gösterilmiştir. Bu alanda çalışma yapmak isteyen firmalar için destekleyici bir çalışma gerçekleştirilmiştir.

### 1. Giriş

Paslanmaz çelikler 150 yıl gibi kısa bir tarihe sahip olmasına rağmen günlük hayatımızda çok önemli alanlarda kullanılmaktadır. Paslanmaz çelikleri, diğer çelik gruplarından ayıran en önemli özelliği atmosfer koşullarındaki yüksek korozyon direncidir. Yüksek korozyon direnci ve parlak dış görünüşleri ile paslanmaz çelikler çok geniş kullanım alanlarına sahiptir ve bu kullanım alanları ihtiyaç miktarı doğrultusunda kalite ve ürün çeşitliliği bakımından artış göstermektedir. Paslanmaz çeliklerde farklı özelliklerde çelik imalatı için belirleyici unsur bileşimde bulunan alaşım elementleri miktarıdır.

Ülkemizde paslanmaz çelik üretimi mevcut entegre tesislerde ya da yarı entegre tesislerde (ark ocakları) gerçekleştirilebilir. Bu tesislerde bulunması zor ve pahalı olan paslanmaz çelik hürdası yerine entegre tesislerde üretilen sıvı çelik ya da çelik hürdası kullanılabilir. Argon oksijenle karbon giderme potasında sıvı metalin karbonu azaltıldıktan sonra ferrokrom ve ferronikel alyajları eklenerek paslanmaz çelik üretilebilir. Böyle bir paslanmaz çelik tesisi için gerekli yatırım tutarını, argon oksijen karbon giderici, sürekli döküm tesisi, haddehane, ısıtma işlem, asitle temizleme ve malzeme kontrol üniteleri olacaktır. Gerekli olan bu ünitelerin bazıları mevcut tesislerimizde zaten vardır ve paslanmaz çelik üretimine uyarlanmaları gerekecektir [4].

Östenitik paslanmaz çeliklerde şekil alma kabiliyeti yüksektir. Deformasyon sertleşmesi ile mukavemet değerleri artış göstermektedir. Isıl işlem ile sertlik alma kabiliyeti yoktur. Östenit paslanmaz çelikler manyetik özellik göstermezler. Atmosferik ortamda ve asidik ortamda korozyona karşı dayanımları yüksektir. Klorlu ortamlarda sıcaklığa bağlı olarak korozyon kabiliyetleri değişmektedir. Östenitik paslanmaz çelikler farklı kalitelere üretilmelerinin yanında yaklaşık olarak benzer fiziksel özellikler göstermektedir. Yoğunlukları 7,80 kg/dm<sup>3</sup> ile 8 kg/dm<sup>3</sup> arası değişmektedir.

Östenitik paslanmaz çelikler; -alaşım elementlerine bağlı olarak- farklı mekanik özelliklere, genel olarak sürekli akma dayanımına, çekme testinde yüksek uzama miktarı ve bununla beraber sünek kırılmaya, düşük karbon sebebi ile ısıtma işlemi etkisinde düşük sertlik kabiliyetine, deformasyonla sertleşebilmeye, yüksek kaynak kabiliyeti ve sıcaklık dayanımına sahiptir. Deformasyon sonucunda östenit tanelerde martenzit fazı oluşur [5].

Yapılan çalışmada yurt dışına ihraç edilen ekonomik değeri yüksek olan 304 kalite paslanmaz çelik hurdalarının indüksiyon ocağında ergitilerek kullanılabilirliği araştırılmıştır. Çalışmada piyasada bulunan çok sayıda indüksiyon ocağı ile döküm yapan firmalara öncülük etmek ve döküm esnasında oksitleyici ortamda meydana gelen alaşım elementi kayıplarının tespit edilmesi sağlanacaktır. Ergitilen paslanmaz hürdasında meydana gelen alaşım elementleri kayıpları ve kullanılacak olan ferro alyaj miktarları belirlenerek üreticiler için maliyet hesaplamalarını kolaylaştırması sağlanacaktır. Döküm firmaları birçoğu sipariş üzerine çalışan firmalar olup, ergitme esnasında alaşım elementlerinin kaybedilmesi ve tekrar takviye yapılması ile çok fazla kâr edilemediği için AISI 304 kalite östenitik paslanmaz döküm siparişleri üzerine çok fazla çalışmadıkları bilinmektedir.

Çalışmanın 2. aşamasında piyasadaki temin edilen ve prototip ölçekte hurda malzemeyle döküm yapılarak elde edilen AISI 304 kalite çeliklere eşit şartlarda sıcak ve soğuk haddelene işlemleri uygulanmıştır. Soğuk haddelenen saç numunelerin mekanik, mikroyapı ve korozyon dirençleri incelenmiş ve piyasa çeliği ile karşılaştırılması yapılarak döküm yolu ile üretilen paslanmaz çeliğin test koşullarını sağlayıp sağlamadığı kontrol edilmiştir. Bu sayede piyasada indüksiyon ocağı ile oksitleyici atmosfer döküm işlemleri gerçekleştirilen AISI 304 kalite östenitik çeliğin piyasada kullanılan muadilleri ile karşılaştırılması yapılmış ve döküm esnasında kullanılan krom ve nikel gibi pahalı alaşım elementlerinin de verimlilikleri hesaplanmıştır. 2017 yılında yurt dışına 175.892 USD değere sahip

152.892 Ton paslanmaz çelik hurdası ihraç edilmiştir [3]. İhraç edilen paslanmaz hurdalarının değerlendirilmesi ve katma değer sağlayan ürüne dönüştürülmesi için örnek çalışma olacaktır.

## 2. Üretim Çalışmaları

### 2.1. Başlangıç Malzemelerine Yapılan Analizler

Yapılan döküm çalışması için piyasadan uygun boyutta temin edilen AISI 304 paslanmaz çelik hurdası ve alaşımlamada kullanılacak olan ferro alyajların kimyasal analizleri Tablo 1'de verilmiştir.

**Tablo 1.** Döküm işlemlerinde kullanılacak ferro alyajların kimyasal analizleri

Alyaj	AISI 304 Hürda	Düşük Karbonlu Ferro Mangani	Ferro Silis	Düşük Karbonlu Ferro Krom	Nikel
Element/Oksit		(%)	(%)	(%)	(%)
Fe	69,80		21,53		
Si	0,42	1	74,66	1,1	
Al	0,0001		2,14		
Mn	1,53	82			
P	0,0193	0,02		0,035	
Ni	8,06				99,8
Cr	18,75			65	
Cu	0,33				0,02
C	0,023	1,5		0,01	
S	0,0014	0,01		0,003	

### 2.2. Döküm Çalışmaları

Döküm işlemlerinde 5M firmasına ait 50 kg kapasiteli indüksiyon ocağı kullanılmıştır. İndüksiyon ocağında yapılan dökümler Matil A.Ş.'de bulunan haddeleme cihazlarımıza uygun olarak tasarlanan 200x100x20 mm ölçülerinde minyatür slab maça kalıplarda gerçekleştirilmiştir. Çalışmada 1 dökümde 50 kg ergitilmiş çelikten toplam 8 adet AISI 304 kalite slab numunesi üretilmiştir.

Döküm işlemlerinde hali hazırda bulunan AISI 304 kalite paslanmaz çelik hurdası ocak içine şarj edilmiş ve ocakta kademeli olarak voltaj artırılarak 3 saat sonunda ergitme işlemi tamamlanmıştır. Ergitilmiş metal içine tartımı yapılan paslanmaz hurdası ilave edilmiş ve toplamda 50 kg hurda kullanılmıştır. Alaşımlama hesaplamaları için ergitilmiş metal içinden kimyasal analiz için numune alınmıştır. Alınan kimyasal analizler Tablo 2'de verilmiştir. Paslanmaz çelik hurdasının ergitme işlemleri sonrasında alınan kimyasal analizlerinde Mn, Ni ve Cr elementlerinin oksitlenerek cürufa geçtiği tespit edilmiştir.

Paslanmaz çelik hurdasından alınan kimyasal analizde %0,0236 karbon değeri tespit edilmiştir. İlk ergitme gerçekleştiğinde alınan kimyasal analizde ise % karbon oranının %0,0745'e yükseldiği fakat yine de hedef değerinin altında olduğu görülmüştür. Bu yükselmenin nedeni refrakter astar uygulamasında kullanılan metal şablondan gelen karbondur.

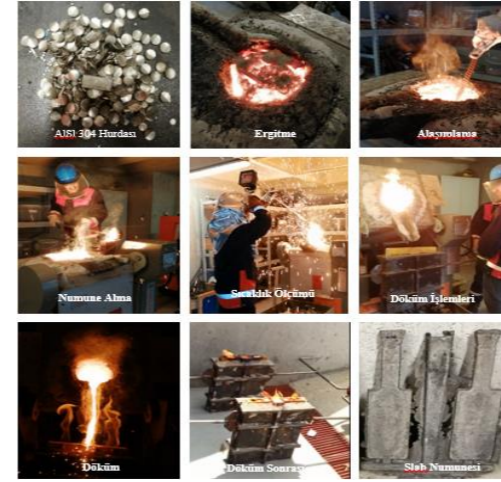
Alaşımlama için ferro alyaj kimyasal analiz değerlerine bağlı hesaplamalar yapılmış ve ergitilmiş çelik içine 1800 gram ferro krom ve 600 gr nikel ilave edilerek tekrar kimyasal analiz alınmıştır. Ferro alyaj ilavesi karbon değerinin yükseldiği nikel ve krom oranlarında istenen hedef değerlerden oksitlenmeye bağlı olarak düşük kaldığı görülmüştür.

Sisteme ilave edilen ferro krom miktarında 1800 gr için krom değerinde %2,48 artış beklenmesine rağmen gerçekleşen artışın %0,74 olduğu hesaplanmıştır. Ferro krom 'dan alınan verimlilik %29,83 olarak hesaplanmış ve kromun %70,16'sı oksitlenerek cürufa geçmiştir. Nikel içinse 600 gram nikel sistem içine beslenmiş, teorik hesaplamada ulaşılmaması gereken artış %1,18 olmasına rağmen alaşımlama sonrasında alınan analizde artış %0,66 hesaplanmıştır. Sisteme alaşımlama için verilen nikel %44,06 verimlilik sağlamıştır. Kimyasal analiz sonrası yapılan ikinci alaşımlamada % verimlilik oranları da göz önünde bulundurulmuş ve ergitilmiş çelik içine 3000 gram ferro krom ve 600 gram nikel ilave edilmiştir.

**Tablo 2.** Döküm hurdası, ergitilmiş metal ve alaşımlama sonrası elde edilen kimyasal analiz değerleri.

Element	304 Kalite Paslanmaz Hürda %	Ergitilmiş 304 Kalite Paslanmaz Hürda %	Alaşımlama Sonrası Ergitilmiş Paslanmaz, %	Döküm Sonrası Slab	Hedef Değerler %
C*	0,0236	0,0745	0,0857	0,0894	%0,08 max
Mn*	1,5388	1,422	1,2332	0,9658	%2 max
Si*	0,3964	0,501	0,5202	0,4149	%0,75 max
S*	0,0014	0,0043	0,0026	0,0038	%0,045 max
P*	0,0248	0,0274	0,0275	0,033	%0,03 max
Ni*	8,0675	6,8295	7,56	8,02	%44,06
Cr*	18,7501	15,8457	16,58	18,11	%18-20
Fe	69,8038	72,2838	72,7344	72,1845	

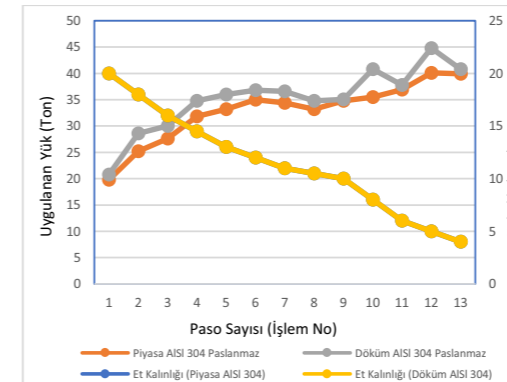
Alaşımlama sonrasında alınan sıcaklık değerinin 1620°C olduğu ve bunun da paslanmaz dökümü için yüksek olduğu görülmüştür. Sıcaklık artışının nedeni alaşımlama esnasında meydana gelen ekzotermik reaksiyonlardır. Bu nedenle ocak voltajı azaltılarak sıcaklığa müdahale edilmiştir. Bekleme sonrasında 1580°C olan ikinci sıcaklık ölçümü sonrasında kimyasal analiz için bekleme yapılmadan döküm işlemleri gerçekleştirilmiştir. Döküm sonrasında soğutulmuş slab numunesinden kimyasal analiz için numune kesilmiştir. Alınan kimyasal analizde krom, nikel ve mangan oranlarının hedef değerleri sağlarken karbon oranının alaşım elementlerinden gelen karbon nedeni ile hedef değerinin üstünde olduğu tespit edilmiştir. Şekil 1'de döküm işlemleri ayrıntılı olarak gösterilmiştir.



**Şekil 1.** Matil A.Ş. AISI 304 Kalite Paslanmaz Çelik döküm işlemleri.

### 2.3. Soğuk ve Sıcak Haddeleme Çalışmaları

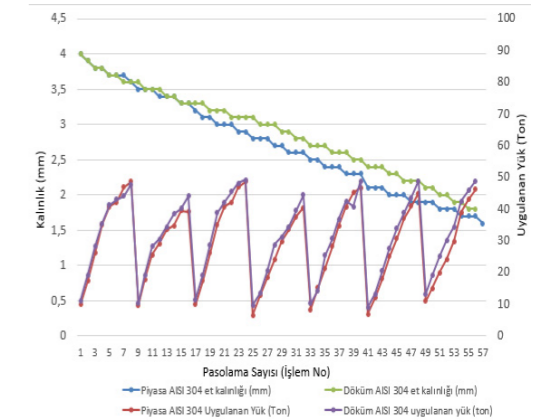
Haddeleme işlemleri Matil A.Ş.'de pilot ölçekli çelik üretim laboratuvarında bulunan minyatür 50 ton ezme kuvvetine sahip Şekermaksan marka otomatik sıcak-soğuk haddeleme cihazında yapılmıştır. Haddeleme işlemlerinde döküm yolu ile üretilen ve piyasadan temin edilen AISI 304 kalite paslanmaz çelikler öncelikli olarak 20 mm kalınlıktan sıcak haddeleme yapılarak 4 mm kalınlığa kadar %80 deforme edilmiştir.



**Şekil 2.** Sıcak haddelemede 13 işlemde uygulanan yük ve kalınlık değişimleri.

Sıcak haddeleme işlemlerinde deformasyon sonrasında her iki numunenin de Brinell sertlik değerlerinde 185'ten 280'e %52,77 artış meydana gelmiştir. Bu nedenle soğuk haddeleme işlemleri öncesinde 4 mm kalınlıktaki numunelere kül fırında 1100°C'de 30 dakika boyunca ısıl işlem uygulanmıştır. Isıl işlem uygulanan numuneler 4 mm kalınlıktan piyasadan temin edilen AISI 304 kalite çelik 1,66 mm kalınlığa %58,5 deforme edilmiştir.

Döküm yolu ile üretilen AISI 304 kalite paslanmaz çelik ise 4 mm kalınlıktan 1,77 mm kalınlığa %55,75 deforme edilmiştir. Şekil 4'te her iki numuneye de uygulanan, azalan kalınlığa bağlı yük değişimleri verilmiştir. Yük değişimlerinin pik noktasına geldiği noktalarda numune tekrar fırına verilmiş ve 1100°C'de 30 dakika ısıl işlem yapılmıştır. Soğuyan numunelerde ezme kuvveti maksimuma gelene kadar haddeleme işlemlerine devam edilmiştir. Soğuyan numunelerden alınan 2,5/187,5 kg yükte Brinell sertlik değerleri yaklaşık 190 HBW değerinde ölçülürken soğuk haddeleme sonrasında bu değer 280 HBW değerine yükseldiği tespit edilmiştir. Döküm yolu ile üretilen AISI 304 kalite paslanmaz çeliğin kalınlık değerinin daha yavaş azaldığı buna karşın uygulanan yüklerin piyasa numunesi AISI 304'e göre daha fazla olduğu tespit edilmiştir.



**Şekil 3.** Soğuk haddelemede 57 işlemde uygulanan yük ve kalınlık değişimleri.

Şekil 4'te soğuk haddeleme işlem görüntüleri ve numune görüntüleri verilmiştir.

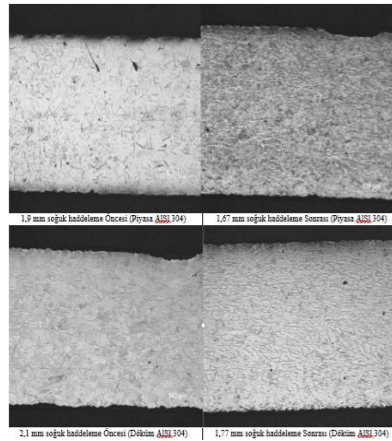


**Şekil 4.** Soğuk haddeleme besleme ve çıkış görüntüleri.



Şekil 5'te 1,9 mm kalınlıkta ve sıcak işlem uygulanmış piyasadan temin edilmiş ve paslanmış AISI 304'ün ve soğuk haddeleme işlemleri sonrasında 1,67 mm kalınlığa indirilen lama numunesinin mikroyapı fotoğrafları verilmiştir. Kesitten de östenitik bir mikroyapıya ve bununla beraber östenit tanelerinin kaba yapılı ve keskin kenar ve köşelere sahip olduğu görülmektedir. Soğuk haddeleme sonrasında tanelerin haddeleme yönünde uzama gösterdiği ve hadde yönünde yönlenme olduğu görülebilmektedir. Haddeleme tanelerinin tamamen ezilmediği ve kaba yapılı tanelerin ezilmesi ile haddeleme işlemlerine devam edilebileceği düşünülmektedir.

Yine şekil 5'te 1,9 mm kalınlığa sahip ısıtılmış döküm ile üretilmiş AISI 304 paslanmaz çeliğin soğuk haddelemiş numune görüntüsü verilmiştir. Taneler soğuk haddeleme sonrasında piyasa mamulü AISI 304 kalite çelikle benzer davranış göstermiştir.



Şekil 5. Soğuk haddeleme öncesi ve sonrası piyasa AISI 304 ve döküm AISI 304 mikroyapı görüntüleri.

Tanelerin maksimum 50 ton kapasiteli cihazda tamamen ezilme göstermediği, daha güçlü haddeleme cihazlarında kaba yapılı tanelerin ezilmesi ile daha ince lama elde edilebileceği öngörülmektedir.

### 3. ANALİZ ÇALIŞMALARI

Döküm işlemleri tamamlanan ve piyasadan temin edilen AISI 304 kalite paslanmaz çelik numunelerine kimyasal, mikroyapı, korozyon ve mekanik test işlemleri yapılmıştır.

#### 3.1. Kimyasal Analiz

Soğuk haddeleme için piyasadan temin edilen ve laboratuvar ortamında indüksiyon ocağında döküm ile üretilen AISI 304 kalite paslanmaz çelik numunelerinin kimyasal analiz sonuçları Tablo 3'de verilmiştir.

Tablo 3. Soğuk haddelemiş slab numuneleri kimyasal analizleri.

Döküm No	Piyasa	Döküm	Hedef Değerler
C*	0,0236	0,0894	%0,08 max
Min*	1,5388	0,9658	%2 max
Si*	0,3964	0,4149	%0,75 max
S*	0,0014	0,0038	%0,045 max
P*	0,0348	0,033	%0,03 max
Ni*	8,0673	8,16	%8-%10
Cr*	18,7501	18,03	%18-20
Fe	69,8038	72,1845	

Piyasa çeliğinin C oranı %0,0236'yken döküm yolu ile üretimi yapılan numunelerin %C oranlarının yüksek olduğu görülmektedir. Oksijen üfleme yapılmadığı için kontrol edilemeyen %C oranının yüksek olması, tane sınırlarında karbür bileşiklerinin oluşumuna neden olmakta ve korozyon dayanımını olumsuz olarak etkilemektedir [3]. Dökümle üretilmiş numunelerde bulunan piyasa çeliğine göre %0,5 daha fazla karbon kuvvetli bir östenit yapıcıdır. Ayrıca yine bu fazladan karbon yüksek mukavemetli alaşımlara sertlik ve mukavemet artırıcı etkiye sahip olmasının yanında metalin korozyon direncini ve düşük sıcaklıktaki tokluğunu olumsuz yönde etkilemektedir.

Döküm yolu ile üretilen AISI 304 kalite çeliğinin korozyon dayanımının artırılması için soğuk haddeleme işlemlerinin periyot aralarında 1100°C'de uygulanan ısıtılmış işlem, tane sınırlarındaki karbürlerin giderilmesini ve hızlı soğutma ile çökeltisiz östenit yapı oluşturulmasını da sağlamıştır [3]. Krom ve nikel oranlarında hedef değerler içinde bulunduğu, Schaeffler diyagramına göre hesaplama yapıldığında östenitik mikroyapının oluşması için yeterli değerlere ulaşıldığı görülmüştür [8]. Paslanmaz çelik hürdası bileşimindeki %1,53 oranında mangan, ergitme esnasında oksitlenmeye azalmıştır. Çalışmada ergitilmiş çelik bileşimine ferro mangan şarj edilmesi durumunda bileşimdeki karbon oranı yükseleceğinden şarj yapılması uygun görülmemiştir.

#### 3.2. Mekanik Testler

Sıcak ve sonrasında soğuk haddeleme işlemleri yapılarak döküm ile üretilen çelik 1,77 mm, piyasa mamulü ise 1,66 mm kalınlığa kadar deforme edilmiştir. Yapılan test işlemlerinde farklı olarak soğuk haddelemiş numunelere ve sonrasında ısıtılmış işlem görmüş numunelere sertlik ve çekme testleri uygulanmıştır. Testlerde firmamızda bulunan Universal sertlik cihazı kullanılmış, 187,5 kg

ağırlığında TS EN ISO 6506-1 standardına göre Brinell sertlik test işlemleri yapılmıştır.

Döküm slab numunesinden alınan Brinell sertlik değeri piyasa mamulü numuneye göre daha düşük çıkmıştır. Piyasa mamulünün döküm yolu ile üretilen paslanmaz çelikten farkı mangan değerinin yüksek, karbon değerinin düşük olmasıdır. Piyasa mamulünde soğuk haddeleme sonrasında yüzeyde oluşan deformasyon sertleşmesine bağlı olarak 197,85 Brinell sertlik değerinden 285,92'ye %44,51 oranında artış görülmüştür. Döküm yolu ile üretilen AISI 304'ün 159,70 olan Brinell sertliği, soğuk haddeleme sonrasında 303,51'e soğuk deformasyon sertleşmesine bağlı olarak %90,05 oranında yükselmiştir. Tablo 4'te piyasa mamulü ve döküm ile üretilmiş AISI 304 numunelerinde soğuk haddeleme ve ısıtılmış işlem sonrasında meydana gelen Brinell sertlik değişimleri ve çekme dayanımı test sonuçları verilmiştir.

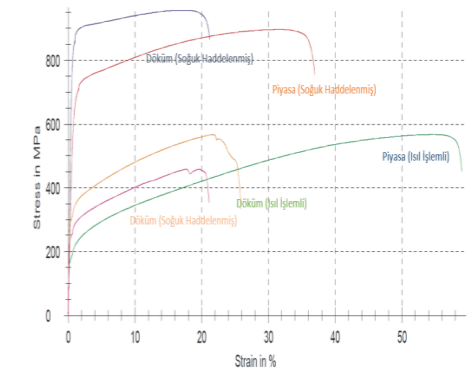
Tablo 4. Soğuk haddeleme öncesi ve sonrası uygulanan mekanik testler

Soğuk Haddeleme Sonrası İncelenen Kalınlık (mm)	Piyasa	Döküm	Standart
Döküm Sonrası Brinell Sertliği (HBW 187,5kg)	197,85	159,70	ISO 6506
Soğuk Haddeleme Sonrası Brinell Sertliği (HBW 187,5 kg)	285,92	303,51	ISO 6506
Soğuk Haddeleme Sonrası Çekme Dayanımı (MPa)	897	957	ISO 6892-1
Soğuk Haddeleme Sonrası Akma Dayanımı (Mpa)	647,4	787,4	ISO 6892-1
Soğuk Haddeleme Sonrası Uzama (%)	37	21,2	ISO 6892-1
Isıtılmış İşlem Sonrası Çekme Dayanımı (MPa)	567	567	ISO 6892-1
Isıtılmış İşlem Sonrası Akma Dayanımı (Mpa)	171,9	293,2	ISO 6892-1
Isıtılmış İşlem Sonrası Uzama (%)	59	25,8	ISO 6892-1

Soğuk haddelemiş numunelerden piyasa mamulü AISI 304 kalite çeliğin plastik deformasyon kabiliyetinin daha iyi olduğu, aynı numuneye 1100°C'de uygulanan ısıtılmış işlem sonrasında plastik deformasyon oranının arttığı tespit edilmiş ve Şekil 6'da gösterilmiştir. En fazla uzamaya ısıtılmış işlem sonrasında piyasa mamulü AISI 304'ün sahip olduğu görülmüştür. Piyasadan temin edilen paslanmaz çelik, ısıtılmış işlem akabinde yapılan haddeleme sonrasında meydana gelen deformasyona bağlı olarak çekme dayanımında 567 MPa'dan 897 Mpa'ya %58,2 artış göstermiştir. Aynı şekilde piyasa mamulü AISI 304'e uygulanan soğuk haddeleme işlemleri sonrasında akma dayanımı 171,9 MPa'dan 647,4 MPa'ya %276 artış göstermiştir.

Piyasadan temin edilen soğuk haddelemiş ve ısıtılmış işlem görmüş numunelere yapılan çekme testlerinde, her iki gruptaki numunenin de döküm yolu ile üretilen numunelere göre sünekliklerinin daha iyi olduğu tespit edilmiştir. Karbon değeri yüksek olan soğuk haddelemiş döküm numunesi en yüksek

mukavemete sahip olup, piyasa mamulü haddelemiş numuneye göre daha düşük plastik deformasyon kabiliyetine sahiptir. Soğuk haddelemiş ve sonrasında ısıtılmış işlemle gerilmeleri ve dislokasyon yoğunluğu giderilen piyasa mamulü AISI 304 kalite çeliğin, döküm yolu ile üretilen AISI 304'e oranla plastik deformasyon bölgeleri daha geniş ve sünekliği daha yüksektir. ısıtılmış işlemli piyasa mamulü AISI 304 en iyi plastik deformasyon değerine sahiptir. Dökümle üretilen AISI 304 mukavemetinin yüksek olması bileşiminde bulunan karbonun fazla olmasından kaynaklanmaktadır. Döküm numunesinin akma dayanımı piyasa numunesine göre daha iyidir. Döküm numunesinin karbon oranı düşürülerek ve mangan oranı yükseltilerek piyasa şartlarındaki AISI 304 numunesine benzer mekanik özellikleri sağlayabileceği düşünülmektedir.



Şekil 6. Soğuk ve Sıcak haddelemiş 304 kalite paslanmaz piyasa, döküm numunelerinin çekme dayanımlarının karşılaştırılması.

Döküm yolu ile üretilen AISI 304'ün sonuçlarını incelediğimizde malzemeye yapılan ısıtılmış işlemle beraber plastik deformasyon kabiliyetinde artış olduğu görülmektedir. Plastik deformasyon kabiliyeti ve mukavemetteki artışa bu iki haddeleme işlemi ve sonuçları sebep olmuştur.

#### 3.3. Mikroyapı İncelemeleri

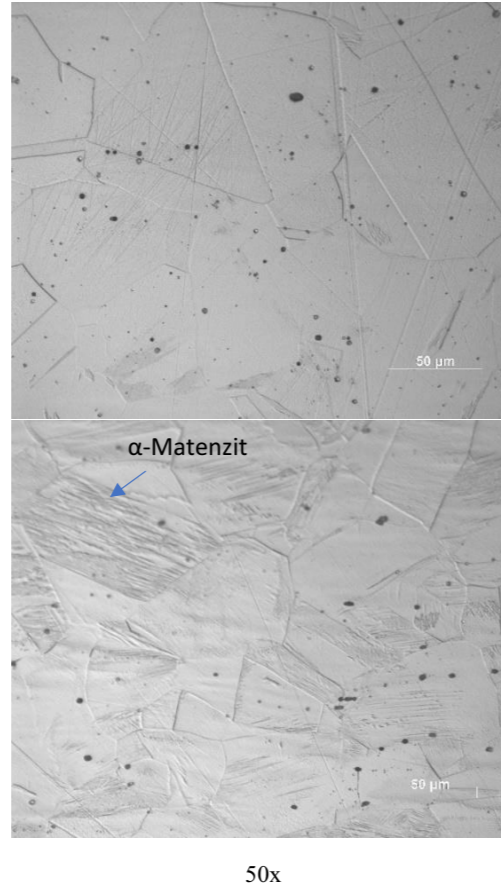
Soğuk haddeleme işlemleri öncesi ve sonrasında lama haline getirilen numune kesitlerinden haddeleme yönünde örnekler kesilmiş ve bakalitleme işlemleri yapılmıştır. Bakalitlenen numunelere Metkon firmasına ait otomatik zımparalama ve parlatma cihazı kullanılarak 400 mesh zımparada 1 dk. kaba zımparalama yapılmıştır. Sonrasında 800 ve 1200 mesh zımparalarda 2 dk. boyunca ince zımparalama işlemleri uygulanarak parlatma işlemlerine geçilmiştir. Parlatma aşamasında 3 mikronluk parlatma çuhasında 4 dk. ve sonra 1 mikronluk parlatma çuhasında 2 dk. parlatma



işlemleri uygulanmıştır. Parlatma işlemleri tamamlanan bakalitlenmiş numunelere %10 oksalik asit çözeltisi ile 2 volt değerinde elektrolitik dağlama işlemleri yapılmıştır. Dağlama işlemi sonrasında firmamızda bulunan Carl Zeiss Axio Imager M2M model optik mikroskopta mikroyapı incelemeleri gerçekleştirilmiştir.

Piyasa mamulü AISI 304 kalite paslanmaz çeliğin mikroyapı görüntüleri Şekil 7 de verilmiştir. Tipik östenitik yapıya sahip olan piyasa mamulü AISI 304 kalite numunesindeki ikizlenmeler ve tane sınırları üzerinde ve yakın bölgelerde krom karbür şeklinde noktalar görülmektedir. Piyasa mamulü paslanmaz çeliklerde cüzi miktarda da olsa delta ferrit olabileceği kaynaklarda belirtilmesine rağmen mikroyapı resimlerinde delta ferrite rastlanmamıştır [6]. Ortalama tane boyutu değeri soğuk haddeleme öncesi ve sonrasında değişmemiş, boyut numarası Ø 6,5 ve ortalama tane büyüklüğü 33,67 µm olarak tespit edilmiştir. 20x ve 50x büyütmede resimler incelendiği zaman östenit tanelerin halen ezilerek deforme edilebileceği görülmektedir. Numunenin ezme yüzeyine yakın bölgelere yapılan mikroyapı incelemelerinde yüzeyde deformasyon sertleşmesine bağlı α-martenzit bir yapılanma görülmüştür [1, 2]. Soğuk haddeleme sonrasında Şekil 6'da tane üzerinde oluşan α-martenzit yapı görülmektedir [1].

Şekil 8'de döküm sonrası meydana gelen yapının östenitik olduğu anlaşılmaktadır. Piyasa üretimi olan AISI 304 kalite çelikle benzer ikizlenmelerin ve yine piyasa mamulü çeliğe göre daha keskin köşeli östenit tanelerin olmadığı görülmüştür. Schaeffler diyagramında yapılan hesaplamalarda yapının östenit-martenzit-ferrit olduğu fakat bileşiminde %10 delta ferritin de olduğu anlaşılmaktadır. Mikroyapıda görülen delta ferritler korozyon dayanımını ve haddeleme davranışlarını olumsuz şekilde etkilemektedir [6]. Soğuk haddeleme sırasında sertleşmeye bağlı olarak 1100°C'de yapılan ısı işlemler, delta ferritin giderilmesinde ve azaltılmasında önemli rol oynamıştır. Soğuk haddeleme sonrasında tane sınırlarında kaymaların meydana geldiği ve tanelerin haddeleme yönünde uzadığı görülmektedir. Haddeleme öncesinde ortalama tane numarası 6,5, tane boyutu ise 33,7 µm olarak ölçülmüştür. Haddeleme sonrasında ise tane numarası 4,5 ve tane boyutu ise 64,28 µm olarak ölçülmüştür. Mikroyapı resimlerinde tane sınırlarında ve tane üzerindeki karbonun, krom karbür şeklinde çökeldiği düşünülmektedir. Piyasa mamulü çeliğe göre tane sınırlarında çökelen karbon miktarının daha fazla olduğu, buna da kimyasal bileşimdeki karbon oranının fazla olmasının neden olduğu görülmüştür. Bu durumun korozyon dayanımını olumsuz etkileyeceği düşünülmektedir.



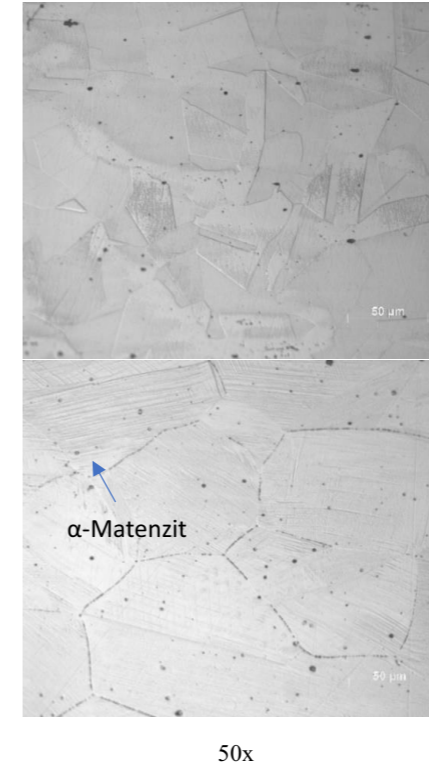
Şekil 7. Piyasa AISI 304 kalite soğuk haddeleme öncesi ve sonrası elde edilen mikroyapı görüntüleri.

Tablo 5'te soğuk haddeleme öncesi ve sonrasında elde edilen kesit kalınlıkları ve tane boyutları verilmiştir.

Tablo 5. Soğuk haddeleme ve sonrası uygulanan mikroyapı analizleri.

	Piyasa	Döküm	Standart	Hedef
Soğuk Haddeleme Öncesi Kalınlık (mm)	18	20 mm	Yok	
Soğuk Haddeleme Sonrası Kalınlık (mm)	1,66	1,77 mm	Yok	1,5
Deformasyon Oranı (%)			Yok	
Soğuk Haddeleme Öncesi Tane Boyutu	Ø 6,5 - 19,39 µm	Ø 5,5 - 45,62 µm	ASTM E45	
Soğuk Haddeleme Sonrası Tane Boyutu	Ø 6,5 - 31,24 µm	Ø 6,5 - 31,8 µm	ASTM E45	
İnkizasyon Testi (k3)	14,88	4,96	DN 50602	

Döküm yolu ile üretilen AISI 304 kalite çeliğin soğuk deforme edilerek tavlandığı ve piyasa numunesine benzer yapıda olduğu fakat yapısında delta ferritin bulunduğu tespit edilmiştir. Yapıdaki delta ferrit oranının azaltılması için uzun süreli tavlama işlemleri yapılması gerekmektedir [6]. Soğuk haddeleme işlemlerinde sertleşme sonrasında yapılan tavlama işlemlerinde delta ferritlerin azaldığı düşünülmektedir. Dökümle elde edilen AISI 304 kalite çeliğin karbon oranının fazla olmasına bağlı sertliği daha yüksektir.



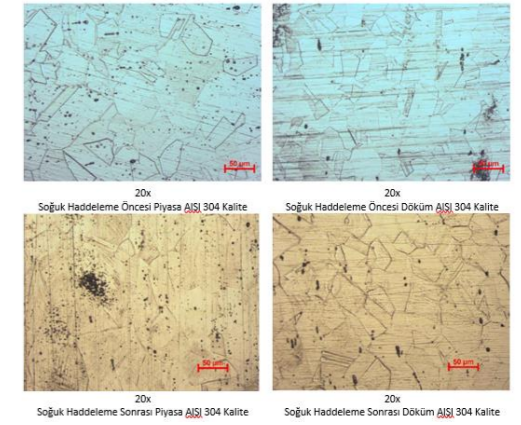
Şekil 8. Döküm AISI 304 kalite soğuk haddeleme öncesi ve sonrası elde edilen mikroyapı görüntüleri.

### 3.4.Korozyon Testleri

#### 3.5.1. Korozyon Duyarlılık Testi

ASTM 2662 standardı A pratiğine göre numunelerin tane sınırı korozyon duyarlılığı incelenmiştir. Buna göre numuneler öncelikle metalürjik inceleme için hazırlanmıştır. Her bir metalin yüzeyinde bulunan oksit tabakasının giderilmesi ve mikroyapı incelemesi için sırasıyla 60, 120, 180, 320, 400, 600, 800, 1000 ve 1200 mesh'lik zımpara ile kabaca parlatılma yapılmıştır. Daha sonrasında incelenecek olan yüzey, elmas pasta ile parlatılmıştır. Parlatılan numunelerin dağlama işlemi standarda uygun olarak 10%'luk oksalik asit çözeltisi içerisinde elektrokimyasal dağlama yöntemi ile gerçekleştirilmiştir. Elde edilen mikroyapı görüntüleri Şekil 9'da verilmiştir.

Şekil 9'da görüldüğü üzere soğuk haddeleme öncesi ve sonrasında döküm ile üretilmiş ve piyasa mamulü AISI 304 çeliklerinde tane sınırı korozyonu sonucu oluşabilecek bozulmanın olmadığı test standardındaki referans resimlere göre saptanmıştır.



Şekil 9. ASTM 2662 A pratiğine göre tane sınırı korozyon duyarlılığı test sonuçları.

#### 3.4.2. Lineer Polarizasyon Testi

Lineer polarizasyon testleri üç elektrotlu sistem kullanılarak gerçekleştirilmiştir. Referans elektrot olarak Ag/AgCl kalomel elektrot, karşıt elektrot olarak 5 cm<sup>2</sup> yüzey alanına sahip platin (Pt) levha kullanılmıştır. Çalışma elektrotu olarak 1 cm<sup>2</sup> yüzey alanına sahip numune kullanılmıştır. Çözelti olarak ağırlıkça %3,5 NaCl çözeltisi kullanılmıştır. Test öncesi çözelti 1 saat boyunca azot gazı ile süpürülmüştür. Her numunenin polarizasyon eğrisi alınmadan önce 400 sn. boyunca açık devre potansiyelleri ölçülmüştür. Polarizasyon eğrileri pozitif tarama yönünde (anodik) -1 V'den başlayıp 1 V'ye kadar 5mV.s<sup>-1</sup> tarama hızıyla elde edilmiştir.

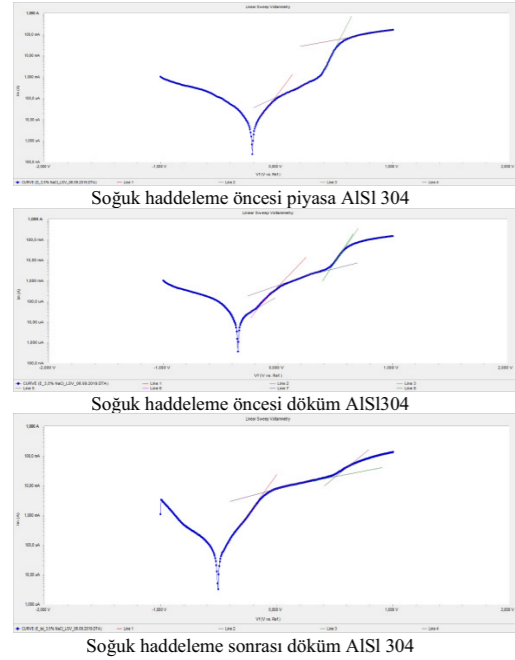
Polarizasyon eğrilerinden lineer fit yöntemi ile belirlenen E<sub>corr</sub>, E<sub>passive</sub> ve E<sub>pit</sub> potansiyel değerleri Tablo 6'da verilmiştir.

Tablo 6. E<sub>corr</sub>, E<sub>passive</sub> ve E<sub>pit</sub> potansiyel değerleri

Numune Kodu	E <sub>corr</sub> (mV)	E <sub>passive</sub> (mV)	E <sub>pit</sub> (mV)
Soğuk Hadde Öncesi (Piyasa AISI 30)	-210	-10	550
Soğuk Hadde Öncesi (Döküm AISI 30)	-350	30	445
Soğuk Hadde Sonrası (Döküm AISI 30)	-505	-90	510

Tablo 6'da verilen korozyon potansiyel değerlerine (E<sub>corr</sub>) göre en düşük potansiyel değerine sahip olan soğuk haddeleme öncesi döküm ile üretilmiş numunenin korozyona karşı direnci, diğer soğuk haddelenmiş piyasa mamulü ve döküm ile üretilmiş AISI 304 paslanmaz çeliklere kıyasla daha yüksektir. Numunelerin yüzeyinde pasif film oluşumunun gerçekleştiği görülmüştür. Potansiyel değerlerine göre inceleme yapıldığında (E<sub>passive</sub>), soğuk haddeleme öncesi döküm ile üretilmiş AISI 304 kalite çelik numunesinde pasif film oluşumu diğer numunelere kıyasla daha hızlı gerçekleşmektedir. Buna karşılık çukuruk oluşumu başlangıç

potansiyelinin ( $E_{pit}$ ) diğer numunelere göre daha düşük potansiyel değerinde gerçekleşmesi, oluşan pasif filmin kararsız olduğunu göstermektedir.  $E_{pit}$  değerinin en yüksek olduğu soğuk haddelenmiş piyasa mamülü AISI 304 kalite çelik numunesi ise en kararlı pasif filme sahiptir. Dinamik polarizasyon eğrileri Şekil 10'da verilmiştir.



Şekil 10. Piyasa ve döküm AISI 304 kalite numunelerin lineer polarizasyon eğrileri.

#### 4. Sonuçlar ve Öneriler

Ergitme işlemleri sonucunda üretimi yapılan AISI 304 kalite paslanmaz çelik numunesi kimyasal hedeflere ulaşmış ve döküm başarıyla gerçekleştirilmiştir.

Döküm işlemlerinde kullanılan AISI 304 kalite paslanmaz çelik hurdasındaki mangan, krom ve nikelin kimyasal oranlarında, hurdanın ergimesi esnasında oksidasyon gerçekleşmesine bağlı önemli azalmalar meydana geldiği yapılan hesaplamalar sonrasında tespit edilmiştir. Aynı durumun kullanılan alaşım elementlerinin verimliliklerinde de meydana geldiği ve alaşımlama sonrasında ferro kromun %80, nikelin %63,09 ve ferro mangan %55,81 verimle alaşımlama yapılabildiği anlaşılmaktadır. İndüksiyon ocağı ile döküm yapan firmalar için oksitlenmeye bağlı olarak hurda bileşiminde Ni, Cr ve Mn miktarlarındaki azalmalar önemli maliyet kayıplarına neden olacaktır. İndüksiyon ocağı kullanan firmalar birkaçı dışında vakumlama sistemine sahip olmadığı için yapılacak

olan çalışmalarda bu miktarlar çok iyi hesaplanmalı ve alaşımlama, ergitme işlemleri olabildiğince çabuk yapılarak kayıpların azaltılması sağlanmalıdır.

Ergitme işlemleri sonucunda üretimi yapılan AISI 304 kalite paslanmaz çeliğin krom ve nikel oranları kimyasal analiz sonrası yapılan alaşımlamadan döküm zamanına kadar geçen bekleme süresi nedeni ile hedef değerlerin altında kalmıştır. Nikel oranının düşük olması yapının tamamen östenit fazında oluşmamasına ve beraberinde martenzit ile delta ferrit oluşumuna neden olmuştur.

Kimyasal bileşimi sağlamış fakat piyasa mamülü muadiline oranla daha yüksek karbon değerine sahip olan döküm ürünü AISI 304 kalite çelikte tane sınırları üzerine karbür ve delta ferrit oluşumlarının çökeldiği tespit edilmiştir. Ancak mikroyapı incelemelerinde delta ferrit görülmemiştir. Bunun nedeni soğuk haddeleme işlemlerinde her periyot arasında yapılan ısı işlemlerin delta ferritleri gidermesidir. Aynı zamanda karbon oranının yüksek olması mukavemet değerini artırmış fakat tane sınırlarında oluşan krom karbürler korozyon dayanımını olumsuz şekilde etkilemiştir.

Döküm ile üretilen ve piyasadaki alınan paslanmaz çeliklerin mekanik özellikleri incelendiği zaman piyasa üretimi olan AISI 304 numunelerinin çekme dayanımlarının daha düşük fakat yüzde uzamalarının döküm ürününe göre daha yüksek olduğu anlaşılmaktadır. Her iki gruptan numunelere de uygulanan soğuk haddeleme periyotları arasında yapılan ısı işlemler sonrasında, piyasa numunesinde yüzde uzama değerinin artış gösterdiği ve sünekliliğinin döküm ürününe göre daha yüksek olduğu tespit edilmiştir. Piyasa numunesinin döküm ürününe göre daha iyi bir uzamaya sahip olması soğuk olarak şekillendirilmesinin daha kolay olacağı anlamına gelmektedir. Nikel ve kromun cürufa geçmesi ve döküm esnasında meydana gelen oksidasyonlar, östenitik yapı beraberinde martenzit ve delta ferrit yapı oluşmasına neden olmuştur. Bu durumun mukavemeti artırıp sünekliliği azalttığı tespit edilmiştir.

Döküm çalışmaları sonrasında yapılan soğuk haddeleme işlemlerinde piyasa çeliği 4 mm'den 1,67 mm'ye kadar %58,25 oranında deforme edilmiş ve lama üretimi gerçekleştirilmiştir. Matil A.Ş.'de dökümü yapılan paslanmaz çelik ise 4 mm kalınlıktan 1,77 mm kalınlığa kadar %55,75 deforme edilerek soğuk haddeleme işlemleri sonrasında lama üretimi başarı ile gerçekleştirilmiştir.

Dökümhanede yapılacak ergitme işlemlerinde her ne kadar AISI 304 kalite paslanmaz çelik kullanılsa da ergitme esnasında meydana gelen oksitlenme sonucunda krom, nikel ve mangan oksitlenmekte ve cürufa geçmektedir. Oksitleyici ortamda yapılan dökümlerde azalan nikel ve krom değerleri ferro alyaj kullanılmasını gerektirmekte ve ek olarak alaşımlama maliyetine neden olmaktadır. Meydana gelen oksitlenmeler sonucu yeniden yapılan alaşımlamalar, karbon oranının artmasına yol açarken dökümhanelerde oksijen giderme yapılmadığı için karbon yapıda kalırken krom ile yaptığı bağ sonucunda krom karbürler şeklinde tane sınırlarına çökelmektedir. Krom karbürler korozyon dayanımını olumsuz etkilerken yapıda bulunan karbon mukavemetin artmasına ve sünekliliğin azalmasına neden olmaktadır. Bu durum soğuk haddeleme özelliklerini olumsuz etkilemektedir.

ASTM 2662 standardı A pratiğine göre numunelerin tane sınırı korozyon duyarlılığı incelenmiştir. Numunelere yapılan korozyon testlerinde soğuk haddeleme sonrası ve öncesinde numunelerde tane sınırı korozyonu sonucu oluşabilecek bozulma, test standardındaki referans resimler baz alındığında gözlemlenmemiştir.

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## Ferritic Grain Size Modeling with Rolling Process Parameters and Chemical Analysis Data

Haddeleme Parametreleri ve Kimyasal Analiz Dataları ile Ferritik Tane Boyutu Modellemesi

Cemre Keçeci

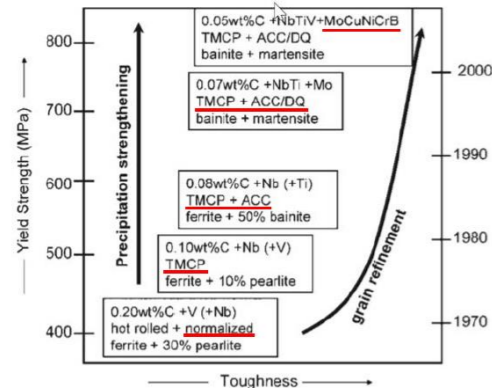
İSKENDERUN DEMİR VE ÇELİK • Türkiye

### Abstract

The grain size and distribution is very important in steel production and rolling process. For example, due to the high grain size, impact, strength and hardness increase at room temperature. For this reason, it is very important to calculate the grain size and take into consideration in the production results depending on the area where the products will be used. With this study, chemical analysis, process parameters and test results were compared in hot rolled coils produced in previous periods. In the data analysis performed with the minitab software, the grain size can be calculated.

### 1. Introduction

In order to achieve high strength characteristics in steel production, micro alloy steel production has been produced in recent years by using alloy elements such as titanium, vanadium and niobium. With the use of these elements in micro alloy steels, it is aimed that the strengths can approach the desired values and at the same time, to provide toughness with the desired mechanical properties depending on the area of use.



Vervynck et al., International Materials Reviews 2012 Vol 57 No 4, pp. 187-207

**Figure 1.** Yield Strength and Toughness Graph To Achieve High Strength Steels

As can be seen from the table above, micro alloy effect and grain size distribution gain great importance in order to

achieve 800Mpa values. In conventional carbon steels, with conventional rolling, a strength of 400Mpa can be achieved with perlitic-ferritic structure. However, for steels with high yield / tensile strength, thermomechanical rolling and secondary phases such as bainite / martensite are required.

These alloying elements are generally important alloying elements that affect the formation of grain structure and distribution of grain size and distribution in steels with rolling processes. In order to obtain the desired mechanical properties, the grain size and distribution in the product produced are of great importance. For this reason, grain size should be pronounced together with mechanical properties. When designing steel as metallurgists, the effect of grain size on mechanical properties should be known.

According to the Hall-Petch equation, the size of the grains affects the strength of a material.

$$\sigma_y = \sigma_0 + \frac{k}{\sqrt{d}}$$

**Figure 2.** Hall Petch Equation

The grain size is denoted by d in this equation. Therefore, the strength increases as the grain size decreases. This is because the larger interaction opportunities between the lattices are reduced, as it is suitable for grain size. The same equation can be written in terms of ultimate tensile strength or strength instead of yield stress.

Most materials exhibit the Hall - Petch effect at room temperature, and therefore have higher strength as mentioned above when grain size is reduced. The opposite is true at higher temperatures because the open and irregular nature of grain boundaries means that empty positions will move faster. Grain boundaries are regions with high energy. They are perfect places for nucleation of second phases.

In line with these importance, ferritic grain size is measured after mechanical testing results after coil and coil production.

Grain size measurement is carried out in accordance with the ASTM E112: Standard Test Methods for Determining Average Grain Size standard. ASTM E112 includes three test methods to determine the average grain size: The

comparison method, the planimetric method and the intersection method.

For grain size measurement in line with this standard, samples are cut from coils and coils and some precise sample preparations are made in the metallography laboratory. With these processes, both the rate of cut and waste from the products increases and it creates the need for labor use. In addition, after this method, only the grain size in the manufactured products can be measured and subsequent process changes can be made for new productions.

In this context, it is planned to create a mathematical model by making statistical study in order to estimate the grain size.

### 2. Experimental Procedure

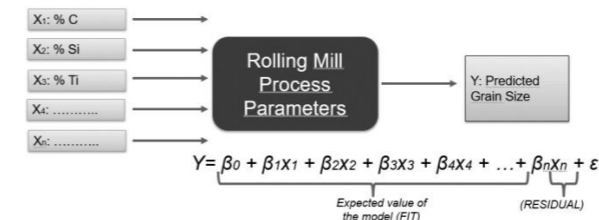
Grain size measurement are made under the microscope according to the ASTM E112 standard in the Metallography Laboratory. Samples cut in square millimeter sizes are analyzed with an optical microscope using software with image analysis technique, and the detected grains are marked and their values in the total area are found.

Disadvantages caused by this method;

1. Time spent in sample preparation
2. Scrap because of sample cut
3. Can be done after production

In order to estimate the grain size, the data of the past productions are used. The grain size of over 1600 pieces of 45 different qualities made in a laboratory environment. Micro alloyed and unalloyed steels ranging from 7.5 to 15 according to grain size ASTM-E112 were used.

In the statistical study, values such as sample thickness, coiling temperature, finishing mill temperature and reduction rates were used along with chemical analysis values. Multiple linear regression analysis was performed to find the best model predicting the metallography laboratory grain size measurement result with Minitab support.



**Figure 3.** Statistical Study Method Selection

The modeled Rsq value was found to be 75%.

The regression formula obtained from the determined inputs is as follows;

Regression Equation

$$\text{ASTM E112-13 Tane Boyutu} = 9.49 - 0.10365 \text{ Haddehane Kalinlik L3} - 8.048 \text{ C} - 1.422 \text{ Si} - 10.83 \text{ Ti} - 2.943 \text{ Mo} + 1.140 \text{ Mn} + 35.94 \text{ Nb} + 0.000008 \text{ PREHEAT\_ZONE\_TIME} - 0.398 \text{ HADDELEME\_ZORLUGU} - 0.000954 \text{ FM\_GIRIS\_SIC} + 0.01519 \text{ F2\_EZME} - 0.02434 \text{ F4\_EZME} + 0.00527 \text{ FM\_CIKIS\_SIC} - 0.001508 \text{ SARILMA\_SIC}$$

**Figure 4.** Grain Size Prediction Formula

### Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	9,49	1,00	9,48	0,000	
Haddehane Kalinlik L3	-0,10365	0,00928	-11,17	0,000	6,80
C	-8,048	0,541	-14,89	0,000	2,26
Si	-1,422	0,204	-6,98	0,000	1,48
Ti	-10,83	1,24	-8,71	0,000	5,06
Mo	-2,943	0,717	-4,10	0,000	2,03
Mn	1,140	0,103	11,06	0,000	7,10
Nb	35,94	1,71	21,03	0,000	6,46
PREHEAT_ZONE_TIME	0,000008	0,000004	2,17	0,030	1,03
HADDELEME_ZORLUGU	-0,398	0,182	-2,19	0,029	6,81
FM_GIRIS_SIC	-0,000954	0,000277	-3,44	0,001	1,34
F2_EZME	0,01519	0,00272	5,58	0,000	6,45
F4_EZME	-0,02434	0,00406	-5,99	0,000	6,07
FM_CIKIS_SIC	0,00527	0,00118	4,48	0,000	2,27
SARILMA_SIC	-0,001508	0,000266	-5,66	0,000	1,78

**Figure 5.** Statistical Data Coefficients

### 3. Results and Discussion

After the statistical study, the grain size has become modelable with an accuracy of +/- 0.5. In the modeling, as in the formulation in figure 4, there are chemical analysis, coiling and finishing mill temperature and reduction rates. The formulation obtained after this study is integrated into the level 4 system. The grain size that can be obtained for all coils currently produced has become reportable.

In addition, for the coils to be produced with the formulation, estimation can be made by realizing the average process parameter.

### 4. Conclusion

With the selected chemical element and hot rolling parameters, a mathematical model was created at the level of Rsq 75. In subsequent studies, a Quality based study will be carried out and the Rsq value will be higher, and the model will be studied with a low sensitivity, closer to the current measurement results.

With this study, it has been observed that the grain size can be determined without any practical material such as material cutting and sample preparation required for grain size measurement.

The determined formula results may vary according to production lines and qualifications.

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## Hadde Fırınlarında Rejeneratif Brülör Uygulamaları

Regenerative Burner Combustion System in Reheating Furnaces

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BCS ENERJİ MÜHENDİSLİK • Türkiye

### Abstract

Regenerative burner combustion system saves fuel consumption % 25 according to recuperator system and % 50 according to cold air burner system in existing rolling mill furnaces.

### Özet

Mevcut hadde fırınlarına rejeneratif brülör sistemleri uygulayarak, merkezi reküperatörlere göre % 25, soğuk hava ile çalışan brülörlere göre ise % 50 ye varan yakıt tasarrufu sağlanmaktadır.

### 1. Giriş

Rejeneratif sistemde amaç; bacadan atılan sıcaklığı maksimum derecede kullanabilmektir. Bunun için de sistemde baca görevini gören; rejeneratif brülörlerin arkasındaki kasalardır. Brülörler fırındaki havayı kendi üzerinden geçirerek içinde seramik toprak bulunduran kasalara iletir. Burada ısınan toprak, değişimden sonra gelen soğuk havayı ısıtıp yakma havası olarak brülöre verir. Kasaların çıkışında bacaya atılan egzoz sıcaklığı yaklaşık 70 °C- 150 °C civarındadır.

Rejeneratif Yakıtlar ile 1250 °C çalışma sıcaklığında % 90'lara varan sıcak hava verimi ile 1000 °C yakma havası sıcaklığına ulaşabilmektedir. Bu sayede de % 50'lere varan enerji tasarrufu sağlamaktadır.

### 2. Sonuçlar ve Tartışma

Rejeneratif brülörsüz ve hava ön ısıtmasız sistemlerde enerji kaybı fazladır. Rejeneratif brülör sistemleri atık ısıyı geri kazandıkları için %30'a varan yakıt tasarrufu sağlar. Fırında yanma verimliliği artar. Emisyon oranları azalır. Uygun kontrollerle, toplam işletme maliyetlerini ve yakıt maliyetleri düşer. Mamül kalitesi ve üretimi artar. Sera gazları ve CO2 emisyonu azalır, NOx ve karbondioksit emisyonları, soğuk hava brülörüyle karşılaştırıldığında sırasıyla %30-40 oranında azalır. Reküperatör sistem yakma havasını yalnızca 400 °C'ye kadar ısıtır; rejeneratif bir sistem yakma havasını 1150 °C'ye kadar ısıtır.

Rejeneratif brülörler metal endüstrisinde işletme maliyetlerini düşürmeye yardımcı olmaktadır. Boru çaplarında küçülme oluyor ve borularda izolasyon ihtiyacı ortadan kalkmaktadır.

	Cold Air	Recuperative 500 C Preheat	Regenerative	Oxy Fuel
Equivalent Burner Input (106Kcal/Hr)	8.09	5.27	3.54	3.54
Natural Gas (NM3)	909	594	399	399
Fuel Cost (\$)	192.40	125.80	84.40	84.40
Oxygen (NM3)	-	-	-	913
Oxygen Cost (\$)	-	-	-	80.52
Electrical Cost for Blowers (\$)	1.97	2.67	2.74	-
Total Cost/Hr (\$)	194.37	128.47	87.14	164.92

**Table 1.** Operating Cost Comparison Per Hour For 10 MM BTU/hr(2.52 x 106 Kcal/hr) Net Heat Input to Furnace



**Şekil 1.** Rejeneratif Brülör Uygulaması

**Teşekkür**

Başta bu sunum için bize fırsat veren Ekinciler firmasından Kadir Kara'ya, ve bu organizasyonu gerçekleştiren ISRS yürütme kuruluna çok teşekkür ederiz.

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## Latest Achievements on Rolling Mill Technology for the Production of Bars, Wire Rod and Profiles

•  
Çubuk, Kangal ve Profil Haddehane Teknolojilerindeki Son Kazanımlar

Andrea Diasparro

DANIELI & C. OFF. MECC. S.P.A. • Italy

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### INTRODUCTION

Being the world's leading supplier of long rolling mills, Danieli use various technological innovations to continuously keep the quality at its highest. With "H3 vision", Danieli identify the key factors for the success, distinguishing Danieli Rolling Mills with;

- High Productivity
- High Efficiency and
- High Quality

In this study you will see that there are several recent technological advances used in 4 different references which should be seriously taken into consideration by the investors in their feasibility studies for new Rolling Mill investments.

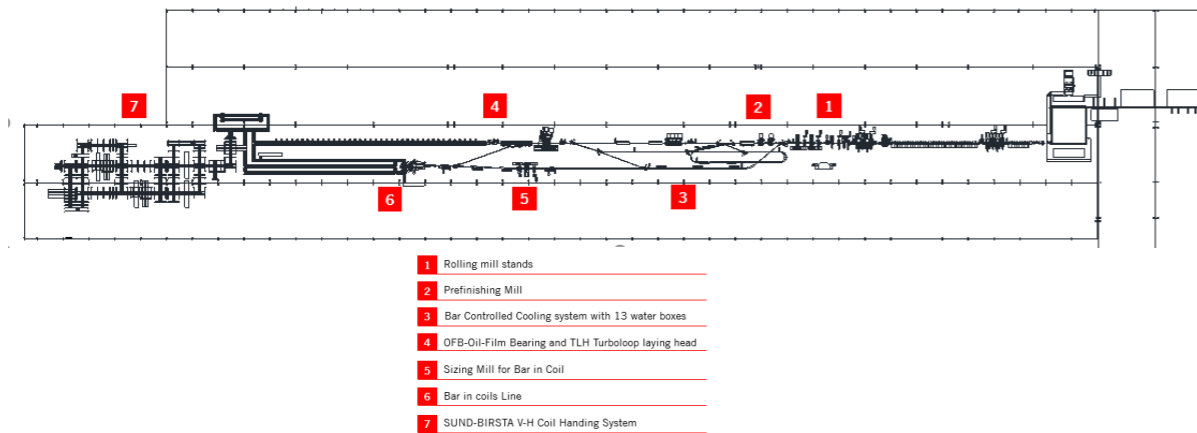
### DISCUSSION

Based on the high quality, high efficiency and high productivity needs of the existing market conditions, Danieli keep developing new state-of-the-art tailor made solutions for their customer demands. Here below there are 4 different projects, each one is a self-explanatory example of particular type of Long Product Rolling Mill having different product mix in terms of material size and characteristics along with different steel grades.

Danieli has selected those rolling mills to present, along with its latest technologies, solid data and concrete references in operation, having outstanding performances in terms of productivity, quality and efficiency.

This presentation differs from the typical marketing approach, entering into the technical characteristics of Rolling Mills already moved into production, along with operating data and achievements.

## 1- Voestalpine Donawitz Wire Rod & Bar in Coil Line - Austria



This Rolling Mill is counted as the latest technology for specialty steel production in coils. More than 500 steel grades with nearly 2000 specific chemistry and characteristics according to end users' applications and requirements are being produced in this state-of-the-art mill.

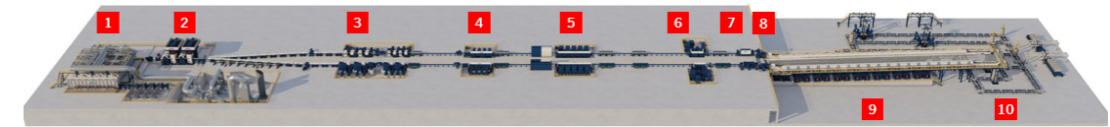
With this unique configuration, mill is designed to produce 500kt/y with full variety of grades composed of; Case hardening steels, Soft grades, Concrete steels, High carbon grades, Cold heading grades, Bearing steels, Welding wire, Cold Working steels, Free cutting steels, Spring steels. Thanks to Bar Controlled Cooling system with 13 different water boxes along with various loops and routes on the line, all these high value-added steel grades are possible to produce in this rolling mill, perfectly matching with the expected qualifications.

Finished product sizes are from 18 to 60 mm in Bar in coils line and from 5 to 25 mm in wire rod line. Thanks to TMB-Twin Module Block technology, product tolerances of +/- 0.1 mm with 50% ovality on the whole production range are possible to produce.

VAAD operators has been trained in a classroom with the help of Hi-Stand, that is a virtual pulpit integrated with a 3D real time simulation of the Plant connected to the automation system.

Software factory tests and operators training, performed with HiStand before start-up, granted good results of the controls from the early stages of the hot tests.

## 2- Acciaierie di Verona Wire Rod Line - Italy



- 1 Reheating furnace: 180 t/h
- 2 High Speed Roughing Mill (4 Housing-less stands)
- 3 Intermediate Mill 2x4 ESS cantilever stands
- 4 Prefinishing Mill 2x4 Multiple drive pre-finishing blocks
- 5 Finishing Mill 2x5 Multiple drive wire rod finishing blocks
- 6 Sizing mill: 2 TMB-Twin Module Blocks
- 7 HSS- High Speed Shear (patented)
- 8 2 oil-film bearing loop laying heads (patented)
- 9 DSC in-line heat treatment system
- 10 SUNDSCO-V Coil Handling and finishing services

As a result of very successful results in their previous rolling mill after long years, this project was taken as their second Wire Rod Mill from the same client. Configuration of the mill was designed as below, as per specific market expectations of our client to produce more than 750.000 tpy.

In this double strand wire rod line configuration, line is divided into 2 strands just after the roughing mill stands. In intermediate mill, ESS stands (cantilever) were used, providing major advantages compared to conventional housingless stands.

For both lines Fast Finishing Blocks and Twin Module Block technology are used for a perfect operation also providing the Low Temperature Rolling (LTR) and Normalized Rolling capabilities. LTR capability of the mill is giving the flexibility of reducing alloying elements without effecting the final mechanical properties of the products.

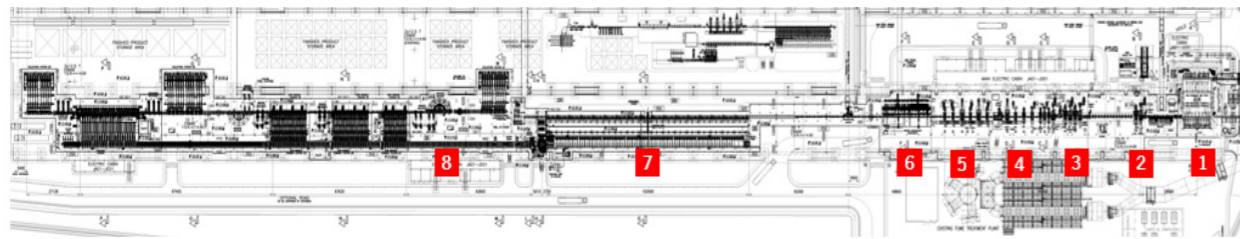
Patented Oil Film Bearing Loop Laying Head and High-Speed Shear technologies are providing the highest quality along with Danieli Structure Control (DSC) in-line heat treatment system. DSC system includes water cooling lines and latest version of cooling conveyor design in it. Cooling boxes equipped with beams for the elements pre-setting, to guarantee perfect alignment and reduce the changing times (cooling set change with beams in less than 10min vs. 40÷50min for conventional element-by-element change). Cooling conveyor system is designed with following features;

- Roller conveyor with multi-step configuration and modular design
- Process flexibility guaranteed by the presence of heat retaining hoods for slow cooling and centrifugal fans for forced air cooling
- Maximized cooling efficiency and reduced noise emissions thanks to the special design of the air dumpers and electro-fans equipped with silencers (102 dB on top of cooling conveyor at 2m from noise source)

With this configuration, this mill is designed to produce 750,000 tpy considering a product mix of Low Carbon, Medium Carbon, High Carbon, Micro Alloyed, Engineering grades.



### 3- Deacero Ramos Arizpe - Mexico



- 1 Reheating furnace capacity: 120 t/h
- 2 High-speed Roughing Mill: 2 SHS Housingless stands
- 3 Roughing Mill 4 SHS Housingless stands
- 4 Intermediate Mill 8 SHS Housingless stands
- 5 Finishing Mill 6 SHS housingless stands
- 6 Water Quenching System QTB System for high tensile rebars
- 7 Cooling Bed: Rake type 102x12 m
- 8 Finishing Services: Cold Cutting-to-Length system, counting, sub-bundling, main bundling, bending, weighing and final collecting facilities

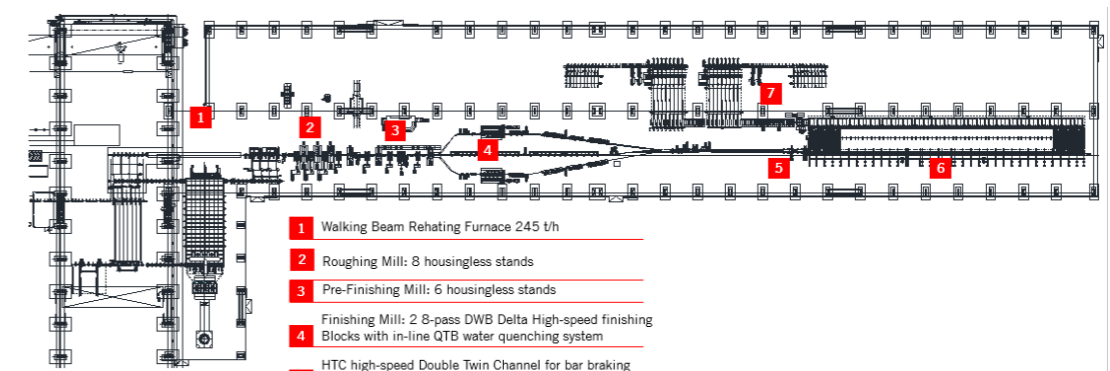
With the above given layout, this rolling mill is designed to produce a wide range of products such as merchant bars, profiles & sections, rounds and rebars.;

This mill is equipped with 5 strand slitting technology. Danieli is the first plant-maker in the world multi-slitting technology to produce 5 strands rebar from 5x8 up to 5x12 mm. Comparing the production costs of 8mm at 13 m/s (3 strands vs 5 strands) we have:

- > Productivity increasing by 38%
- > 10% saving in production costs (20% less energy consumption KWh/Ton)

In this configuration, one of the main points to indicate is the QTB system used for process control. Quenching & Tempering Bars “QTB” process, with low carbon steel as base material and mechanical properties achieved thanks to bar quenching process or grain size refinement on bar surface. Thanks to the “close loop control”, an in-line self-adjusting system being part of the automation process control, it is possible to achieve a temperature variation through the bar length not bigger than  $\pm 10^{\circ}\text{C}$ .

### 4- Shaded I.&s. Co



- 1 Walking Beam Reheating Furnace 245 t/h
- 2 Roughing Mill: 8 housingless stands
- 3 Pre-Finishing Mill: 6 housingless stands
- 4 Finishing Mill: 2 8-pass DWB Delta High-speed finishing Blocks with in-line QTB water quenching system
- 5 HTC high-speed Double Twin Channel for bar braking and discharging onto cooling bed
- 6 Rake type cooling bed: 102 x 12 m
- 7 Bar Finishing Services: Cold cutting-to-length system, twin bar counting and bundling services, short bar recovery, tying and final collecting facilities

The bar mill installed at JSPL Shaded (Oman) is designed to have the most productive performances for the rolling of deformed bars;

When all these technological features combined with the experience of our client, they now have a very productive plant under operation and recently they have already broken a production world record relevant to deformed bars metric tons in one day. To match with the requirements of such high-speed line, highly productive finishing lines for superior quality bar bundles have been implemented in this rolling mill, as well. Bar counting station has 99,9% counting accuracy with the ultra-compact design

All above mentioned technological solutions are of course available with a perfect match of automation systems which is a result of more than a 100 years of experience in the field. Danieli Automation fully integrated system for process technology and equipment control guarantees a fast learning curve and continuous data analysis to lead the steel producers to continuous improvement in quality and performance. For instance, for a perfect wire rod production, there are 4 instruments implemented in the system;

To succeed with the First Billet in Quality we developed a set of on-line instruments.

At the mill end, innovative lighting system and high speed cameras are applied to HiNSPECT to detect surface defects. The second sweet donut is HiProfileLite for contour measurement.

With the Infrared speed meter at the TMB exit we can provide to the laying head the right speed reference. A perfect loop formation is therefore granted since the first billet of a campaign.

The next step will be the transform of those three into all-in-one instrument.

Than Hi-Section completes the panorama for a perfect mass flow control to adjust roll gaps accordingly to reduce the roll wears significantly.

With the up-to-date requirements of Industry 4.0, all these huge amount of data is conveyed into the multidimensional analysis database of our Q3 Intelligence tool, which is a business intelligence application dedicated to steel production. Thanks to all these features, outstanding figures and utmost plant availability results give a high plant production capacity along with flexibility to cope with sudden market demands and changes.

## High Quality Wire Rod and Bar Production at YongXing Special Stainless Steel

YongXing de Yüksek Nitelikli Kangal ve Çubuk Üretimi

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### Abstract

A new combination bar, bar in coil and wire rod mill has recently been commissioned at YongXing Special Stainless Steel Co. Ltd. In Huzhou City, China. The mill is designed to produce 250,000 tons per year of stainless valve steels, nickel-based alloy steel and numerous stainless grades, including austenitic, ferritic, dual phase and hardening steels. As production in the new mill continues to increase, YongXing is able to meet demands of customers seeking special grades for applications in the nuclear, automotive and petrochemical industries, among others, affirming their position as a top stainless steel supplier in China. This paper presents several equipment and process innovations incorporated into the new mill design and examines the initial results.

### 1. Introduction

YongXing Special Stainless Steel Co., Ltd (YongXing) specializes in the development and production of special stainless steel rod and wire, mainly used in petrochemical, basic energy, equipment manufacturing and other industrial fields.

The recent evolution in the industry has also led to a severe lack of skilled/experienced workers. The previous generation of workers could rely on their experience to optimize aging equipment and process practices. Now, the key to success in sustaining/improving operations is to replace outdated equipment with new technology and increase the level of automation in a new facility. The installation of a modern mill can provide consistent operations with higher speeds, less maintenance and downtime, and longer wear part life for more up time between changes, and as little operator intervention as possible.

### 2. Project Details

#### 2.1. Products and processing

YongXing produces wire rod and bar products for applications in nuclear and petrochemical industries,

among others. Grades rolled in the combination mill are principally various stainless steels and nickel-based alloys. The stainless steels include austenitic, ferritic, martensitic, welding, vulcanized, dual phase and hardening grades, plus austenitic and martensitic stainless valve steels.

YongXing rolls a wide range of sizes to satisfy the specialty steel market – wire rod from 4.5 – 16.0 mm, bar in coil from 16.0 – 40.0 mm and straight bar from 30.0 – 130.0 mm. The wire rod is formed into coils with an outer diameter of 1,250 mm and an inner diameter of 850 – 900 mm. The bar in coil package has an outer diameter of 1,250 mm and an inner diameter of 850 mm. Straight bar bundles are made in lengths from 6 – 12 m.

Starting billets for the stainless steel grades are either 220 mm, 180 mm or 150 mm square, from 6 - 7 m in length and weights from 1,200 – 1,800 kg. The nickel-based alloy billets are 120 mm round, with a length of 7 m and weight of 612 kg. The mills are designed to roll at a maximum speed of 80 m/s with production rates up to 62 t/h. Yearly production for the new mill is expected to be approximately 250,000 t.

#### 2.2. Rolling mill equipment

A significant amount of equipment was provided to YongXing for the new mill, including a new reversing breakdown mill and a 3-roll sizing block in the main roughing and intermediate mill trains. The straight bar line included a cooling bed run-in table with brake slide, cooling bed, plus bar handling with hot saws and bar counting. Automated bar bundling and binding prepare the finished bar for storage and shipment.

The wire rod line equipment included a 680 shear, a 10-stand Morgan Vee No-Twist® Mill, 4-stand Morgan Reducing/Sizing Mill, Morgan Water Boxes, Morgan Intelligent Pinch Roll and Morgan High Speed Laying Head. For controlled cooling, a 4-zone Morgan Stelmor® Conveyor was installed, ahead of a new stepless coil reforming station.



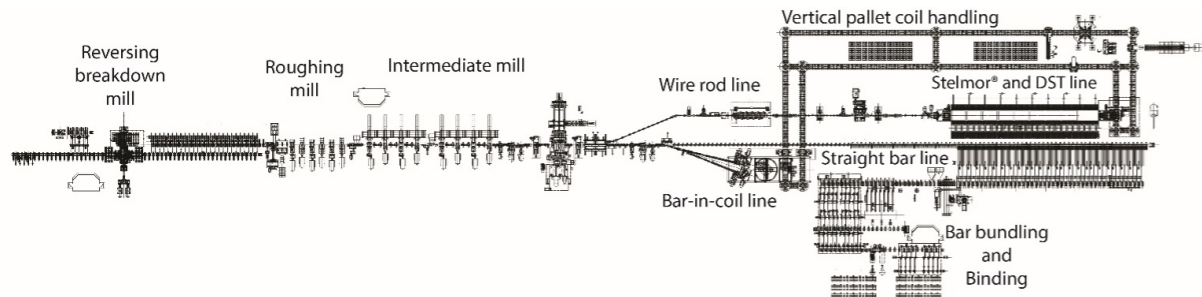


Figure 1. Mill layout.

The bar in coil line was configured with pouring reels and coil quenching tanks for heat treatment of the coiled product. Coil handling of both bar in coil and wire rod coils was combined in a common system with vertical stem pallets and a vertical coil compactor. Figure 1 above shows the overall layout of the rolling mill

#### Bar line - mill

The breakdown mill is a housing-less reversing sliding stand, with RedRing® design (see Figure 2). Grooves are changed according to pass design by sliding the stand transversally to the rolling line, which remains fixed. Between subsequent passes, rotating devices turn the bar under rolling. The sliding breakdown has a 940 mm maximum roll centerline distance and a 1,800 mm roll barrel length.



Figure 2. Reversing sliding breakdown with bar rotating.

The roughing, intermediate and pre-finishing trains are all composed with fifth-generation RedRing stands, scaled in three sizes, with maximum roll openings variable from 450 to 750 mm. The fifth-generation RedRing features components with extended life duration, such as nitrided high-hardness surfaces for reduced friction and increased resistance to oxidation and wear.

#### Bar line – cooling bed

In order to cover the complete size and speed range, a 1,400 mm dual ratio crop and divide shear with 600 mm chopping shear is used for dividing sizes  $\leq 60$  mm. For sizes greater than 60 mm, no divide cuts are necessary due to the length of the cooling bed. The cut length optimization software adjusts the primary cut lengths to the cooling bed to minimize yield losses. The tail end of the last bar can be cobble cut or collected at the short bar recovery after the abrasive saws.

The approach table has individually driven horizontal rollers that are gradually inclined to match the incline of the run-in roller table. The brake slide, as shown in Figure 3, lifts the bar off the run-in table rollers to allow braking of the bar under friction before discharge onto the cooling bed. Wear-resistant plates prevent scratching of the bars prior to the lifting of the brake slide.

For conventional operation the bars are deposited from the brake slide onto the straightening grid of the cooling bed. Variable speed moving rakes, advance the bars one notch at a time from the straightening grids to the fixed rakes. Fast transfer across the cooling bed is also provided to deliver products to the slow cooling bins at elevated temperatures. In this case, the bars are cut to final commercial lengths before depositing them into the slow cooling bins

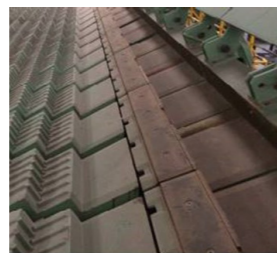


Figure 3a. Brake slide to the cooling bed.



Figure 3b. Cooling bed with walking beams and aligning rollers.

#### Bar line – sawing systems

EVO abrasive disc saws, Figure 4, enable cutting several different sizes, shapes and grades with the same machine, improving operational flexibility. This high-speed, fully automated process allows full production capability of the plant with high-quality cuts to prevent product surface cracks or undesirable hardening effects. Both hot and cold materials may be processed and all the cutting parameters are system-controlled, including sample cuts and removal, disc wear compensation.



Figure 4. EVO Abrasive Disc Saw.

#### Bar line – bar counter

The patented bar counting system at the entry to the bar bundling area provides the accurate and reliable piece count of the bars as they are transported to the stacker. The autonomous system consists of illumination of the ends of groups of bars as they pass on the conveyor, an image processing camera, and ancillary components.

#### Bar line – bar bundling and binding

The bundle-forming station includes three independently driven chain sections. The first is a buffer chain section accumulating bars that cannot be advanced to the next section. The second section pre-selects a fixed number of bars for feeding into the bundle-forming cradle. The third section feeds the bars to the bundle-forming cradle. Figure 5 shows the bundle-forming station arrangement.

#### Wire rod line – shears

A 680 mm continuously rotating divide shear arrangement, preceded by a pinch roll unit, is used for front and tail end crop cuts which are collected in scrap buckets below mill floor level. In case of production interruptions downstream, the shear makes a divide cut and chops the bar.



Figure 5. Bundling station and tying machines.

#### Wire rod line – Vee No-Twist® Mill

The Vee No-Twist Mill, Figure 6, can be configured with 250 mm, 230 mm or 160 mm cantilevered roll housings, depending on the processing requirements and product size range. Roll housings are interchangeable, allowing the mill configuration to be changed to increase the mill's product size range (4.5 mm to 26.0 mm) or enhance the processing requirements, depending on the future demands of the world market. For this application, a 10-stand 16 % average reduction Vee No-Twist Mill was installed with a 230 mm ultra heavy-duty (UHD) roll housing providing the optimum configuration for the size range specified as well as reduced roll cost and improved section control



Figure 6. Morgan Vee No-Twist Mill.

#### Wire rod line – Reducing/Sizing Mill

The patented Morgan Reducing/Sizing Mill (RSM) serves as a post-finishing mill block. More than 70 strands of RSMs have been installed worldwide.

A two family rolling method is used in conjunction with the 16% average reduction No-Twist Mill to restrict the overall reduction of the special stainless and nickel alloy products. A single roll groove setup is used in each stand, from the first stand in the roughing mill to the last stand in the



finishing mill, to produce the necessary feed sections to the rod outlet, which simplifies mill setup, improves yield through reduced number of cobbles and elimination of trial bars. It also significantly reduces the roll and guide changes, and therefore the need to maintain their inventory. The mill's design provides for future off-line roll units and the quick-change transfer car to allow size changes to be made within five minutes. As a result, even when the rolling rate or finishing speed has not been significantly increased, the mill is still capable of improving its productivity through increased operating efficiency with the reduction in downtime for roll changes.

The RSM also provides improved product tolerance and ovality – typically  $\pm 0.1$  mm tolerance and 0.12 mm ovality. With special steel products, the ability to produce a close-tolerance product reduces the amount of peeling required, resulting in large savings during post-rolling operations.

In addition, experience with the oval-round-round-round pass sequence in many mills has shown that the overall pass life is double that of conventional rolling, thereby reducing the downtime for pass changes. This pass sequence is also beneficial to wire drawers and other post-rollers, since it minimizes circumferential surface variations at the parting areas.



Figure 7. Morgan Reducing/Sizing Mill.

#### Wire rod line – water boxes

A common limitation in rod and bar mills is the control of product temperature through the process line. In many cases, there is a lack of cooling capacity, making difficult the control of mechanical and metallurgical properties, as well as amount and type of scale. Product quality requirements, particularly for specialty grades like those produced at YongXing, have therefore driven many mills to install latest technology water box systems that offer efficient cooling with components that are easy to maintain. The Primetals Technologies split bore cooling nozzle design allows operators to quickly and easily open a nozzle for inspection or cleaning.

#### Wire rod line – pinch roll and laying head

The Morgan High Speed Laying Head was developed to operate at high speeds and has achieved a good reputation for reliable high-speed operation. Numerous mills have upgraded their laying head and pinch roll systems in recent years to increase production, reduce manpower, improve yield and ensure consistent product quality.

Recent developments have led to even better performance at high speeds, with extremely low vibration levels. Also, a significant advancement in the technology of the laying head pipe, the patented SR Series® pipe, now enables the rolling of many, many more tons of small diameter products at high speeds – resulting in a dramatic reduction in downtime for pipe changes.

The success of the laying head and pinch roll system is also dependent on the mechatronics package that is integral to an equipment upgrade. This system provides for consistent coordination of speeds between the units, for repeatable front end positioning of each coil, fine control of ring diameter and wobble adjustment for large sizes. The Morgan Intelligent Pinch Roll incorporates servo control of pinch force and position, closed loop control of pinch force and speed, plus rapid and repeatable roll close times.



Figure 8. Morgan High Speed Laying Head and Pinch Roll

#### Wire rod line – Stelmor® conveyor

The Stelmor controlled cooling system incorporates a wide range of processing conditions, including both fast and slow or hybrid fast and slow cooling in a single system to produce a wide spectrum of plain carbon, alloys, and stainless steel grades. This flexibility, coupled with controlled temperature rolling, allows more grades to be produced in a directly useable condition, thus eliminating or accelerating downstream processes such as recrystallization and solution treatment.

For slow cooling, the Stelmor is equipped with insulated covers which can be closed to retard the cooling rate. Solid conveyor rollers on the conveyor deck are designed to dissipate heat transferred from the rings during slow

cooling, thus preventing distortion and reducing maintenance requirements. For YongXing, this operating mode is specifically used for martensitic stainless steels that will be heat treated off-line.

Immediately after the entry section is a curved traversing zone that directs product to either the Stelmor conveyor or Direct Solution Treatment (DST) line (Figure 9). This is used for direct charging of the coils on the conveyor into the solution treatment furnace for annealing/slow cooling through isothermal transformation of stainless steel grades.



Figure 9. Morgan Stelmor Conveyor and DST line.

#### Wire rod line – coil reform

Integral to the reform tub is the ring distributor system, with a specially designed rotating blade to guide the rings as they fall, creating a well-ordered coil package. At YongXing, the new, patented stepless reform station replaces the conventional long tub assembly that had fixed position iris fingers. In the new design, a dual coil plate arrangement supports the forming coil with independent drives for each. The two coil plates maintain a constant distance from the bottom of the ring distributor to the top of the forming coil during the forming cycle, eliminating the conventional system's crop between iris fingers and coil plate.



Figure 10. Stepless reform station.

#### Bar-in-coil line – pouring reels

A high-speed switch located immediately before the rollerized turn-down directs alternating bars within the billet gap into the individual pouring reels, providing sufficient time to transfer the coils from the reels onto the walking beam cooling conveyor. The turn-down utilizes three cluster rollers to prevent scratching of the bar. These roller clusters are water cooled and air/oil lubricated for long life and reduced maintenance.

Pinch rolls are located close to the pouring reels for control of tail ends as they enter the reel and are traversable to allow quick change between the grooves required to cover the complete size range and include hydraulic roll mounting. The pouring reels are equipped with wear strips on the outer rotating drum to prevent mechanical damage during the formation of the coil. An elevating coil plate assembly incorporated in the reel removes the coil from the tub. A coil transfer mast transports the coils from either of the two pouring reels and delivers them directly to either water quenching tanks or the vertical pallet system (Figure 11).

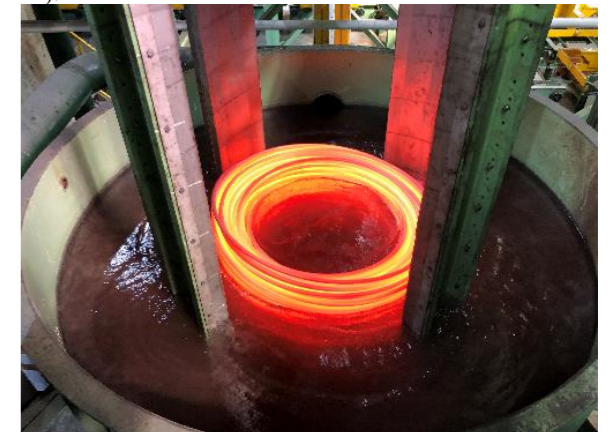


Figure 11. Pouring reel outlet with water quenching tanks.

#### Wire rod and bar-in-coil line – coil handling and compacting

A common vertical pallet coil handling system used to transport both the wire rod from the Stelmor or Direct Solution Treatment lines and bar in coil products to either the slow cooling pits or unloading station for internal transportation to off-line annealing and pickling facilities. The vertical pallet system has been designed with the flexibility to ensure the shortest transport time to allow the coils to be delivered to the slow cooling pits as quickly as possible, while also providing sufficient cooling distance to ensure low coil temperatures prior to trimming and compacting.





Figure 12. Vertical pallet coil handling system.

### 3. Results

#### 3.1. Production experience

The newly expanded combination wire rod, bar in coil and bar mill in Huzhou has been installed and has begun production.

The wire rod and bar mills are ramping up their production with a focus on the commercial austenitic stainless steel grades such as 201Cu, 204Cu, 303Cu, 304DC, 304H, 304HC (1, 2 & 3), 304L, 304S, 316 and 316L. Harder stainless grades such as ER2209, ER 309LSI and Nickel Alloys will begin their initial testing in the upcoming months.

The contracted mill production rates and finishing speeds have been achieved on grades rolled to date with a maximum finishing speed of 80 m/s and rolling rate of 62 t/h for all rod sizes and bar in coil sizes < 40.0 mm.

Very good product tolerance has been achieved on all rod and bar products, with all rod products achieving the guaranteed tolerance of  $\pm 0.1$  mm with an ovality  $\leq 0.12$  mm. For many sizes these performance parameters have been exceeded (Figure 13). The only rod product size remaining to be rolled is 4.5 mm.

A major focus of the mill performance is related to surface defects. Many improvements have been made to reduce the defect depth especially on the rod and bar in coil lines. Surface defect depths of 0.04 mm are being achieved consistently on rod sizes  $\leq 8.0$  mm and between 0.04 to 0.08 mm on rod sizes  $> 8.0$  mm. Bar in coil product surface defect depths are typically 0.08 to 1.0 mm; however, additional testing on reducing these depths to levels consistently  $< 0.08$  mm are currently underway.

From a metallurgical properties standpoint, the mill has been able to meet or exceed the performance parameters for the grades and sizes rolled to date. Tables 1 and 2 below show comparisons between the on-line and traditional off-line heat treatment processing routes for both rod and bar in coil products.

#### 3.2. Customer response

Improved dimensional tolerance and surface quality has provided yield savings to the downstream processing lines due to reduced peeling after pickling. Production of rod sizes  $\leq 5.5$  mm has reduced the downstream wire drawing cost to produce fine wire.

Based on the above product tests, the material quality is more uniform with respect to grain size through the on-line heat treatment process route compared with off-line. This has already met the higher material property requirements for spring wire and valve steel grades. In addition, the on-line heat treatment cost is less than 50% of the traditional off-line heat treatment cost.

#### 4. Conclusion

The mill has successfully demonstrated the ability to produce high-quality stainless steel products with superior dimensional tolerance, surface quality and mechanical properties. This, coupled with high operating flexibility, allows the mill to support short delivery cycles while maintaining a high operating efficiency by minimizing downtime due to reduced family rolling and quick-change capabilities. Increased productivity and reduced conversion cost through in-line heat treatment puts YongXing Special Steel in a dominant and unique position in the Chinese market.

With the continuing focus on rolling harder stainless grades with enhanced properties, the new mill will allow YongXing Special Steel to better service and expand their existing customer base within China and the export market to Europe and the United States.

No-Twist, SR Series and Stelmor are registered trademarks of Primetals Technologies USA LLC. RedRing is a registered trademark of Primetals Technologies Italy S.r.l.



Figure 13. Finished product tolerances.

Table 1. Comparison of heat treatment process for rod products.

Grade	Size [mm]	Wire Rod Products				
		Property	Stelmor	Direct Solution Treatment	Off-line Treatment	
304HC	7.5	Mechanical Property	Tensile Rm (MPa)	578	519	513
			Elongation A(%)	56	64	67
			Reduction Z(%)	80	82	83
		Grain Size (ASTM No.)	9.5 - 10	4.5 6-	3.5 - 5 Partial 1.5 - 2.5	
304HC1	7.5	Mechanical Property	Tensile Rm (MPa)	588	529	525
			Elongation A(%)	58	68	70.4
			Reduction Z(%)	80	83	81.8
		Grain Size (ASTM No.)	9.5 - 10	4.5 - 6	3.5 - 5 Partial 1.5 - 2.5	
304HC3	7.5	Mechanical Property	Tensile Rm (MPa)	572	511	505
			Elongation A(%)	54	61	62
			Reduction Z(%)	79	82	81
		Grain Size (ASTM No.)	9.5 - 10	4.5 - 6	3.5 - 5 Partial 1.5 - 2.5	

Table 2. Comparison of heat treatment process for bar in coil products.

Grade	Size [mm]	Property		Water Quench	Off-line Treatment
304D	18.0	Mechanical Property	Tensile Rm (MPa)	582	554
			Elongation A(%)	58	58
			Reduction Z(%)	78	77
		Grain Size (ASTM No.)	8 - 9	2.5 - 4.5	
304HC	16.0	Mechanical Property	Tensile Rm (MPa)	560	503
			Elongation A(%)	53	55
			Reduction Z(%)	78	80
		Grain Size (ASTM No.)	8 - 9	3.6 - 6	
304D	16.0	Mechanical Property	Tensile Rm (MPa)	580	542
			Elongation A(%)	59	60
			Reduction Z(%)	79	79
		Grain Size (ASTM No.)	8 - 9.5	2 - 4.5	

## SAE 1080 Kangal Kalitesinde Soğutma Hızı, Kimyasal Analiz ve Çapın Mekanik Özellikler ve Mikroyapı Üzerine Etkisi

The Effect of Cooling Rate, Chemical Analysis and Diameter on the Mechanical Properties and Microstructure in SAE 1080 Wire Rod Grade

Serdar Günbay, Cemre Keçeci, Erdi Gönülalan, Ahmet Sağlam

İSKENDERUN DEMİR VE ÇELİK • Türkiye

### Abstract

In the present work, influence of different cooling rate, chemical analysis and diameter on the mechanical properties and microstructure in SAE 1080 Wire Rod Grade during the process of wire rod rolling. Ø11 and Ø13 mm diameters were used in the study. It is aimed to optimum strength and microstructure. CCT / TTT diagrams were acquired by using JMatPro software transformation temperatures were determined. According to the diagrams obtained, wire rod produced with same laying head temperatures (880 °C) in different chemical compositions for each diameter, were subjected to cooling with a cooling rate of between 3-16 °C/sec. The mechanical and microstructure results were examined after trial productions. The aimed mechanical properties were not provided at all cooling rates.

### Özet

Bu çalışmada, kangal haddeleme işlemi sırasında kangal kalitesinde farklı soğutma hızı, kimyasal analiz ve çapın mekanik özellikler ve mikroyapı üzerindeki etkisi incelenmiştir. Çalışmada Ø11 ve Ø13 mm çaplara yönelik üretim gerçekleştirilmiştir. Optimum mukavemet ve mikroyapı amaçlanmaktadır. JMatPro yazılımı kullanılarak CCT/TTT diyagramları çıkarılmış, dönüşüm sıcaklıkları belirlenmiştir. Elde edilen şemalara göre, her çap için farklı kimyasal bileşimlerde aynı serme kafa sıcaklıkları (880 °C) ile üretilen kangallar, 3-16 °C / sn arasında bir soğutma hızı ile soğutmaya tabi tutulmuştur. Deneme üretimlerinden sonra mekanik ve mikroyapı sonuçları incelenmiştir. Amaçlanan mekanik özellikler tüm soğutma hızlarında sağlanmamıştır.

### 1. Giriş

Çalışması yapılan SAE J403 1080 kalitesi alaşımly yüksek mukavemetli karbon çelikleri olarak nitelendirilmekle beraber ön gerilemeli beton demeti (PC strand) olarak kullanılmaktadır. İSDEMİR'de sipariş çelik kalitesi olarak 1.1082\_01 ve 1.1082\_02 kalite kullanılmakta olup Ø5,5-16 mm arası üretim gerçekleştirilmektedir.

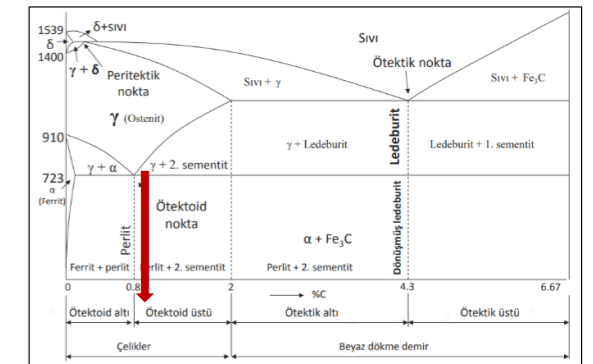
Kangal haddehanesinde tavlanan 130X130 mm ebatlarına sahip kütük, kaba grupta 9 tezgah sonrası Ø40-45 mm çapa, 1.ara grup 4 tezgah sonrası Ø25 mm çapa, 2.ara grup 2 tezgah sonrası Ø18 mm çapa indirilir. Finish grubunda dikey ve yatay 15 tezgahtan Ø5,5-16 mm çapa indirgenen kangal 4 bölgele soğutma bölgelerinde soğutulurak hedef sıcaklık olan 880°C ile serme kafadan düşürülmektedir.

Çalışmaya konu olan SAE 1080 kangal kalitesinde müşteriler kangal çekilebilirliği iyi bir mikro yapı ve uygun mukavemet değeri talep etmektedir. Çekme mukavemeti Ø11 ve Ø13 mm çapın talep edilen mukavemet değerleri ~1200 MPa dır. Kimyasal analiz limitleri Çizelge 1.'de verilmiştir.

Çizelge 1. Kimyasal Analiz Limiti

	Kimyasal Kompozisyon (%)				
		C	Mn	Cr	V
1.1082_01	Min	0,81	0,67	0,25	0,030
	Max	0,84	0,77	0,3	0,050
1.1082_02	Min	0,81	0,67	0,17	0,015
	Max	0,84	0,75	0,22	0,025

Ötektoid üstü çeliklerde %C miktarı arttıkça tane sınırı sementit miktarı da artmaktadır.(Şekil 1)Ötektoid üstü



Şekil 1. Fe-C Faz Diyagramı



çeliklerde östenitik bölgeden soğutulduğunda, sıcaklık Ac<sub>m</sub> hattının altına ulaştığında, ana östenitik tanelerin tane sınırlarında sementit fazının oluşumu başlar. Ac<sub>m</sub> ve A<sub>1</sub> sıcaklıkları arasındaki hızlı soğutma tane sınırı sementit oluşumunu azaltacaktır.

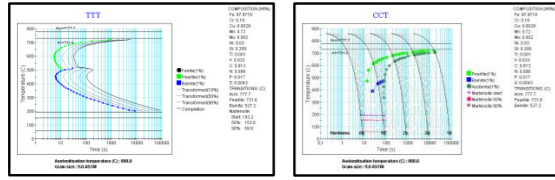
## 2. Deneysel Çalışmalar

Çizelge 2'de verilen analize uygun olarak olarak JMatPro yazılımında Şekil 2-3'da verilen Advance CCT ve TTT diyagramları çıkarılmıştır.

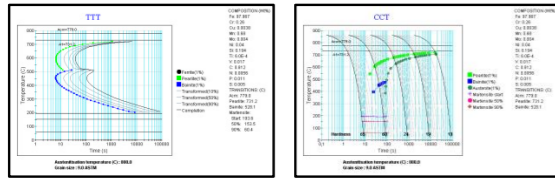
880°C serme kafa sıcaklığında Çizelge 3'deki soğutma hızları verilmiştir.

**Çizelge 2.** Çalışmada kullanılan SAE 1080 Kalite Kargal Kimyasal Kompozisyonu

Döküm No	Kalite	C	Mn	Cr	V
1	1.1082_01	0,81	0,72	0,26	0,033
2	1.1082_02	0,81	0,68	0,19	0,017



**Şekil 2.** 1 Nolu Döküme ait TTT ve CCT diyagramları



**Şekil 3.** 2 Nolu Döküme ait TTT ve CCT diyagramları

Kargal Haddehanesi'nde üretimler ön çalışmalardan sonra yapılmıştır. Elde edilen diyagramlara, aynı kimyasal özelliklere sahip aynı çaptaki kargallara, aynı serme kafa sıcaklığında farklı soğutma hızlarına göre deneme üretimleri gerçekleştirilmiştir.

**Çizelge 3.** Stelmor® Konveyör Hattı Soğutma Hızları

Kalite	Ebat	Döküm No	Serme Kafa Sıcaklığı (°C)	Deneme No	Ortalama Soğutma Hızı (°C/sn.)
1.1082_01	13	1	880	1	13
				2	9
				3	3
1.1082_02	11	2	880	1	16
				2	11
				3	4

Deneme üretim sonucuna mekanik özellikler ve mikroyapı incelemeleri yapılmıştır.

## 3. Sonuçlar ve Tartışma

Deneme üretimi Çizelge 2.'deki kimyasal analize ve Çizelge 3.'deki çap ve soğutma hızlarına göre yapılmıştır.

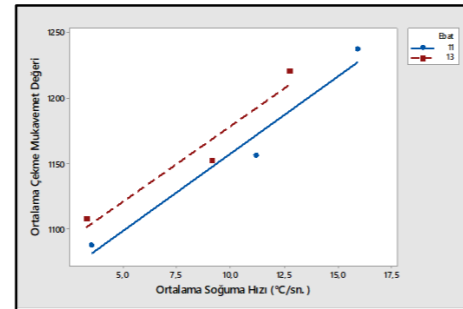
Deneme üretimlerine ait kargal numuneleri mikroyapı ve mekanik özellik açısından incelemeye tabii tutulmuştur.

Çizelge 4.'de kargal numunelerine TS EN ISO 6892-1 standardına uygun olarak mekanik test yapılmıştır.

**Çizelge 4.** Deneme Üretimine Mekanik Özellik Sonuçları

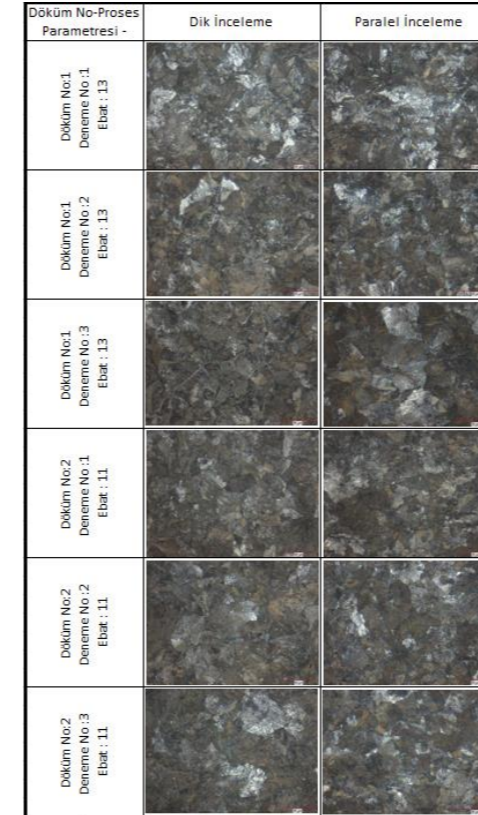
Kalite	Döküm No	Çap (mm)	Deneme No	Ortalama Çekme Mukavemet Değeri (MPa)	Ortalama Uzama Değeri (%)	Ortalama Kesit Daralma Değeri (%)
1.1082_01	1	13	1	1220	11	20
			2	1152	12	26
			3	1108	14	27
1.1082_02	2	11	1	1237	11	23
			2	1156	14	35
			3	1087	15	31

Çekme mukavemetinin soğutma hızı ve çap ile ilişkisi Şekil 4.'de gösterilmiştir.



**Şekil 4.** Soğutma Hızı ve Çapın Çekme Mukavemetine Etkisi

Mikro yapı sonuçları Şekil 5 'da gösterilmiştir. Mikroyapı incelemesine tabii tutulan kargal numuneleri ASTM E3 - 11 standardına göre hazırlanıp incelenmiştir. Numuneler %3 lük Nital dağılayıcı ile incelenmiştir.



**Şekil 5.** Çizelge 4'de verilen Kargal Haddehanesi Endüstriyel Deneme Üretimleri Ait X500 büyütmede Dik ve Paralel Mikroyapılar

## 4. Sonuç

Yapılan çalışmada ön gerilemeli beton demeti (PC strand) olarak kullanılan SAE 1080 (1.1082\_01 ve 1.1082\_02 ) kargal kalitelerinde farklı ebatlarda soğutma hızına bağlı olarak mekanik özellik ve mikro yapı sonuçları incelenmiştir.

JMatPro yazılımında Advance CCT ve TTT diyagramları çıkarılarak belirlenen soğutma paternlerine göre Kargal Haddehanesinde endüstriyel deneme üretimleri alınmıştır. Deneme üretimlerinde aynı ebat ve aynı döküm analizine sahip farklı soğutma hızlarıyla üretilen kargalların mikroyapı ve mekanik sonuçları incelenmiştir.

Ø11 mm çapta deneme üretimlerinde;

- Düşük soğutma hızına ait kargallarda ortalama çekme mukavemet değeri 1087 MPa, ortalama uzama değeri %15, ortalama kesit daralması değeri %31 dir. Yapıda herhangi bir sert faz tespit edilememiştir.

- Orta hızda soğutma hızına ait kargallarda ortalama çekme mukavemet değeri 1156 MPa, ortalama uzama değeri %14, ortalama kesit daralması değeri %35 dir. Yapıda herhangi bir sert faz tespit edilememiştir.
- Hızlı soğutma hızına sahip kargallarda ortalama çekme mukavemet değeri 1237 MPa, ortalama uzama değeri %11, ortalama kesit daralması değeri %23 dür. Yapıda herhangi bir sert faz tespit edilememiştir.

Ø13 mm çapta deneme üretimlerinde;

- Düşük soğutma hızına ait kargallarda ortalama çekme mukavemet değeri 1108 MPa, ortalama uzama değeri %14, ortalama kesit daralması değeri %27 dir. Yapıda merkez bölgede tane sınırında sementit fazı tespit edilmiştir.
- Orta hızda soğutma hızına ait kargallarda ortalama çekme mukavemet değeri 1152 MPa, ortalama uzama değeri %12, ortalama kesit daralması değeri %26 dir. Yapıda herhangi bir sert faz tespit edilememiştir.
- Hızlı soğutma hızına sahip kargallarda ortalama çekme mukavemet değeri 1220 MPa, ortalama uzama değeri %12, ortalama kesit daralması değeri %20 dür. Yapıda herhangi bir sert faz tespit edilememiştir.

Üretimi gerçekleşen kargallarda soğutma hızıyla doğru orantılı olarak mukavemet değerinin azaldığı, % uzama değerinin arttığı ve % kesit daralması değerinin arttığı tespit edilmiştir.

Tane sınırı sementit yapısının oluşumuna yüksek ebat ve düşük soğutma hızının etkisi tespit edilmiştir. Soğutma hızının oluşan tane sınırı sementit yapısına doğrudan etkisi olmuştur.

Sonuç olarak, ön gerilemeli beton demeti (PC strand) olarak kullanılan SAE 1080 (1.1082\_01 ve 1.1082\_02 ) kargal kalitelerinde 13-16 °C/sn soğutma hızına sahip kargallarda hedeflenen uygun mekanik mukavemet ve mikroyapı koşulları her iki ebatla sağlanmıştır.



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## Thermomechanical Rolling Termomekanik Haddeleme

### Tuning of Thermomechanical Rolling Model and Its Effects on Mechanical and Microstructure of Nb-Ti Alloy Steels

Nb – Ti Alaşımli Çeliklerde Termomekanik Haddeleme ve Mikroyapı İle Mekanik Özellikler Üzerindeki Etkileri

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İSKENDERUN DEMİR VE ÇELİK • Türkiye

#### Abstract

Thermomechanical Rolling method is used to obtain high mechanical strength and toughness , combined efficient workability and weldability. This is a controlled process, from slab reheating rough and finish rolling, up to accelerated cooling. Rolling is performed in accordance with a defined rolling-pass schedule, with proper holding time to cool down to temperature of no recrystallization, finish rolling in austenite phase above Ar3 temperature and cooling to achieve target microstructure and mechanical properties. In this study, thermomechanical rolling model applied in ISDEMİR HSM is investigated analyzing rolling schedule, transfer bar thickness, oscillation of transfer bar and cooling parameters while taking into account the mill technological restricting conditions.

#### 1. Introduction

Increase in the customer demand on the rolled steel with high strength and high toughness combination has made the thermomechanical rolling method more popular in the recent years Pipe producers tend to produce pipe with large diameter and work under high internal pressure to increase the transportation efficiency and avoid the use of high wall thickness in order to decrease its weight and to decrease the project cost. Beside, automotive industry needs lightweight steel to reduce fuel consumption cost without sacrificing high mechanical properties. [1]

Numerous studies was carried out on the hot rolling of the microalloyed steels with high mechanical performance. Thermomechanical rolling method is known as one of the most effective way to obtain high strength and toughness without huge addition of alloying elements. The diffusion of thermomechanical rolling method in Isdemir commenced after 2014. Pilot batch of hot rolling coils(14-17 x 1500 mm API X70 PSL2 steel grade )has been produced using thermomechanical rolling method without exceeding the existing process constraints and without upgrading. During the period of implementation, thermomechanical rolling method in Isdemir has evolved and required change in

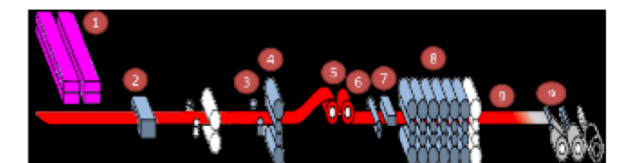
production parameters has been performed. Currently, this production practice presents high potential and still is developing. Another pilot batch of hot rolling coils is grade of S700 MC (with a size group of 5-10 x1500 mm, 3,5-10 x 1250 mm) also produced using this method.

The critical issue during implementation phase of thermomechanical rolling, optimal combination between chemical composition of steel and mill restricting conditions should be taken into account in order not to manufacture expensive final product.

The objective of this paper is to develop optimum production way to produce the high strength-toughness combination steel with a thermomechanical rolling method without equipment upgrading.

#### 2. Experimental Procedure

The existing equipments of the mill consist of 2 walking beam type slab reheating furnaces, 1 four-high roughing mill, 6 four high finishing mill stands, accelerated cooling unit and 2 coilers. It is worth noting that 7 descalers with a main line pressure of 220 bar are installed at the rolling mill. Layout of the main equipments of Isdemir Hot strip Mill is shown in Figure.1



**Figure.1** Flowchart: 1 – slab furnaces, 2 – hydraulic scale breaker, 3-edger, 4- roughing mill, 5 – coilbox, 6- rotary shear, 7- finish scale breaker, 8- finishing mill,9- cooling units, 10 – downcoilers

During the production using thermomechanical rolling method, first, optimum chemical composition is determined.(Table.1)

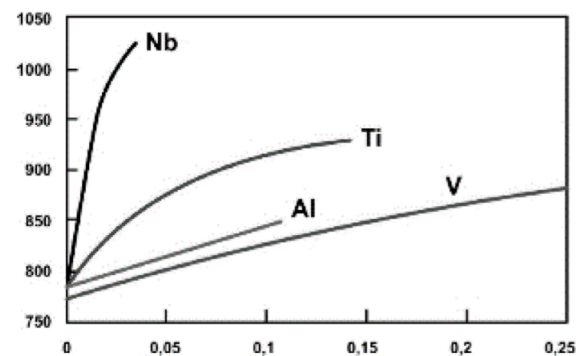
Steel Grade	%					
	C max.	Mn max.	Nb max.	V max.	Ti max.	CE max.
S700 MC	0.07	1.90	0.08	0.01	0.12	0.42

**Table.1** Chemical Composition for S700 MC

Nb and Ti are used as chemical composition elements which make it possible to monitor the grain sizes during the austenization and rolling.[2]

Based on chemical composition (Table.1), not recrystallization temperature  $T_{nr}$  is calculated (1). During rolling below  $T_{nr}$  temperature the deformation takes place without recrystallization with pancaked austenite grains at the end.[3] In deformations made under  $T_{nr}$ , austenite grains deform after reduction since there is no possibility of recrystallization. After reduction, the grains decrease in width, while their length increases and they turn into a thinner long morphology. The grains in this morphology are called pancake structure. As the cooling continues, the ferrite grains are formed within the austenite grains in the form of pancakes under the  $Ar_3$  temperature. Ferrite grains nuclei from this type of morphology are much smaller than classical recrystallization, as they contain much more grain boundaries than coaxial grains. In addition, the new ferrite grains formed in the twinning bands in the austenite grains of pancakes with small in size.

$T_{nr}$  temperature can be influenced by the reduction rate and largely by the addition of micro alloys. Nb which has the highest increasing effect on  $T_{nr}$  in micro alloy elements. In the Figure 2, the effect of alloying elements can be seen. Ti and Nb elements contribute to the formation of pancake austenite by increasing  $T_{nr}$  temperature.



**Figure 2.** Effect of Micro Alloys Elements on  $T_{nr}$

$$T_{nr} [^{\circ}\text{C}] = ((174 \cdot \text{LOG}(\text{Nb} \cdot (\text{C} + 12/14 \cdot \text{N}_2)) + 1444) \quad (2)$$

Based on the chemical composition,  $T_{nr}$  temperature and coil size, process parameters used in thermomechanical rolling method are determined in Table.2

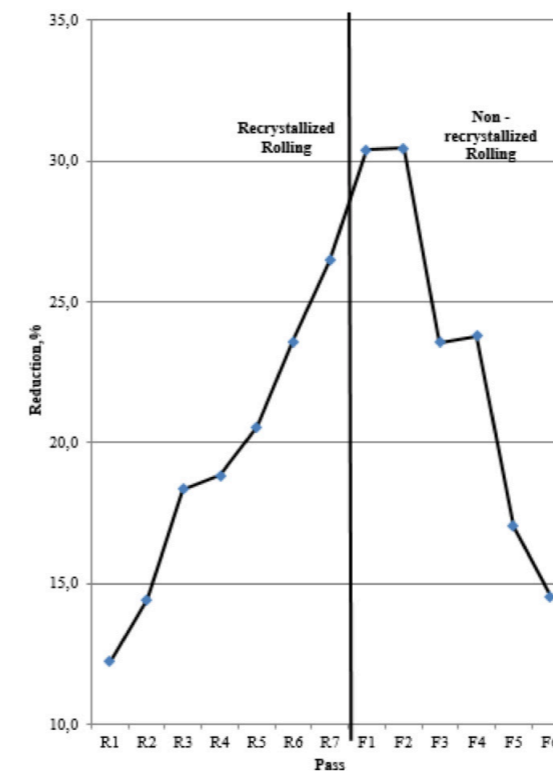
Parameters	Unit	Parameter Value
Slab reheat temp	[ $^{\circ}\text{C}$ ]	1210 $\pm$ 20
Heat time	[hours]	2-3
Finishing Entry Temperature	[ $^{\circ}\text{C}$ ]	<970
Finish Rolling Temperature	[ $^{\circ}\text{C}$ ]	820-880
Coiling Temperature	[ $^{\circ}\text{C}$ ]	550-650

**Table.2:** Process Parameters

To determine finish rolling temperature,  $Ar_3$  temperature should be taken into account. It needs to be higher than  $Ar_3$  temperature.

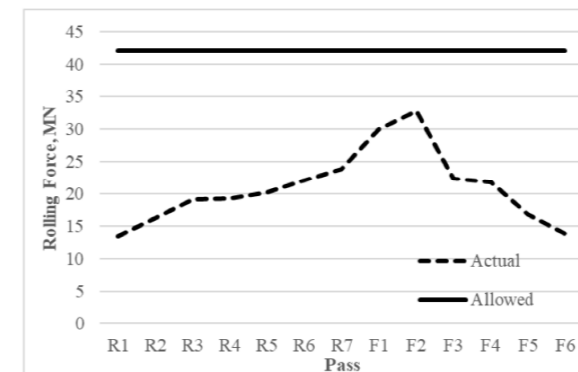
### 2.1. Determination of Passing Schedule

For a fixed grade and steel chemistry, increasing the total reduction below  $T_{nr}$  temperature generally reduces the final austenite grain size due to heavy "pancaking" of grains as strain is accumulated below the  $T_{nr}$ . Total reduction ratio below the  $T_{nr}$  should be kept above 3. In order to obtain required reduction below  $T_{nr}$  and considering mill constraints, passing schedule including roughing and finishing operations for thermomechanical rolling method is calculated. (Figure.3) Holding position is located between roughing and finishing mill sections where transfer bar thickness to final thickness ratio is above 3.[4]



**Figure.3** Passing Schedule for 10x1500 mm S700MC grade Condition of The Mill During Rolling

The pilot batch of hot rolling coils with a section of 10x1500 (steel grade S700 MC) was produced according to the calculated conditions. During production, rolling forces applied are also monitored.(Figure.4)



**Figure.4:** Rolling Forces

During production the reduction conditions may be partially adjusted by altering rolling rate or rolling forces from the target ones not to result in overloads of the main motors. It is worth mentioning that in order to prevent the overload of the main motors, decrease in the rolling forces at the early stand compensated by increase in the transfer bar thickness.

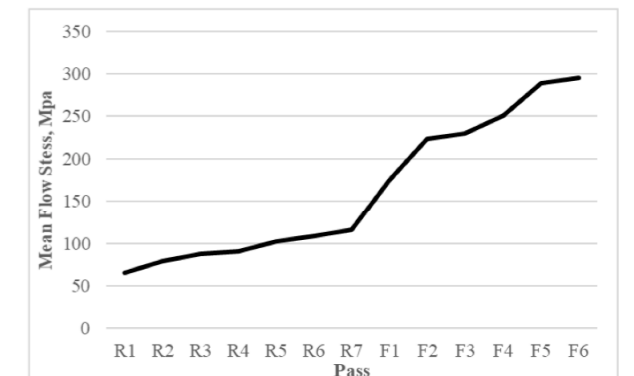
### 3. Results and Discussion

Analysis of the obtained results was carried out based on the mechanical tests, metallographic research. The samples for evaluation of mechanical properties from coils of the pilot batch were taken after the final cooling in the air ambient. The results of the mechanical tests are compatible with the requirement described in EN 10149-2 for steel grade S700 MC (Table.3). Thus the thermomechanical rolling method can be applied to obtain high mechanical properties in Isdemir hot strip mill conditions.

	Yield Strength [MPa]	Tensile Strength [MPa]	Elongation [%]
Actual Coil	708	790	21
EN10149 Requirements for S700 grade	700 (min.)	750 (min.)	12 (min.)

**Table.3:** Mechanical testing result for actual coil S700 grade

Metallurgical mean flow stress (MFS) just after the final rolling stand is kept above 270 MPa and this is the key point for sufficiently effective result of thermomechanical rolling method in Isdemir Hot Strip Mill.(Figure.5)



**Figure 5:** Mean Flow Stress for S700 MC grade (10x1500 mm)

For the analysis of internal quality of the hot rolled products, metallographic studies of the samples taken after final cooling were carried out. The microstructure of the samples is shown in Figure 6. The obtained microstructure is typical ferrite-bainite and contains fine grain. Grain number is 13 according to ASTM E112-96 standard. Such a state of microstructure in thickness of the rolled product shows that desired result during the thermomechanical rolling have been achieved.



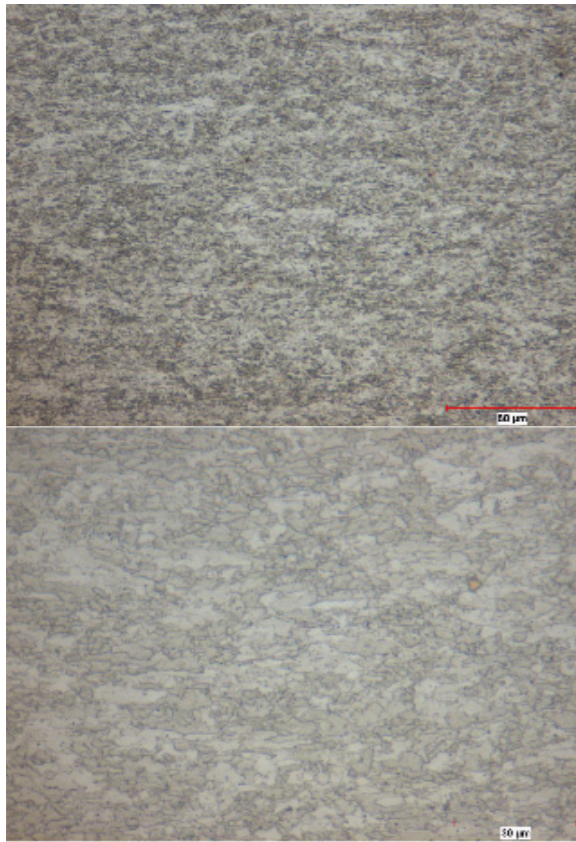


Figure 6: S700MC microstructure X-200 and X-500

Another pilot batch of hot rolling coils has been produced with similar process parameters mentioned with a chemical composition given in Table.4

Quality	C	Mn	Al	N	Ti	Mo	Nb
X70	0,062	1,62	0,045	0,007	0,030	0,006	0,055
X70	0,076	1,62	0,045	0,008	0,043	0,005	0,055

Table 4. Chemical Composition

With this process, yield, tensile and % elongation values were obtained as given in Table 5;

Quality	Coiling Temp	Thickness	Yield Strength	Tensile Strength	% Elongation
X70	576	15 mm	56,3	67,1	20
X70	536	15 mm	61,7	71,1	19

Table 5. Mechanical testing result for actual coil X70 grade

At the same time, notch impact test and dwtt were performed on the produced coils. The test results are shown in table 6. As seen from the results, 100% ductile area can be seen in the dwtt results. The notch impact test was carried out at -30 °C and dwtt test at -20 °C. It can be seen that the high yield strength and toughness required in X70 quality petroleum pipe steels are produced by thermomechanical rolling to meet customer expectations.

Charpy Impact 1	Charpy Impact 2	Charpy Impact 3	DWTT 1	DWTT 2
211	270	274	100	100
250	252	275	100	100

Table 6. Charpy Impact and DWT Test Results

After etching with 2% nital solution from the coil samples, microstructure analysis was performed. In the examinations made with Nikon optic microscope, microstructure distribution in X100, X200 and X500 magnifications and grain size measurement according to ASTM E112 were performed. Grain size measurement was done by image analysis evaluation method and average grain size was measured as 12.8 and 13.2. As can be seen at X100 magnification, it can be said that a microstructure with a very small-grained ferritic structure is formed.

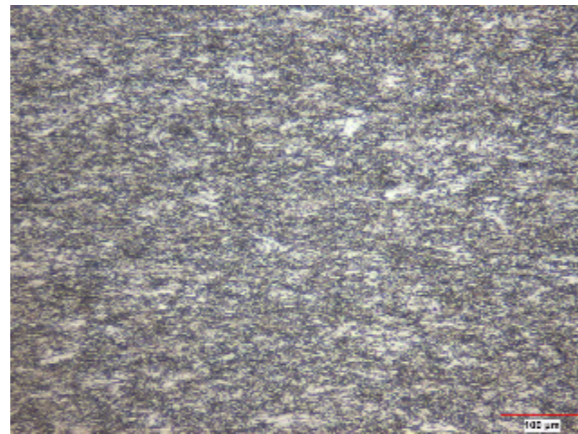


Figure 7. X-100 Microstructure

Central region microstructure image of 15 mm thick coil is shown with the above picture at X100 magnification. In Figure 8, there is the microstructure image at X500 magnification. The microstructure image of both coils is similar and represents a ferritic structure.

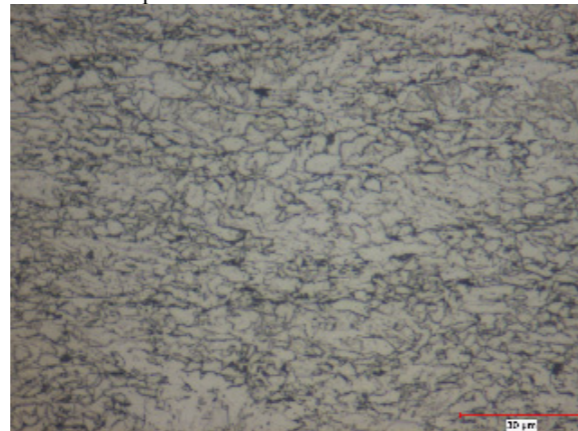


Figure 8. C-500 Microstructure

#### 4. Conclusion

Thermomechanical rolling method successfully implemented in Isdemir Hot Strip Mill for producing S700 MC grade (6-12 x1500 mm) and API X70 PSL2 grade (12-18 x 1500 mm) with compatible mechanical testing result. with the requirements of EN 10149. Reduction ratio above 3,5 while rolling below  $T_{nr}$  temperature and keeping the metallurgical mean flow stress at the final rolling stand above 270 MPa is the critical point for obtaining required mechanical results and desired microstructure including fine grains. During the production phase, to decrease the surface temperature lower than  $T_{nr}$ , material is hold in front of finishing mill for suitable time. This may increase scaling rate and red oxide formation. To improve surface quality for the customers lowering Si content and using the descaling capacity with a maximum amount plays a key role. The results obtained show the technical potential for further development of producing higher grade or producing higher thicknesses of existing grades. Furthermore, for Isdemir hot strip mill situation to keep the reduction ratio in rolling above 3 below  $T_{nr}$  temperature, technological investment of another roughing mill stand is an opportunity for producing larger thicknesses and the development of higher strength categories.

#### Acknowledgment

Authors are grateful to Doug STALHEIM from President at DGS Metallurgical Solutions, Inc. for metallurgical studies in Isdemir Hot Strip Mill, and special thanks to Ayhan AYDIN Isdemir Hot Strip Mill Manager and Serdar GUNBAY Isdemir Quality and Metallurgy Manager for supporting all efforts and trials to reach sufficient results in thermomechanical rolling method.

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- [4] Rina Consulting - Centro Sviluppo Materiali (CSM) /Italy, 2014 ( Isdemir X70-X80 studies)



## Effect of Thermomechanical Rolling Process on the Mechanical Properties of Medium Carbon Microalloyed Steel

Termo-Mekanik Haddeleme Prosesinin Orta Karbonlu Mikroalaşımli Çeliklerin Mekanik Özelliklerine Etkisi

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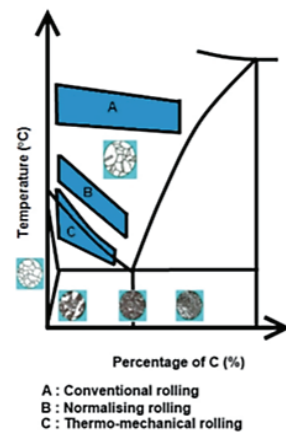
### Abstract

The thermomechanical rolling (TMR) process is a modified hot rolling process which is characterized by deformation in the non-recrystallization region of austenite. TMR process is generally applied to thin section microalloyed steels primarily to obtain the desired grain refinement. The main purpose of TMR is to control the microstructure and provide the material with the desired properties during rolling. Moreover, with the application of this method additional heat treatments applied to improve the mechanical properties of the materials can also be eliminated.

In the present study, medium carbon microalloyed steel bars with a diameter of 55.6 mm were produced by TMR instead of conventional rolling (CR) in Asil Çelik. The effect of TMR process parameters on the microstructure and mechanical properties of this particular steel grade were investigated in comparison to those of the same steel grade processed by CR.

### 1. Introduction

In principle, hot rolling can be divided into three different categories namely conventional rolling, normalizing rolling (NR) and thermomechanical rolling. These three different processes vary in the temperature at which the final deformation takes place (Figure 1) [1].



**Figure 1.** Representation of the temperature regions on the Fe-C diagram where three types of rolling methods are applied [1].

The conventional rolling and normalizing methods are carried out only at elevated temperatures where only stable austenite phase exists. Relatively lower rolling forces are required at higher rolling temperatures, and large reduction ratios can be easily achieved. However, controlling the final grain size and the mechanical properties at the finished material becomes difficult [2].

TMR is also called as “warm rolling” in literature, because required temperatures are not as high as those of the CR process or as low as those of the cold rolling process. The purpose of the process is inhibiting the recrystallization of the grains by conducting the final rolling at the appropriate temperature. Multiple critical temperatures exist during the course of the hot rolling process. During cooling, the first one is known as the  $T_{NR}$  (temperature of no recrystallization) where complete static recrystallization no longer occurs for a given holding time. Subsequent critical temperatures are the phase transformation temperatures upon cooling ( $Ar_3$ ,  $Ar_1$ ) [3]. Deformation above the  $T_{NR}$  results in equiaxed recrystallized grains. Without further recrystallization, the grains could increase in size through grain coarsening. Deformation below  $T_{NR}$  results in elongated grains and the formation of deformation bands, which act as nucleation sites for proeutectoid ferrite formation. If the starting grains were the same size, rolling below the  $T_{NR}$  would result in finer ferrite grains than rolling above the  $T_{NR}$ , as the ratio of grain boundary surface area to grain volume is increased [4].

During hot working recrystallization occurs both dynamically and statically. Recrystallization during deformation (while the material is in the roll bite) can occur if enough strain has accumulated, and it is called dynamic recrystallization [5,6]. Static recrystallization occurs with effect of high temperature upon the completion of the deformation. It was observed that the desired fine grain structure is obtained when the process is performed at temperatures lower than the  $T_{NR}$  [7-9].

Thermomechanical rolling process is mainly applied on microalloyed steels to decrease grain size by the formation of small precipitates. The elements used for microalloying are generally Nb, Ti and V. It is expected that these added elements will form precipitates such as Nb(C, N), TiC, TiN, VN and VC on the austenite grain boundaries upon cooling and delay recrystallization. Presence of these precipitates directly affects the grain size of the final product, as the austenite grains are restricted by these precipitates, and the final microstructure forms in this fine grained structure.

Another critical parameter for the process is the material thickness. It is seen that TMR process is generally applied to small sectioned materials like sheets and thin rods to achieve homogeneous cooling along the material section [10,11].

### 2. Experimental Study

At the beginning of the study material property simulations were conducted to determine the critical temperatures ( $Ar_3$ ,  $Ar_1$ ,  $T_{NR}$ ) which are used to guide the processes. Based on these results, the hot rolling process line was modified according to TMR process requirements, and after several rolling trial runs optimum process parameters were determined. Consequently, effect of TMR process on the microstructure and mechanical properties was examined.

#### 2.1. Material

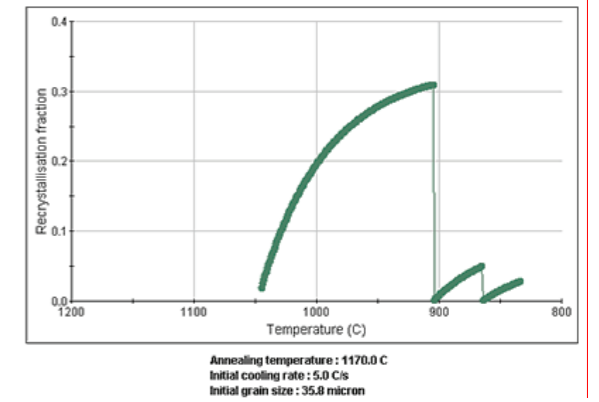
The aim of this study carried out at Asil Çelik is to decrease grain size and improve mechanical properties of microalloyed steel bars using TMR process as an alternative to conventional rolling. 240 mm square billets obtained by continuous casting were hot rolled to 55.6 mm diameter rods, which were subsequently processed by TMR to achieve the final rod products of 40 mm in diameter. The section size of the material to be processed by TMR is of critical importance, since homogeneous cooling becomes more complicated through the section of thick materials. Studies available in literature on TMR process mainly concentrate on sheet or thin sectioned materials to avoid this complication. Therefore, the rod 55.6 mm in diameter to be processed by TMR is a relatively large section in terms of the challenge for homogeneous cooling.

The microalloyed steel that contains low amount of alloying elements including vanadium, titanium and molybdenum. They are used to refine the grain structure by suppressing the grain growth of the prior austenite phase during solutionizing.

#### 2.2. Material Property Simulations

For the success of the TMR process phase transformation temperatures on cooling ( $Ar_1$ ,  $Ar_3$ ) and no-recrystallization temperature ( $T_{NR}$ ) of the material under consideration should be known to obtain desired mechanical properties. Therefore, in the first part of this study material property simulations were conducted to determine these critical temperatures ( $Ar_3$ ,  $Ar_1$ ,  $T_{NR}$ ).

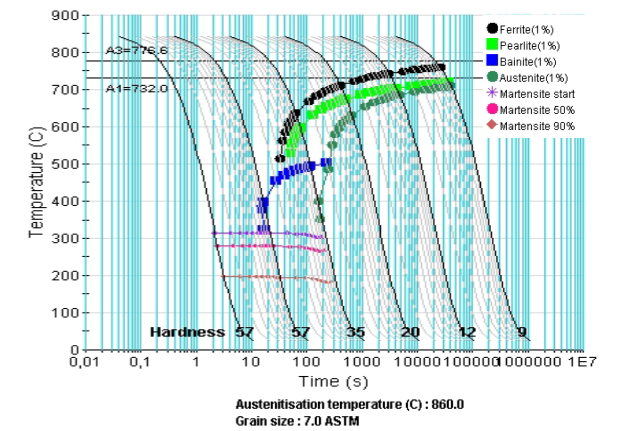
In order to determine the critical temperatures ( $Ar_1$ ,  $Ar_3$ ,  $T_{NR}$ ) of microalloyed steel, simulation studies were carried out using J-MatPro<sup>®</sup> simulation software which is a tool used to determine material properties of multi-component alloys in industrial practice, as well.  $T_{NR}$  temperature was determined based on the recrystallization fractions of the grains shown in Fig. 2.



**Figure 2.** Recrystallization fraction of microalloyed steel as a function of temperature.

$Ar_1$  and  $Ar_3$  temperatures of this microalloyed steel were determined using its simulated CCT diagram (Fig. 3) considering the solutionizing temperature, cooling rate, initial grain size and chemical composition. Determined critical temperatures are as follows:

$Ar_1$ :732 °C,  $Ar_3$ :776 °C and  $T_{NR}$ : 830 °C.



**Figure 3.** Simulated CCT diagram of microalloyed steel.

#### 2.3. Thermomechanical Rolling

Based on the critical temperature calculations, the hot rolling process line was modified according to TMR process requirements, and after several rolling trials optimum process parameters were determined.

Rolling speed, water pressure and water flow rate are important parameters to obtain homogeneous cooling and to allow the material to enter the final rolling unit below the recrystallization temperature,  $T_{NR}$ . Several TMR trial runs were carried out on the hot rolling line to determine the optimum process parameters.

Cooling effect on the material surface was also checked visually to follow the cooling homogeneity on the material surface at these points.

## 2.4. Metallographic Examination

Specimens were taken from the top, middle and bottom locations of the processed steel rods at the end of the rolling line. Microstructural characteristics of the specimens were investigated at Asil Çelik laboratories. Surfaces of the specimens were prepared according to ASTM E3-11, and a fully automated polishing machine (Struers Hexamatic) was used for this purpose. In addition to the observation of the specimen surfaces using optical microscope, detailed metallographic analysis was conducted using scanning electron microscope (SEM, Zeiss Evo MA15) equipped with energy dispersive spectroscopy (EDS, Oxford X-Max 20) and electron back scattered diffraction (EBSD, Oxford Symmetry) detectors. Metallographic examinations were carried out on 3 different locations (surface, midradius, center) of each specimen as shown in Fig. 4.



**Figure 4.** Cross-section of a typical specimen showing the 3 different locations where metallographic examinations of TMR and CR processed rods were conducted.

## 2.5. Mechanical Characterization

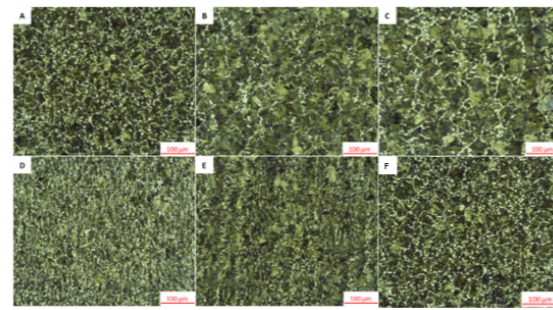
Tensile tests (ISO 6892-1), impact tests at -40, -20 and 20°C (ISO 148-1) and hardness measurements (ISO 6506-1) were applied at Asil Çelik laboratories to determine the mechanical properties of the materials processed. In order to determine the effect of the TMR process on fatigue properties of the studied microalloyed steel, rotating bending fatigue test was performed using a Walter & Bai type instrument at Istanbul Technical University (ITU).

## 3. Results and Discussion

Thermomechanical rolling process was carried out at a slower rolling speed than CR to ensure the entry of the material to the final rolling unit under the  $T_{NR}$  temperature.

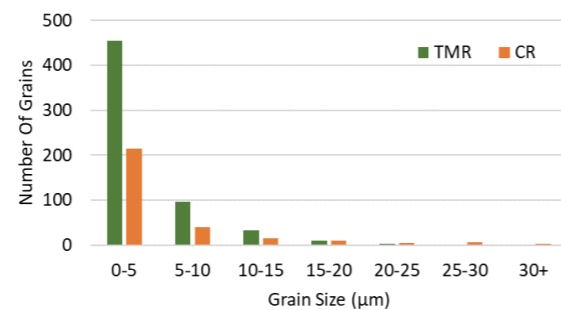
### 3.1. Microstructure Analysis

The grain refinement effect of the TMR process is clearly seen on the optical micrographs of the specimens (Fig. 5 D-F). This effect is more pronounced at the surface where the cooling rate is the fastest. When compared at the same location of the cross-section, the grain size of the CR processed material is not as fine as that of the TMR processed one (Fig 6 A vs. D, B vs. E and C vs. F).



**Figure 5.** Microstructure of the CR (A,B,C) and TMR (D,E,F) processed materials at the surface A and D, midradius B and E and center C and F, respectively.

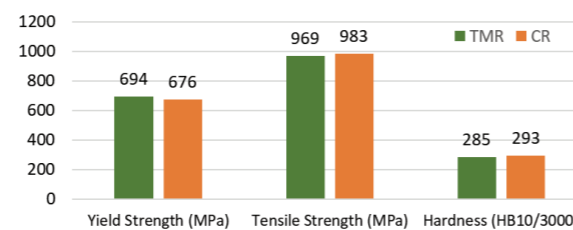
Grain size was measured using EBSD method in SEM. Crystallographic differentiation of the ferrite and pearlite regions is ambiguous with this method; therefore, sizes of both regions are being regarded as the grain size. Results have shown that in all grain size ranges measured TMR processed material contains higher number of grains (Fig. 6).



**Figure 6.** Number of grains in different size ranges for both TMR and CR processed materials.

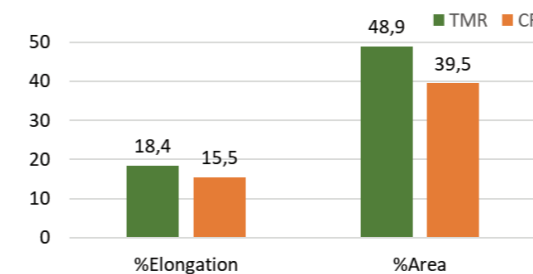
### 3.2. Mechanical Properties

When the mechanical properties such as yield and tensile strengths along with hardness of both TMR and CR processed materials are compared, there does not seem to be a remarkable difference in the respective values (Fig. 7). This points out to the fact that TMR process does not have a pronounced effect on the strength of the microalloyed alloy under investigation.



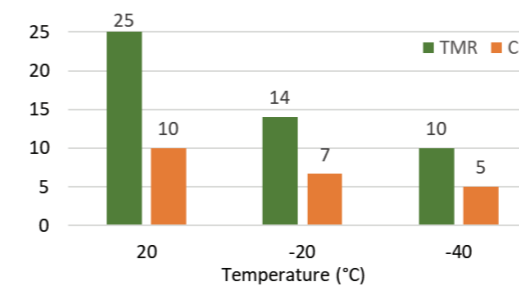
**Figure 7.** Yield and tensile strengths along with hardness of both TMR and CR processed materials.

On the other hand, % elongation and % area reduction values of the TMR processed material obtained by the tensile tests seem to be notably higher than those of the CR processed one (Fig. 8). This difference clearly demonstrates the improvement in the ductility by the TMR process, which in turn should reflect itself by an enhancement in the toughness of the material.



**Figure 8.** Effect of TMR and CR processes on the % elongation and % area reduction of the studied material.

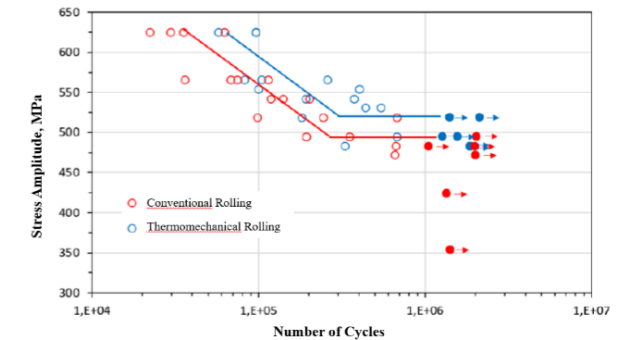
Impact tests were performed at different temperatures to determine the response of the TMR processed material to dynamic stresses under high loading rates. As can be seen in Fig. 9, the impact toughness of the material increased considerably at all temperatures where this increase reaches to ca. 125% at 20°C.



**Figure 9.** Effect of TMR and CR processes on the impact toughness of the material at different temperatures.

After determining that TMR process improves the ductility and toughness of the studied microalloyed steel significantly, fatigue behavior of both TMR and CR processed materials were compared based on the rotating bending fatigue tests. In the experiments, the loading frequency was taken as 25 Hz, and the test was terminated in  $10^6$  cycles for the samples those did not break. Stress amplitude vs. number of cycles to failure (S-N) curves were obtained for varying stress levels for both TMR and CR processed materials. The fatigue limits of the materials were determined and compared on the basis of the highest tensile amplitude for at least one sample that did not break in  $10^6$  cycles. According to this fatigue limits of the TMR and CR processed materials were determined to be 519 and 495 MPa, respectively (Fig. 10). It is clear that the fatigue limit of the TMR processed material is higher than that of the CR processed one, which is in good correspondence

with the improvement in ductility and toughness of the material achieved by the TMR process.



**Figure 10.** Effect of TMR and CR processes on the fatigue behavior of the microalloyed steel.

## 4. Conclusion

According to the results of this study, it was observed that TMR process had no dramatic effect on the strength and hardness of the microalloyed steel. However, it is seen that ductility and toughness is considerably improved by the TMR process due to the refinement in the grain structure, which has a positive effect on the fatigue behavior of this material.

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## 6. Acknowledgement

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## Optimization of Thermomechanical Processes for AISI 304 Stainless Steel Sheet Production

AISI 304 Kalite Paslanmaz Çeliklerin Üretiminde Termomekanik Proseslerin Optimizasyonu

Hamdi Ekici, Onur Ay, Tuncay Yıldız, Erdem Güler, Bedirhan Güraydın, Eda Dağdelen

TRİNOX METAL • Türkiye

### Abstract

AISI 304 quality stainless steel has become an indispensable material for daily use thanks to its high corrosion resistance, high heat conductivity, formability and visual properties [1-2]. Stainless steel flat materials are produced with hot rolling, annealing and cold rolling after the casting process and then it is prepared for service processes by ensuring annealing and surface passivation. [3]

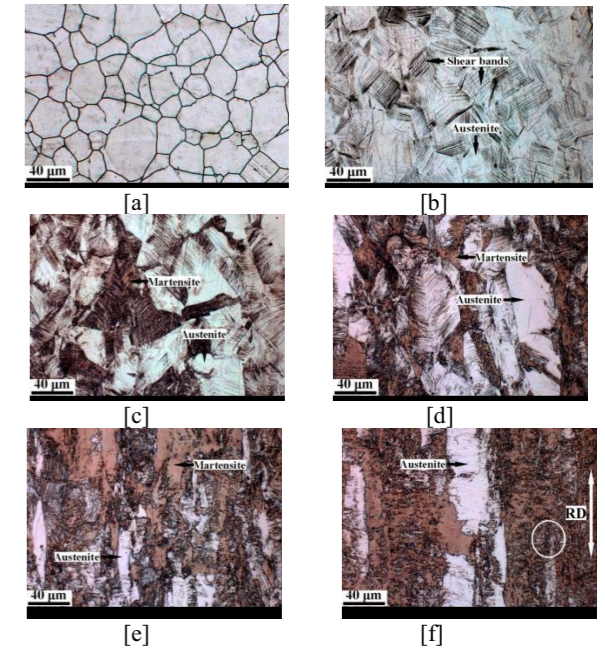
In this study, the effect of phase of ratio, cold deformation amount after hot rolling, number of cold rolling pass, annealing temperature and time of the material on the final mechanical properties has been studied. The effect of the thermomechanical process parameters on hardness after annealing operation was modeled with using Taguchi experimental design method.

### 1. Introduction

Cold rolling is the process of the forming plastic as cold to the material which is intervened under the influence of pressing force of two rotary rollers against each other. Cold rolling is carried out after continuous casting, hot rolling and annealing – acidification in the production of the stainless steel flat. After cold rolling, stainless steel flats are re-annealing and acidification processes and directed to service operations. During the cold forming of metallic materials, usually grain elongation is seen in the direction of the rolling. This change causes increased strength in certain proportions. [4-5]

In some materials, the grain fracture and phase transformation together with the grain elongation due to high pressure force during cold rolling. In 304 austenitic stainless steels, this phase conversion is in the form of austenite → martensite. [5-6]

During the cold deformation, the amount of deformation, pass and phase rates of the material highly effective in increasing the strength of stainless steel.



**Figure 1:** AISI 304 phase conversion of stainless steel under cold deformation [5]  
(a: %0, b: %10, c: %30, d: %50, e: %70, f: %90)

After the cold rolling process, AISI 304 stainless steels are subjected to annealing process. Purpose of annealing process; provide to change martensite phase → austenite phase with the getting the material to austenite temperature, remove the internal tension of the material, deciphered metal carbonions to the grain boundary, to reduce the material to final hardness. [7-8]

2. Experimental Procedure

Cold rolling and annealing processes are examined and modeled by individual experiment designs for the thermomechanical process model and optimization.

The purpose of separate modelling of processes; to provide material which certain mechanical properties independent of the thickness to the annealing line. In the Figure 2, modeling and optimization steps are given.

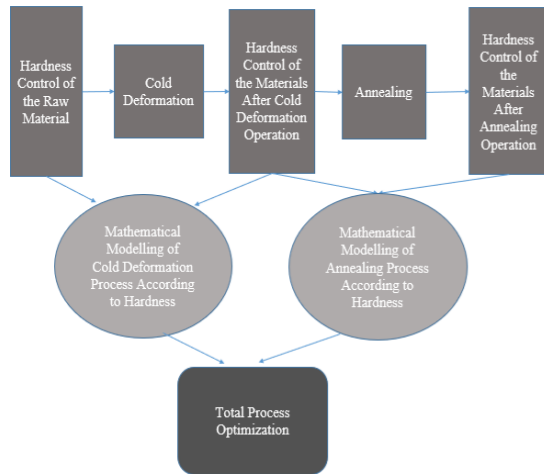


Figure 2: Totally Process Model and Control Steps

Process works were carried out in Trinox Metal Corlu Plant production machines. Rolling operation in the Sendzimir machine, the annealing operation was made on the Atlas machine. The hardness results are measured in the Trinox Metal Quality Control Laboratory. Each metric is made by the same operator. Hardness controls are made with the Emcotest DuraScan 10 brand device. The device is shown in Figure 3.



Figure 3: Emcotest DuraScan 10 Hardness Machine

2.1. Cold Rolling Experiments

Materials alloys analysis are done with optical emission spectrometer machine and the sample sets which are contained ferrite content %15 and %10 according to

Schaeffler Diagram (Figure 4) are taken. The sample set consists of 4 separate samples.

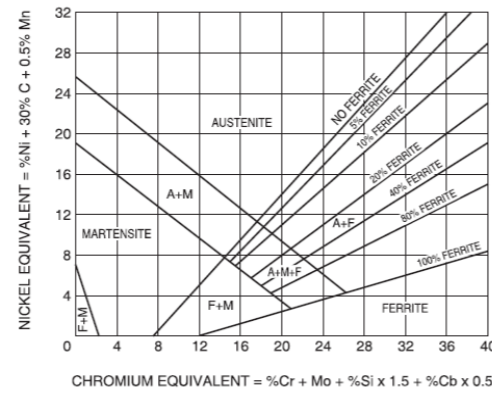


Figure 4: Schaeffler Diagram [1]

The effect of the relevant parameters on material hardness (Vickers Hardness) was investigated by cold rolling of the samples with different deformation quantities and different pass numbers. The experiment for each sample has been repeated three times.

Sample and experimental processes for cold rolling are given in table 1.

Table 1: Cold Rolling Experiment Sets

Sample Number	Ferrite Amount (%)	Deformation Amount (%)	Pass
1	10	60	9
2	10	60	10
3	10	70	9
4	10	70	10
5	15	60	9
6	15	60	10
7	15	70	9
8	15	70	10

2.2. Solution Annealing Experiments

Furnace temperature, thickness and line speed values of the materials which are passed through annealing line in the production, are taken as experimental input. Process parameters are given in the table 2.

Table 2: Solution Annealing Process Parameters

Number	Thickness (mm)	Line Speed (m/m)	Temp (°C)	Hardness (Hv)	Number	Thickness (mm)	Line Speed (m/m)	Temp (°C)	Hardness (Hv)
1	0,5	14	1098	161	38	1	9	1120	156
2	0,5	14	1098	164	39	1	7	1120	158
3	0,5	15	1120	158	40	1	9	1120	164
4	0,5	15	1119	160	41	1	9	1125	155
5	0,6	13	1120	157	42	1	9	1128	163
6	0,6	14	1120	158	43	1	9	1130	165
7	0,6	14	1120	161	44	1	10	1150	159
8	0,6	14	1122	159	45	1	9	1120	160
9	0,6	14	1120	157	46	1	9	1120	151
10	0,6	14	1119	162	47	1	8,5	1120	161
11	0,7	12	1100	159	48	1	9	1120	159
12	0,7	12	1120	161	49	1,2	8	1100	166
13	0,7	12	1120	155	50	1,2	7	1100	160
14	0,7	11,5	1119	156	51	1,2	7	1100	157
15	0,7	12	2220	157	52	1,2	7	1120	161
16	0,8	12	1100	168	53	1,2	7	1120	165
17	0,8	11	1100	163	54	1,2	8	1127	163
18	0,8	11	1100	159	55	1,2	7	1100	163
19	0,8	11	1120	166	56	1,2	8	1100	162
20	0,8	11	1119	165	57	1,2	8	1150	165
21	0,8	11	1119	162	58	1,2	6,4	1120	158
22	0,8	11	1119	155	59	1,2	7	1120	155
23	0,8	11	1119	165	60	1,2	6	1120	155
24	0,8	11	1119	159	61	1,35	8	1070	180
25	0,8	11	1121	162	62	1,35	8	1100	173
26	0,8	11	1120	156	63	1,35	8	1190	169
27	0,8	10,5	1120	150	64	1,35	8	1100	169
28	0,8	11	1120	156	65	1,35	8	1100	167
29	0,8	11	1120	158	66	1,35	6	1100	165
30	0,8	11	1119	161	67	1,35	8	1120	163
31	0,8	11	1120	160	68	1,5	5	1100	165
32	0,8	11	1119	154	69	1,5	6	1120	169
33	0,8	11	1120	159	70	1,5	6	1120	161
34	0,9	11	1120	169	71	1,5	6	1120	168
35	0,9	9,5	1120	161	72	1,5	6	1110	163
36	1	9,6	1099	163	73	1,5	6	1120	164
37	1	9,6	1100	168	74	1,5	6	1150	167

3. Results and Discussion

3.1. Cold Rolling Process Optimization

The values belonging to the cold rolling test group were given in the Taguchi reports (Table 3). In the result axis, the hardness difference is written in the materials (the hardness of the output from the process by calculating the hardness of the raw material entry).

Table 3: Cold Rolling Effect Assessment Table

Sample Number	Ferrite Amount (%)	Deformation Amount (%)	Pass	Hardness Increase (Hv)			
Process Specifications	10	15	60	70	9	10	
S1	210	210	210	210	210	210	210
S2	217	217	217	217	217	217	217
S3	252	252	252	252	252	252	252
S4	259	259	259	259	259	259	259
S5	210	210	210	210	210	210	210
S6	220	220	220	220	220	220	220
S7	241	241	241	241	241	241	241
S8	246	246	246	246	246	246	246
Total	938	917	857	998	913	942	
Average	234,5	229,25	214,25	249,5	228,25	235,5	
Difference	-5,25		35,25		7,25		
Influence Degree	-1,05		3,525		7,25		

Hardness measurement results of samples subjected to different processes were evaluated and effect coefficients of process inputs were found.

According to this conclusion, the 1% increase in the amount of ferrite phase reduces the hardness of the material by 1.05 HV, %1 increase in deformation by 3,525 HV increases material hardness and 1 pass increase in the number of pass in cold rolling process, increases material hardness by 7,25 HV. After modeling, deformation amount and pass numbers have a more important effect.

The high effect of deformation amount and pass number is due to breaking under pressure and austinite → martensite conversion instead of elongation of grains when the material is rolled [E].

The following formula is created taking into account amount of influence.

$$H = GKK + 3,525 * D + 7,25 * P - 1,05 * F \quad (1)$$

- H : Cold Rolling Process Out Hardness Values (HV)
- D : Deformation Amount (%)
- P : Numbers of Pass
- F : Ferrite Values (%)
- GKK : Cold Rolling Process Input Values (HV)

3.2. Annealing Process Optimization

The pre-annealed hardness of the materials has been brought to a specific value according to the mathematical model and the materials were annealed. Annealing process is done in the form open and continuous annealing. Appearance of furnace is shown Figure 5.

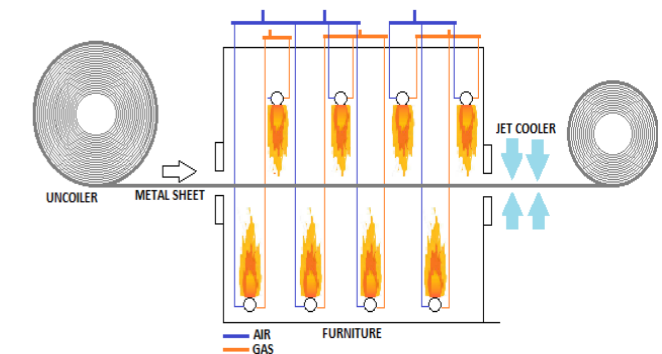


Figure 5. Annealing Furnace with Open Atmosphere

Based on the annealing conditions specified in table 2, the output hardness is determined according to the furnace temperature, line speed and material thickness.



The generated mathematical model provides the line speed and furnace temperature, which should be desired hardness according to the thickness of the material.

Thickness-based derived equations are as follows:

For 0.5 mm thick material;  
 $Hardness = (V * 10\ 000 * t) / (T + 273) + 104,15937$  (2)

For 0.6 mm thick material;  
 $Hardness = (V * 10\ 000 * t) / (T + 273) + 99,00574$  (3)

For 075 mm thick material;  
 $Hardness = (V * 10\ 000 * t) / (T + 273) + 96,69849$  (4)

For 0.8 mm thick material;  
 $Hardness = (V * 10\ 000 * t) / (T + 273) + 93,82699$  (5)

For 095 mm thick material;  
 $Hardness = (V * 10\ 000 * t) / (T + 273) + 94,104115$  (6)

For 1,0 mm thick material;  
 $Hardness = (V * 10\ 000 * t) / (T + 273) + 94,39124$  (7)

For 1,2 mm thick material;  
 $Hardness = (V * 10\ 000 * t) / (T + 273) + 97,69849$  (8)

For 1,30 mm thick material;  
 $Hardness = (V * 10\ 000 * t) / (T + 273) + 98,67337$  (9)

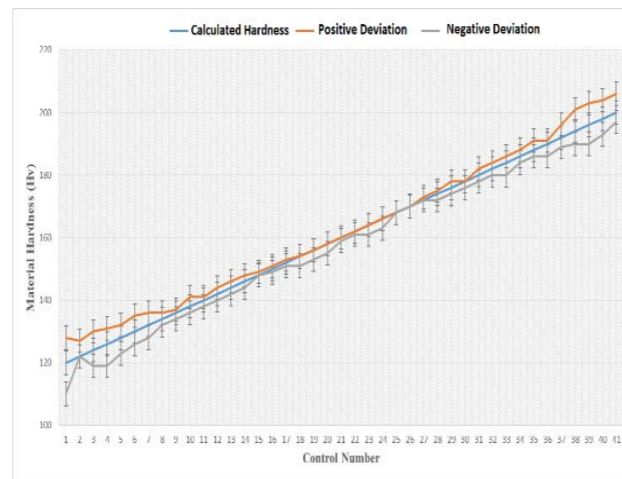
For 1,50 mm thick material;  
 $Hardness = (V * 10\ 000 * t) / (T + 273) + 98,39129$  (10)

V : Line Speed ( m/m)  
 t : Thickness ( mm)  
 T : Temperature of Furnace ( °C )

The deviation graph based on equations is given in Table 4 and Figure 6.

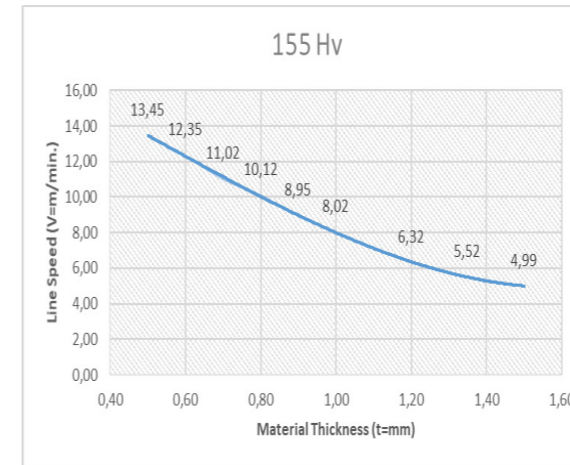
**Table 4:** Estimated hardness values and realized hardness values with the algorithm

Calculated Hardness (Hv)	Material Hardness (Hv)		Calculated Hardness (Hv)	Material Hardness (Hv)	
	Positive Deviation	Negative Deviation		Positive Deviation	Negative Deviation
120	128	110	162	162	161
122	127	122	164	164	161
124	130	119	166	166	163
126	131	119	168	168	168
128	132	123	170	170	170
130	135	126	172	173	172
132	136	128	174	175	172
134	136	132	176	178	174
136	137	134	178	178	176
138	141	136	180	182	178
140	141	138	182	184	180
142	144	140	184	186	180
144	146	142	186	188	184
146	148	144	188	191	186
148	149	148	190	191	186
150	151	149	192	196	189
152	153	151	194	201	190
154	154	151	196	203	190
156	156	153	198	204	193
158	158	155	200	206	197
160	160	159	-	-	-



**Figure 6.** Deviation Graph

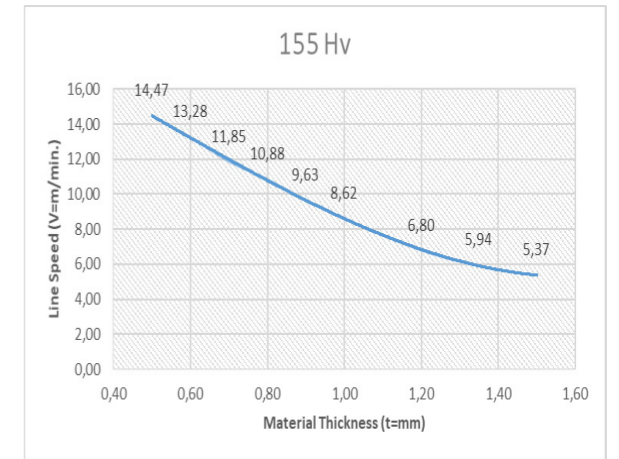
According to the equations No. 2, 3, 4, 5, 6, 7, 8, 9, and 10, 155 HV fixed hardness is required depending on thickness 1050 °C, 1100 °C, 1150 °C and 1200 °C operating temperatures, line speed graphs and equations are as follows:



**Figure 7:** Line speed chart based on thickness (1050 °C and required 155 HV hardness)

$$V = 3,3533t^3 - 5,1269t^2 - 9,1047t + 18,875$$
 (11)

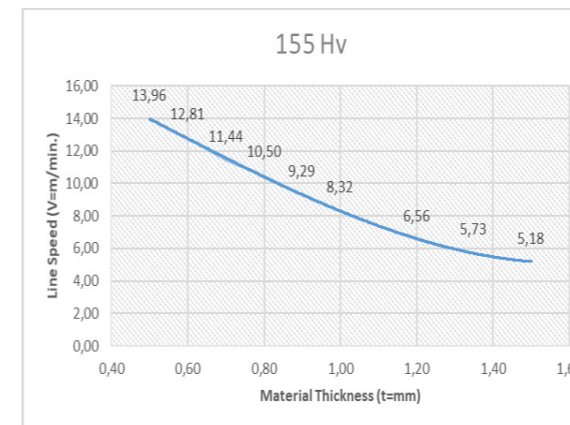
V : Line Speed ( m/m)  
 t : Thickness ( mm)



**Figure 9:** Line speed chart based on thickness (1100 °C and required 155 HV hardness)

$$V = 3,6068t^3 - 5,5145t^2 - 9,7929t + 20,301$$
 (13)

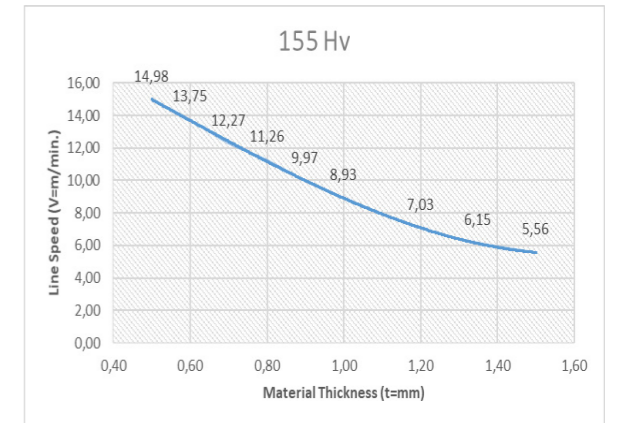
V : Line Speed ( m/m)  
 t : Thickness ( mm)



**Figure 8:** Line speed chart based on thickness (1100 °C and required 155 HV hardness)

$$V = 3,48t^3 - 5,3207t^2 - 9,4488t + 19,588$$
 (12)

V : Line Speed ( m/m)  
 t : Thickness ( mm)



**Figure 10:** Line speed chart based on thickness (1200 °C and required 155 HV hardness)

$$V = 3,7335t^3 - 5,7082t^2 - 10,137t + 21,015$$
 (14)

V : Line Speed ( m/m)  
 t : Thickness ( mm)

#### 4. Conclusion

Considering the industrial conditions, it is an extremely efficient approach to the application of experimental design methods in order to carry out these experiments in the most efficient way by taking into account economic conditions and temporal constraints and to interpret the results correctly. [9]

In the framework of this modern approach, the Taguchi experimental design method is a successful method in solving the optimization problems. The Taguchi method not only ensures that the solution is achieved with the least number of experiments, but it supports high quality process and product development from every angle. This includes assessing the minimum sensitivity of the process or product to the production conditions and uncontrollable factors, ensuring the necessary tolerances at the lowest cost, and evaluating a new quality cost approach. [9]

L8 (2<sup>3</sup>) full factorial experimental design was used which One of the methods of statistical experiment design in analysis, we used in the analyzes.

All factors and their interactions are listed according to their on the Pareto chart. It was concluded that the pass number is more effective on thermomechanical properties than other factors. In addition, the rates of other effects were also calculated.

After statistical study, programming was done. Production will begin to be used in the coming period.

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Flat Products  
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## Danieli Universal Endless (DUE®): The First-Ever Universal Solution for Flat Products is Now on Stream

Danieli Universal Endless (DUE®): Yassı Mamül Üretimi için İlk Universal Çözüm Artık Devreye Girdi

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### INTRODUCTION

In 2016 Shougang Jingtang United Iron & Steel Co. Ltd. (SGJT) confirmed its trust in and satisfaction with the technological equipment supplied by Danieli in previous projects, placing another order with the Group for the world's first Danieli Universal Endless (DUE®) plant. The new facility would be installed in the Caofeidian Industrial Area, Tangshan City, Hebei Province, P.R. China.

The thin-slab casting and rolling process continues to gain a greater share of the global market for the production of hot-rolled strip, mainly thanks to its competitiveness over conventional routes as well as to the growing ability for this technology to cover the majority of all market requirements, not strictly commodity steel grades.

Anticipating the market trend, Danieli progressively developed a new generation of thin-slab casting and rolling layout, called Danieli Universal Endless. DUE® represents a new phase in the evolution of this process.

### DISCUSSION

#### The Concept: low consumption, low emissions and high efficiency

The new DUE® plant features an innovative layout (Danieli patented technology – US patent n. 8087449, January 3rd, 2012), developed in a continuous effort to improve existing processes and technologies, and to overcome their current limitations. This new concept in thin-slab casting and rolling unifies in a single production line all the winning features that have been demonstrated up to now, using either endless or coil-to-coil rolling in separate production lines, while eliminating the limiting factors of each. With its characteristics of low consumption, low emissions and high efficiency, the DUE® perfectly fits to the “new normal” vision that establishes the guidelines for worldwide industrial development, including the steelmaking sector.

What makes the DUE® different are the “universal” rolling modes that prove it is possible now to perform endless and coil-to-coil rolling in a single plant: it is a major technology innovation compared to the previous generation of thin-slab casting and rolling plants.

In fact, SGJT's DUE® plant will be the first thin-slab casting and rolling plant in the world able to reach all the production niches of the flat products market by applying the process that is best suited to each steel grade and product.

Shougang Jingtang's DUE® plant is designed to produce 2,100,000 tpy of high value-added, hot-rolled coils for a wide mix of steel grades and strip dimensions, from 0.80 to 12.7 mm thick and 900 to 1,600 mm wide.

#### A unique switchable layout

The unique DUE® vertical-curved caster features a 5.5-m main radius, designed to produce a single, 110-mm thick slab after dynamic soft reduction (130 mm at mould exit), with a casting speed in excess of 6 m/min, depending on the steel grade. Such an unprecedented combination of slab thickness and speed makes it possible to easily reach the mass-flow conditions required by the full endless production mode, necessary for effective production of ultra-thin gauge products. Additionally, the ability to supply the rolling mill with a thicker slab, compared to the traditional thin-slab approach, is demonstrated by a remarkable increment in the reduction ratio from slab to strip. In turn, this allows the production of a wider mix of steel products, including low-, medium- and high-carbon grades, high-strength/low alloyed, peritectic, silicon, pipeline, API and more. This caster is the logical development of Danieli's already consolidated vertical curved design, taking full advantage of the operational experience accumulated over more than 25 years, as well as the considerable experience gained in high-speed casting.

The tunnel furnace is approximately 80 m long, including a shuttle section to manage emergency slab evacuation, and provides a fundamental buffering function that increases plant flexibility. Thanks to the tunnel furnace, the mill's work-roll changes can be performed as a background task, without affecting the operation of the caster and meltshop. In any case, “switching” from endless to coil-to-coil operating mode during roll changes does not reduce plant productivity.

The DUE® mill features the well-known and successfully proven configuration in which the mill stands are separated into high-reduction units and finishing units, in order to perform the dual step rolling. The transfer bar area includes:

- > A crop shear, used to cut the transfer bar head and/or tail end, particularly for coil-to-coil rolling mode, in order to have smoother threading into the finishing mill as well as reducing tail chew-up. It also provides the bar chopping function, in case an emergency occurs.
- > An induction heating system, designed and manufactured in-house by Danieli Automation, for consistent production of thin and ultra-thin gauges, particularly in endless mode. Can be retracted off-line when not in use or for maintenance purposes.
- > A dedicated high-pressure descaling unit at finishing mill entry (in addition to the one at the high-reduction stand entry), to eliminate imprinting scale phenomena on the final strip, thus significantly improving the relevant surface quality.
- > An intensive cooling system is incorporated into the descaler box at finishing mill entry, for use when producing TMR and/or API grades, in order to guarantee the correct bar temperature profile and proper control of grain growth, which are essential features of the thermo-mechanical rolling process.

The mill stands are designed to guarantee superb geometrical and mechanical properties of the final product and are equipped with all the state-of-the-art features for maximum strip crown and profile control, bearing in mind that these control functions also have to be operational under load conditions, as required by the endless rolling process.

The line is completed with the laminar cooling system, consisting of a combination of power and normal units for outstanding strip cooling strategies. This is followed by the coiling area, made up of a high-speed shear to cut coils to length when working in endless mode, pinch rolls and downcoilers.

#### Modes of operation

A DUE® plant can be operated in various production modes, see Figure 1.

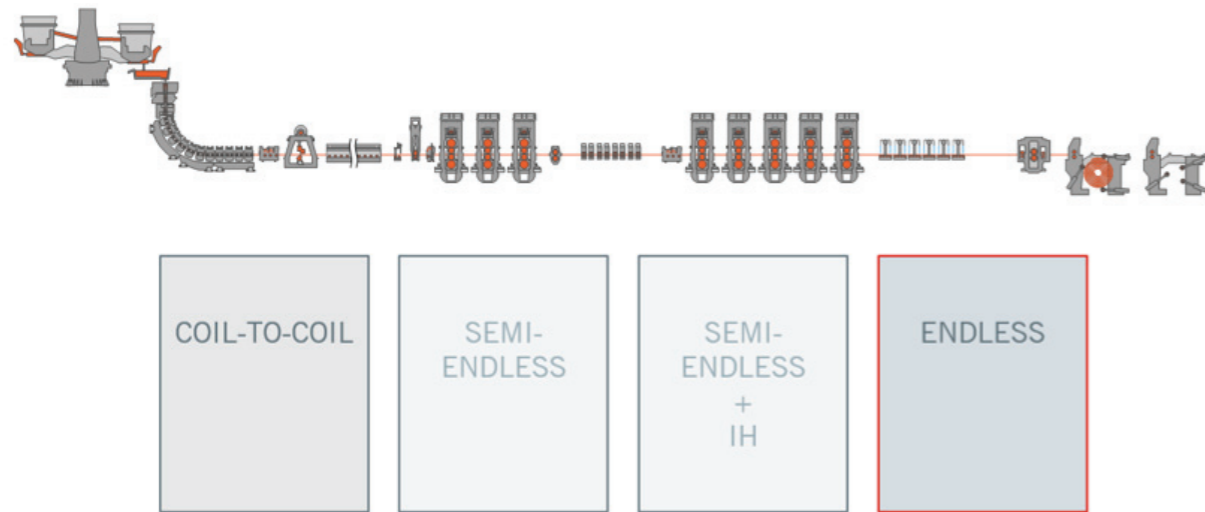


Figure 1. Production modes of DUE®.

The “coil-to-coil” production mode is characterized by a non-continuous rolling mode. Casting and rolling process are decoupled from each other, operating independently with different mass flows. The slabs are generated by cuts of the pendulum shear (PS) at the caster exit (one slab for each coil). The slab weights are calculated by the L3 production planning system.

In the “semi-endless” production mode, the slab can be up to about 80 m long (hence, the tunnel furnace length). The semi-endless slab is rolled and cut with the high-speed shear in separate strips that are coiled as products. In case of SGJT, there can be up to three coils of max weight rolled out of a single semi endless slab. The rolling speed is independent from casting speed.

For some non-planned conditions, it could also be considered to separate the strip not with the HSS but the bar with the crop shear.

For the production mode “semi-endless + IH” mainly the same conditions as described for “semi-endless” are valid. The difference for this production mode is the position of the IH unit in-line, which allow a further process speed reduction and consequently a smoother threading, as well as to reduce the achievable final strip thickness for wide and hard products (e.g. S700MC or DP800). Compared to endless production, it is possible to reduce the IH energy consumption, due to higher mass-flow.

Strip with the thickness range from 0.8 – 4.0 mm can be processed in “endless mode”. The endless operation mode is characterized by a linked casting and rolling process with same mass flow throughout the whole plant, defined by the casting machine. All parts of the plant are connected by the material that is currently being processed, therefore there is a direct relation between the casting and rolling speed. The high-speed shear separates the strip into final lengths before the downcoiler.

Main advantages of the endless production mode are:

- > Rolling stability for ultra-thin gauge production (no threading and tailing out)
- > Further reduction of the minimum achievable strip thickness
- > Tighter geometrical tolerances for ultra-thin gauge production

#### Endless operation

In order to prepare the hot rolling mill for endless production, coil-to-coil slabs have to be produced to build up a thermal crown on the work rolls of the finishing mill. During coil-to-coil production, the induction heater is in off-line position.

The step-down practice as well as the step-up practice are based on different parameters (e.g. production schedule, steel grade...) that will result in an overall rolling campaign as exemplarily shown in Figure 2.

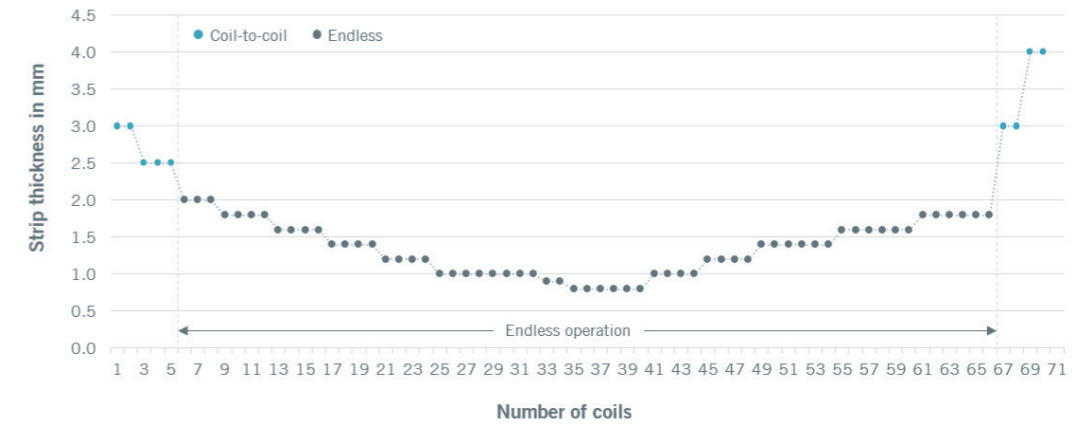


Figure 2. Exemplary rolling campaign with step down and step up practice.

In real production, the rolling campaign is based on a level 3 production planning system resulting in:

- > Estimating the number, thickness and length of required coil-to-coil slabs according to necessary thermal crown and production schedule
- > Estimating the number, thickness and length of required endless slabs according to production schedule
- > In case that the thickness step down from one endless coil to the next, based on the plant's production schedule is too high, the system will plan intermediate coil(s) accordingly

Once the last coil-to-coil slab left the intermediate area (the third 2.50 mm coil in the exemplary rolling campaign), the induction heater is moved in-line. Further step down during endless production is done by flying gauge change (FGC).

#### Induction heater

The inductors are made of water-cooled copper-tube windings and magnetic concentrators, supplied by a voltage-source frequency converter based on IGBT technology, whose working range is from 200Hz to 500Hz. The dedicated power converter was developed by Danieli Automation.

The electromagnetic design of the two inductors of each IH module is oriented to obtain a symmetric power density distribution, along the width of the transfer bar. The magnetic concentrators, arranged along the straight sides of the copper coils, are primarily used to increase the electrical efficiency of the system. A specific magnetic core, whose configuration is patented, is installed at the coil edges and it is used to compensate the lack of power density, helping to flatten the transversal temperature profile of the transfer bar.

The concept design, the engineering of the IH station and the study of the process were performed using numerical methods, both commercial software and internally developed. Specifically, we performed 3D-electromagnetic analysis for different upper-lower inductor positions first, to get the power density distribution in the bar. We then applied this latter as a power generation in a 2D finite-difference thermal model, based on a Lagrangian approach, for reproducing a real process.

A 2D-slice of the bar moves along the rolling line starting from the exit of a tunnel furnace, placed at the inlet of the roughing mill, where the slab has a thickness of 110mm. Applying the proper boundary conditions, we predict the final temperature distribution of the bar, at the entry of the finishing mill stand. We then performed 3D thermal analysis to evaluate transitory conditions.

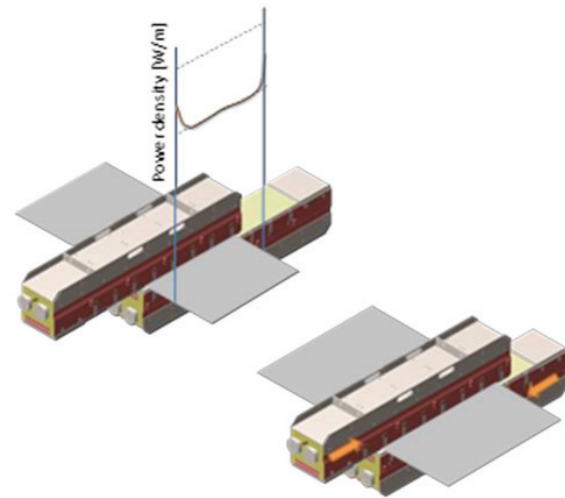


Figure 3. Each IH module transfers a symmetric power density distribution along the width of the bar. The relative shift of the two inductors permits to control the heating of the edges of the bar and to adapt to all the slab widths to be processed.

With reference to the graphs reported in Figure 4, the transfer bar temperature profile is not uniform at the inlet of the IH station because the edges are colder, as predicted by the thermal analysis of the DUE® process. In the same figure, three different temperature profiles are reported, at the entry of the finishing mill.

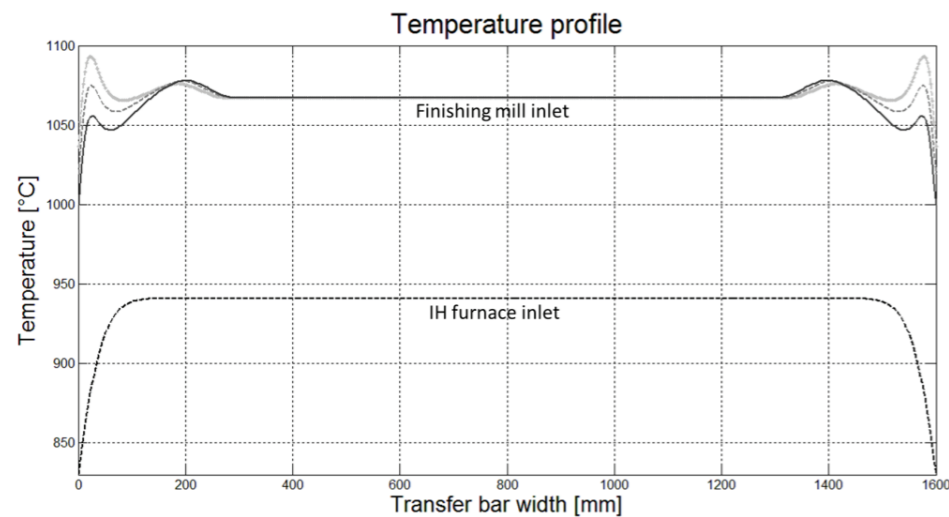


Figure 4. Result of the thermal analysis for a 1600x18 low-carbon steel transfer bar, moving at 360mm/s. Initial distribution and final distributions for three different inductor positions.

These traces, overlapping at the center, refer to three different relative positions of the upper and the lower inductors, showing the compensation capability of the device at the edges of the bar.

So, the main issue of the Transversal Flux Heating (TFH) technology is rather exploited for compensating the temperature at the edges of the transfer bar, effectively controlling the level of the compensation by a relative shift of the upper and the lower inductors. Moreover, the magnetic core design leads to limit the drop of temperature near the edges. With reference to

Figure 3, the upper inductor position affects the power density on the right-edge of the transfer bar, while the lower inductor is used to control the left-edge making even possible to get a nonsymmetric heating.

### Data analytics

In endless operation, the level 1 and level 2 system generate a virtual intermediate strand of the future coil, see Figure 5.

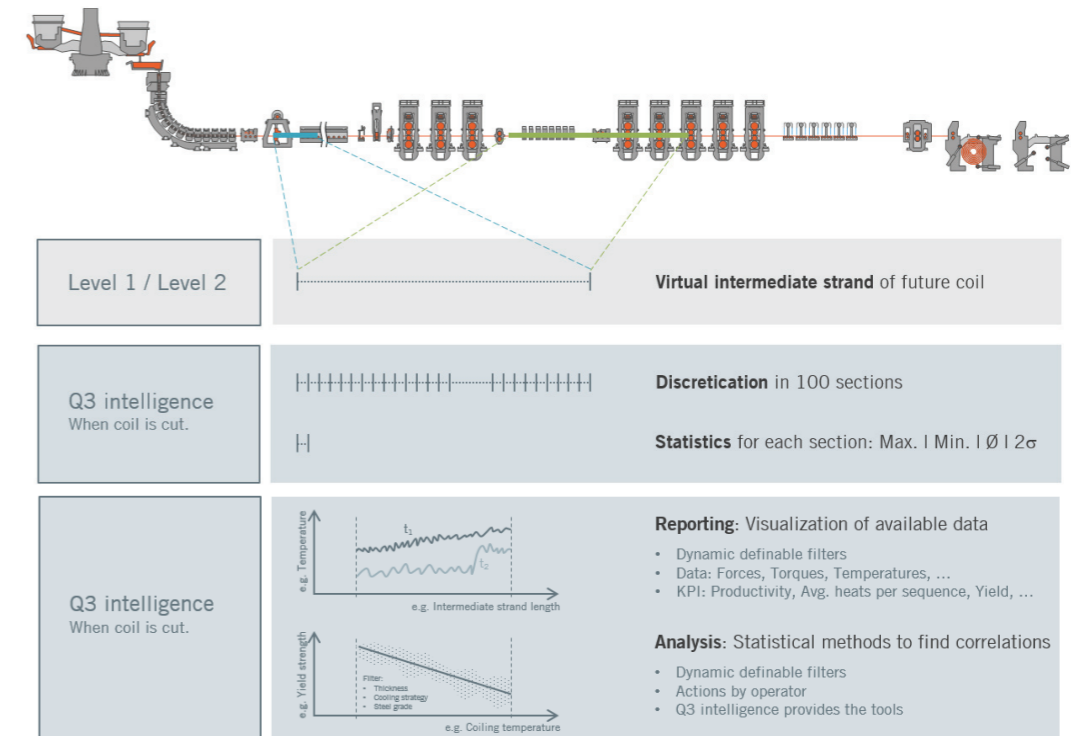


Figure 5. In endless operation, offline data evaluation with Q3Intelligence.

As soon as the high-speed shear in front of the downcoiler cuts the endless strand and creates a coil, the advanced data analysis and visualization system of Danieli Automation - called Q3Intelligence - starts to execute its work. Q3Intelligence allows the users to analyze data in depth and from different perspectives, summarizing it into useful information, without the need of any special skills or the support of any IT expert.

In case of SGJT, the virtual intermediate strand is always discretized in 100 evenly divided sections. For each section, the maximum value, minimum value, average value as well as the standard deviation are calculated. A multidimensional model empowers end users to analyze data interactively from multiple perspectives.

Thanks to the full integration with Microsoft tools (Excel, SharePoint and PowerBI), the learning curves are remarkable shorter, making the users autonomous in the data access and retrieval. A typical structure of a Q3Intelligence OLAP data structure brings together groups of measurements and variables arising from multiple sources into a consistent and unified model.

Typically, a data model includes measures relative to chemical analyses, production quantities, process times, process variables and quality control assessments, as well as classification perspectives such as dates, heats, grades, practices and product features. This gives the users the ability to perform multiple analyses using the same source scheme within the same spreadsheet. Along with the data models, a set of advanced statistical Excel workbooks are available making it possible to rapidly investigate correlations, distributions, outliers and patterns.

With Q3Intelligence, production managers, quality inspectors, process engineers, etc. are supported in reporting (visualization of available data) and analyzing (use of statistical methods to find correlations).



### First-ever universal solution for flat products is now on stream

SGJT's DUE® plant is presently in the commissioning stage. After the successful start-up of the caster and of the mill, the completion of commissioning activities will follow the availability of liquid steel from blast furnaces, which had been limited through August.

To date, all the liquid steel made available had been cast successfully by the single-strand thin-slab caster, producing slabs reduced from 130 mm (mould exit) to 110 mm (TSC exit), using Danieli's well proven Dynamic Soft Reduction.

Automatic Start Cast has been functioning since the very beginning of hot commissioning and the start cast success rate is nearly 100% so far. Also, 123-mm thick slabs have been cast successfully with sound quality.

The commissioning plan foresees a further increase in casting speed up to 6 m/min, coupled with tuning of the secondary cooling for optimal solidification.

Semi-endless rolling has been implemented with the target of fine tuning the Induction Heating system and also securing the sequences at the downcoiler. First coil in full endless mode obtained after having rolled just 45,000 t of HRC since commencement of hot commissioning and strip thickness  $\leq 1.00$  mm reached in full endless after just one month from commencement of endless trials.

The unique DUE® layout configuration currently is proving its outstanding flexibility, being capable of performing different production modes, which indeed is also beneficial for commissioning purposes.

The next scheduled step of the commissioning program will be a further reduction of strip thickness, coupled with high casting speed, for consistent production of thin and ultra-thin gauges in endless mode.

The DUE® layout configuration, together with an effective and optimized energy consumption, represents the most extensive application to date for Danieli's concept of flexibility in thin-slab casting and rolling. The configuration allows SGJT to exploit the production of a wide product mix with an optimized OpEx, achievable by selecting the most convenient rolling process mode.

At the same time, the DUE® plant allows SGJT to properly rearrange the overall production of hot-rolled coils between the new plant and the existing conventional HSMs, increasing profitability and competitiveness in today's market by optimizing conversion costs and production routes.

A brilliant concept has become reality, leading to the implementation of an actual plant that now is in its commissioning stage and ready soon to start full production.

## Precise Profile Control and Concise Maintenance - Latest Evolution of Pair Cross Mill

Kusursuz Kesit Kontrolü ve Bakım – Sıcak Haddehanelerde Son Gelişmeler

Longze He, Akira Sako, Toru Takeguchi, Jiro Hasai

PRIMETALS TECHNOLOGIES JAPAN • Japan

### Abstract

Pair Cross (PC) technology is an effective and proven solution for strip profile and flatness control, developed by Primetals Technologies, Ltd.

Since the world's first hot strip mill with PC mill stand started operation in 1984, over 150 stands have been supplied worldwide and contributed to producing high quality hot rolled strip.

PC mill kept evolving in the last 30 years to correspond to the constantly change in customer's demand. Lately, a new generation PC mill, the 4th generation, with hydraulic control concept was launched. Instead of electro-mechanical control system, the new PC mill is equipped with full hydraulic control system which can remarkably reduce the burden of maintenance, meanwhile, provide precise strip profile and flatness control ability as it has been doing in these years.

This paper will introduce the change of PC mill and new features and functions in the 4th generation PC mill.

### 1. Introduction

It has been long recognized that the shape and profile control of rolled strips are exceedingly important for both product quality and material yield. Moreover, to raise productivity and save energy, it is necessary for a line has more flexibility in combination of rolling schedules. Consequently, there has been a strong demand for the development of rolling mill to control the shape and profile. Pair Cross mill (hereinafter PC mill) is one of the most successful solution for these needs, it achieves excellent crown controllability by crossing work roll and back-up roll in pair.

After the first PC mill started operation in the 1984<sup>[1]</sup>. In the last 30 years, over 150 stands of PC mill were supplied around the world. They contribute to the achievement of high accuracy and quality of rolled strips through superior strip crown and flatness controllability.

Lately, the 4th generation PC mill was launched with full hydraulic control system. Instead of electro-mechanical driven system, full hydraulic driven system is in charge of crossing rolls and keep them in parallel. This feature enables a few valuable functions in PC mill. Meanwhile, the 4th generation PC mill is also provided with strong shape and crown capability, simple structure and better maintainability.

### 2. Principle of PC Mill

Figure 1. shows the principles of the PC mill. The top rolls and bottom rolls are crossed in a pair, which consists of work roll and back-up roll. The cross angle is defined as the half skew angle between the upper and lower roll units and can be adjusted by the roll crossing system. When top and bottom rolls set parallel, strip has convex crown. As cross angle increases, strip becomes flat and turns to concave crown. Additionally, to avoid generating thrust force between work roll and back-up roll, they always cross in pair, therefore, flat and symmetric rolls can be applied which is suitable for high load and high rolling speed rolling.

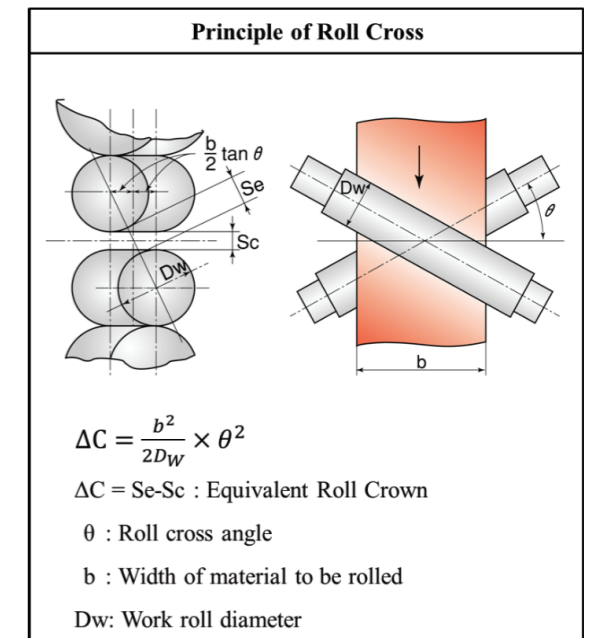


Figure 1. Principle of strips crown control by PC mill

Control of Strip Crown by Roll Cross	
Cross Angle	Strip Crown
0 degree	Convex
Middle	Flat
Large	Concave

Figure 2. Control of Strip Crown by Roll Cross

As shown in Figure 2, the roll gap formed by crossing upper and lower roll units increases in the form of a parabola as the distance from the center increases. It is equivalent to convex roll crowning of the work roll. The equivalent roll crown  $\Delta C$  is expressed by the equation indicated in Figure 1. When the cross angle becomes larger, the edge gap between top and bottom work rolls becomes larger than the center gap. And so, strip crown can be changed from convex profile to concave profile in a wide range. Adjustment of the cross angle enables crown control of the rolled strips. In practical use, PC mill shows excellent controllability of crown and shape for various strip thicknesses, width, and materials.

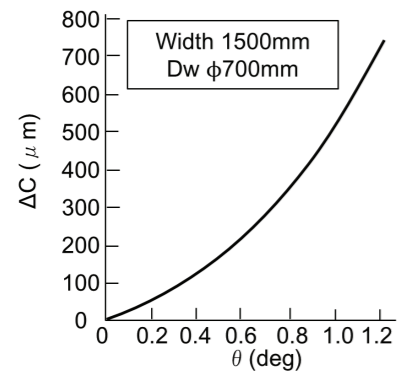


Figure.3 Equivalent roll crown

Figure.3 shows the equivalent roll crown  $\Delta C$ , which expresses change of roll gap difference between strip width

end and center caused by cross angle  $\theta$ . The width is 1500mm, the diameter of the work roll is 700mm, and the cross angles vary from 0 to 1.2 degrees. It shows that a wide roll gap controllability is obtained by roll crossing.

3. Footprints to 4<sup>th</sup> generation PC mill

Figure.4 shows the changes of the pair cross system as it evolved over time. The most remarkable change happened in the roll cross system.

The 1st generation has motors and clutches mounted on the mill top. Crossing device are equipped both on the entry side and delivery side. The 2nd generation PC mill has the roll crossing system at only the work side or the drive side, thereby drastically reducing the number of parts of the mechanism.

In the 3rd generation, a special designed hydraulic cylinder called mill stabilizing device (hereinafter MSD) is introduced. This cylinder partially replaced the role of electrical motor for one side. But MSD cylinder is more than holding chocks at the opposite of cross device.

The latest, 4th generation, PC mill no longer has motors and for crossing rolls. Rolls are completely controlled by hydraulic cylinders. Therefore, the mechanical structure are hugely simplified.

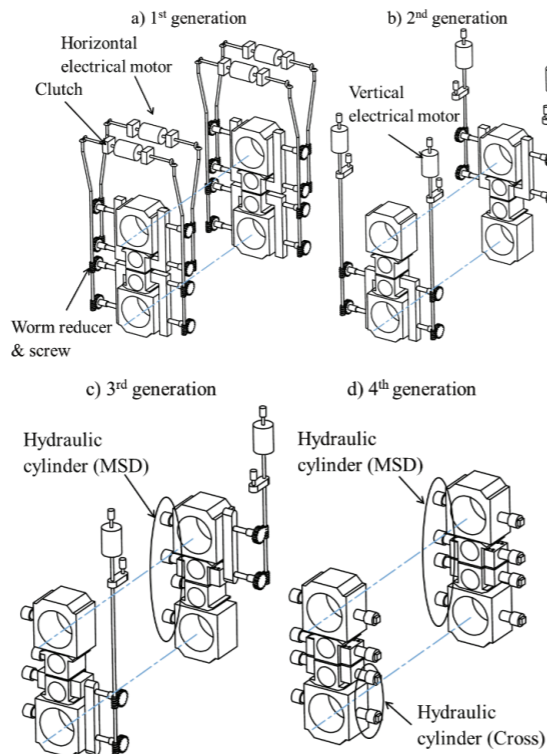


Figure 4. Scheme of roll PC mill roll cross system

Currently, Primetals Technologies are executing two upgrading projects from 1st generation PC mill to 4th generation PC mill. New features applied in this two projects, MSD and Auto-zeroing function are described below.

4. Mill Stabilizing Device (MSD)

Recently, the strips are rolled harder and faster to obtain thinner and higher quality strips. Especially for some certain steel grade, higher flow stress and reduction results in higher rolling force.

Strips with high speed and reduction generate larger impact forces during threading, vibration occurs at upstream mill stands. This intensive mill vibration reduces life time of the mechanical parts, reduces operation stability and restricts production gauge. Mechanism of this mill vibration was investigated, and the origin turned out to be the clearance between roll chock and housing.

To solve these issues, the MSD which consists of the hydraulic cylinder with orifices has been developed. The hydraulic cylinders are installed between the work roll chocks and housing to eliminate the clearance between them. MSD has excellent performance in reducing threading troubles and suppressing mill vibration.

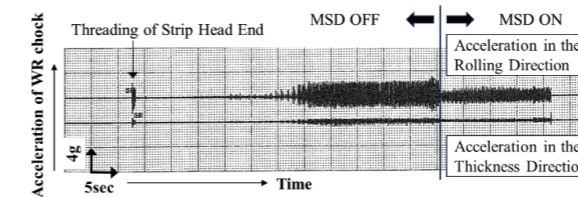


Figure 5. Effect of MSD on suppressing mill vibration [2]

Figure 5 shows the effect on suppressing mill vibration during rolling.[2] The accelerations are measured by sensor mounted on the work roll chocks in the rolling and thickness direction. The acceleration in the rolling direction is much larger than that in the thickness direction. When the MSD is turned ON, the acceleration in the rolling direction becomes about half as large as that with the MSD OFF.

5. Automatic chock position zeroing function

Apart from application of MSD inherited from 3rd generation, auto-zeroing is newly developed for 4<sup>th</sup> generation PC mill.

When work roll and back-up roll are not perfectly paralleled, micro skew between them generates thrust force, which creates a rotational moment on mill stand. Due to this unbalanced moment, differential load between work side and drive side happens. Finally, this unbalanced load leads to pinching problem. This problem troubles hot strip mill plants around the world, regardless the type of mill

stands, pair cross mill, curved roll mill, work roll shift mill or conventional mill.

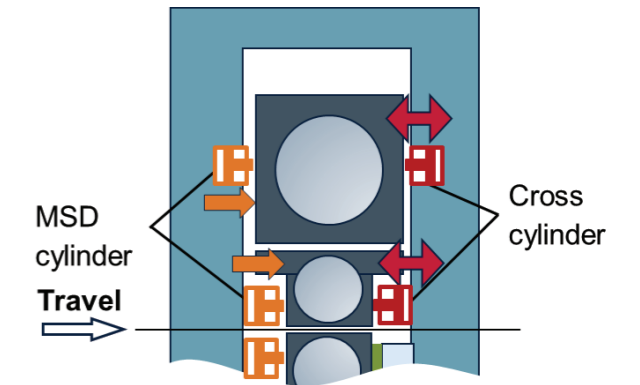


Figure 6. Roll cross system of 4<sup>th</sup> generation PC mill

Figure 6 shows the scheme of roll cross system of 4th generation PC mill. MSD cylinder is on the entry side. Each MSD cylinder follows a chock respectively. On the delivery side, there is another cylinder named cross cylinder. The cross cylinder controls the cross angle by a built-in sensor.

This mechanism enables work roll and back-up roll to move independently and keep them in parallel always. Therefore, auto zeroing turns out to be a promising solution to prevent micro skew between work roll and back-up roll, freeing operators from traditional countermeasures, such as reduction limit, regular monitoring and adjustment of liner. As a result, maintenance workload can be relieved and maintenance cost also can be considerably reduced.

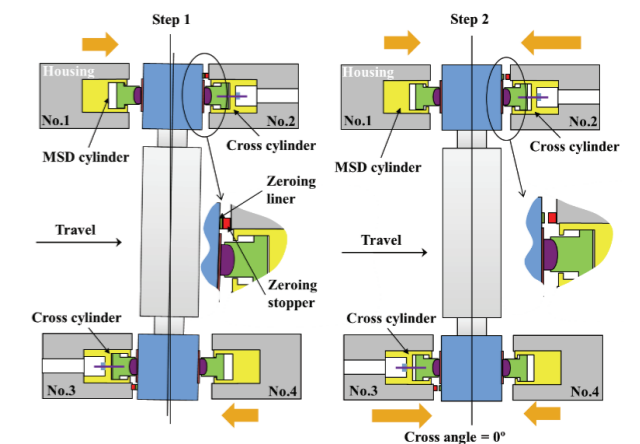


Figure 7. principle of auto-zeroing function

Figure 7 shows the principle of auto-zeroing function. This is view from top side of finishing mill stand. For the convenience of explanation, only work roll is shown in the

figure. Back-up roll has completely the same movement as work roll. Strip runs from left to right.

After work roll exchange, auto-zeroing can be conducted automatically. For the first step, cross cylinder pulls back to backward limit and MSD cylinder pushes chock forward until zeroing liner and zeroing stopper touches each other.

As the touching point position is known and fixed, it is possible to use it as a reference position for chock.

Step 2 is to push chock back to 0° position from the reference position by cross cylinder. The corresponding cylinder stroke back to 0° position can be calculated. The built-in sensor help control the cross cylinder to push forward for this certain stroke. After top and bottom rolls step 2, auto-zeroing finishes and all rolls now are all paralleled and the cross angle is 0.

## 6. Conclusion

PC mills have been developed for superior strip crown and flatness control. The number of PC mills has been consistently increasing and PC mills are now widely used throughout the world. The total number in operation is approximately 150 stands. After years of development, the 4th generation PC mill is launched to correspond the increasing needs of current steel market for flexible production, high quality products and low maintenance workload.

The new generation PC mill equipped with full hydraulic control system can control the position of work roll chock and back-up roll chock independently. In addition, the auto-zeroing function is realized. With these new features, threading trouble during strip biting can be considerably reduced and maintenance workload can also be relieved significantly. Primetals Technologies will continue to propose new hot rolling technologies and facilities for the abovementioned requirements.

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## Optimisation of Roll Cooling and Descaling Processes at Erdemir 2. HSM

Ereğli Demir Çelik 2. Sıcak Haddehanesinde Merdane Soğutma ve Tufal Alma Optimizasyonu

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### Abstract

Low prices for steel semi products, world-wide overcapacities in steel production and strong international competition demand for highly efficient steel production processes in order to reduce production costs and increase productivity. This also demands for continuous improvement even of well-established production lines.

Since the startup the 2<sup>nd</sup> Hot Strip Mill of Ereğli Demir Celik (Erdemir) in 1978, two major revamps have been done in 1995 and 2007. In 1995, the roll cooling system and in 2017 the roughing descaling system design have been revised.

Lechler was tasked to investigate both, the roll cooling and descaling system in order to optimize both processes while utilizing the available resources and avoiding major modifications. Based on detailed technical proposals both systems have been adjusted.

A thermal roll cooling study evaluated a potential efficiency increase utilizing the existing cooling water capacities. As a result a revised cooling nozzle layout has been proposed for the existing header types. With the new nozzle layout the cooling water was redistributed on the roll surface in order to reduce the work roll surface temperature, minimize roll defects and extend the work roll lifetime. An increase of the product quality and a reduction of the maintenance costs would be additional benefits.

Simulations on the descaling operations were conducted as a benchmark of the existing systems performance. Revised descaling nozzle layouts have been proposed for the roughing and finishing mill in order to increase the efficiency. As a result a significantly improved descaling performance could be achieved in combination with reduced water consumption of the descaling operations.

These optimizations increased the productivity of the hot strip mill. Work roll cooling problems such as roll wear, surface quality problems, nozzle clogging have been minimised. Additional cost savings have been achieved by decreasing the energy consumption of descaling pumps. The product quality was increased by decreasing the scale and roll surface quality problems.

### 1. Introduction

Erdemir and Lechler jointly evaluated potentials for an efficiency increase in the roll cooling and descaling system of HSM#2.

Potential for optimization was expected in the roll cooling header design which initially comprised a wide range of different nozzle types including very small nozzles, which are prone to clogging. The existing strip thickness across the width was affected and the roll surface quality was poor.

Also the efficiency of the roll cooling system had to be checked after HSS type rolls were in operation.

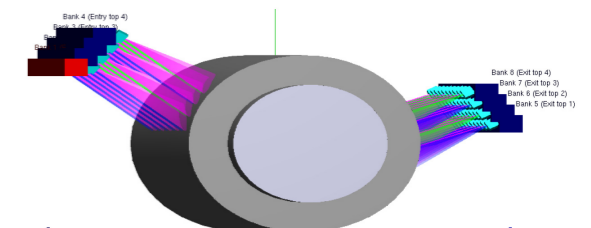
At the same time a study of the descaling efficiency was requested in order to evaluate the existing performance and evaluate the potential for energy efficiency increase.

### 2. Optimization of the roll Cooling System

The roll cooling system of HSM#2 consists of 7 stands with 4 roll cooling headers each.

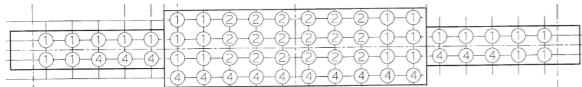
The system was revamped in 1995. Since then several process parameters have changed, e.g. HSS rolls have been installed. Therefore an increase in roll cooling efficiency was desired.

The existing nozzle layout was maintenance intensive as various nozzle types were installed in each roll cooling header. An example of the existing design is shown in **Figure 1** and **Figure 2** below.



**Figure 1.** Existing center top work roll cooling design.





**Figure 2.** Existing nozzle types installed in top entry work roll header.

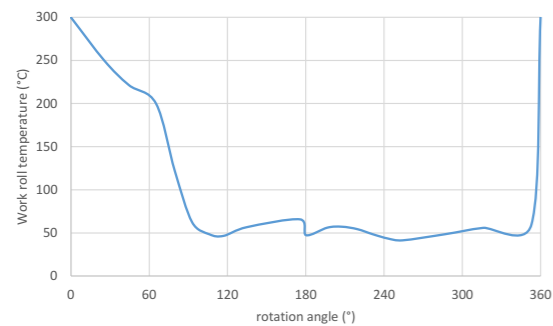
In each header a total of 60 nozzles with 3 different nozzle types were installed, totally 9 different nozzle types were installed in the 4 headers. The nozzles were arranged in 4 rows in the center area and 2 rows on the edge.

**2.1. Thermal Study**

In order to evaluate the roll cooling system’s efficiency, a thermal study was performed by Lechler in cooperation with Innoval. The work roll temperature profile during continuous mill operation was calculated based on actual process parameters.

The study included an on-site survey of the roll cooling system and measurements of the work roll temperature during operation in order to benchmark the simulation results.

Subsequently the existing thermal roll profile was simulated in a thermal model. An example of the existing thermal profile of the top work roll of stand F1 is shown in **Figure 3**.



**Figure 3.** Simulated existing center top work roll temperature profile during operation.

The work roll temperature was predicted at 95 °C, which was in good agreement with the on-site measurements. This thermal load is too high for HSS rolls and resulted in strong roll wear. An increase of cooling efficiency was strongly recommended.

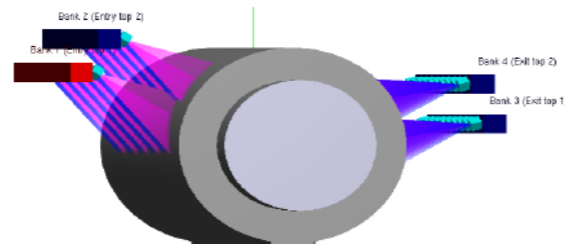
**2.2. Optimized nozzle types and arrangement**

Based on the findings in the simulations of the existing conditions an optimized roll cooling nozzle layout was created and the thermal profile was simulated accordingly.

A sketch of the revised top work roll cooling nozzle layout is shown in **Figure 4**. The nozzle layout is strongly

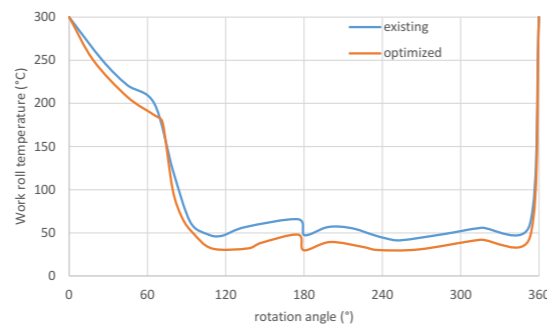
simplified compared to the existing condition. Totally 30 nozzles are installed in each header. The number of nozzle rows is also reduced by 50 %.

At the same time the spray footprint on the work roll has been increased resulting in increased cooling efficiency. The same cooling ratio between center and edge region is maintained in order to maintain the axial strip expansion.



**Figure 4.** Optimized center top work roll cooling design.

The resulting work roll temperature profile is compared to the existing profile in **Figure 5**. As a result of the optimized roll cooling nozzle layout the work roll temperature can be reduced by 15 °C utilizing the existing cooling water flow rates and pressure. The cooling efficiency is increased accordingly by 38 %. This will have a positive effect on the roll condition and lifetime.



**Figure 5.** Optimized center top work roll temperature profile during operation compared to the existing profile.

The nozzle series proposed for the revised headers is the Lechler 6F series with a rigid and precise self-aligning connection as shown in **Figure 6** which will reduce maintenance time [1].



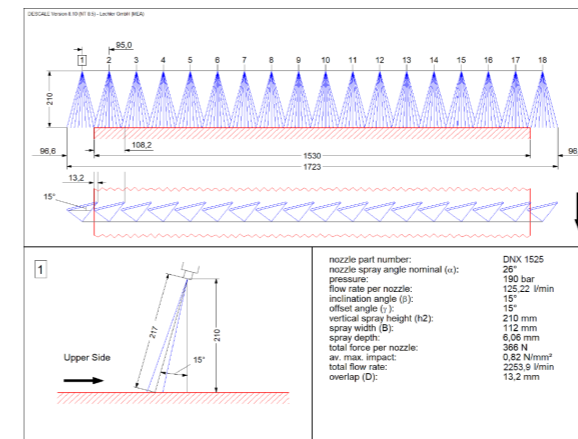
**Figure 6.** Recommended Lechler 6F-series nozzle types nipple and nut for the revised headers.

**3. Optimization of the Descaling system**

Lechler investigated the existing descaling systems in the roughing mill (RM) and the finishing mill (FM) in order to optimize the energy efficiency of both systems. In order to reduce the costs of optimizations the existing header design had to be maintained.

The existing RM descaling system comprised headers with 18 nozzles for top and bottom side at a vertical spray distance of 210 mm. The operating pressure was 190 bar.

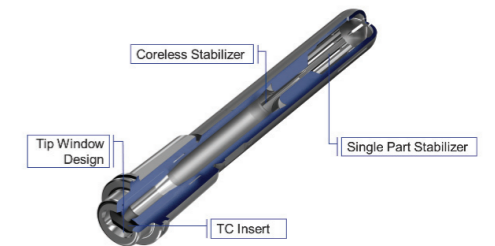
The existing nozzle types have been evaluated at operating conditions in terms of the existing spray impact and descaling width. The spray impact distribution has been implemented in Lecher’s descale simulation software. The result in **Figure 7** shows the existing condition with an average maximum impact of 0.82 N/mm<sup>2</sup> at a water flow rate of 2,254 l/min per header.



**Figure 7.** descaling simulation result for existing RM layout

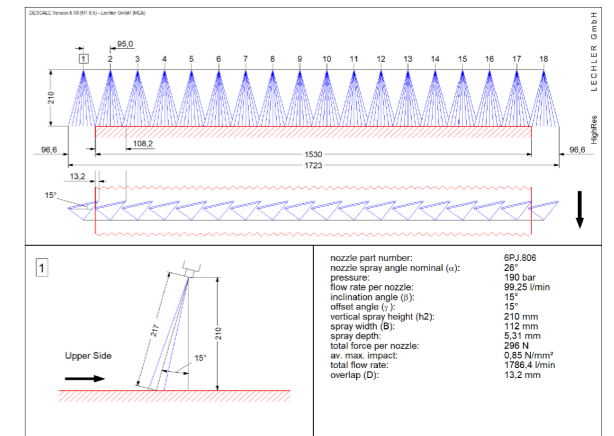
An optimized nozzle type was required for the RM header, maintaining the same header configuration and operating pressure and improving the energy efficiency of the descaling unit.

For this purpose, Lechler nozzle type Scalemaster HPS has been proposed. The Scalemaster HPS provides an optimized utilization of the available spray energy resulting in strongly increased impact and improved impact distribution compared to the existing nozzle types. Thanks to these features an increase in average maximum impact can even be achieved at a reduced water flow rate, maintaining the descaling width and water pressure [2]. The Scalemaster HPS with according filter/stabilizer is shown in **Figure 8**.



**Figure 8.** Scalemaster HPS nozzle with filter/stabilizer unit

The simulation of the optimized descaling nozzle layout is shown in **Figure 9**. The average maximum impact is increased to 0.85 N/mm<sup>2</sup> (+3.7 %) while the total water flow rate is reduced to 1,786 l/min (-20.8 %) at the same time.



**Figure 9.** descaling simulation result for proposed RM layout

The existing FM descaling system comprised headers with 22 nozzles for the top and the bottom side at a vertical spray distance of 210 mm. The operating water pressure was 190 bar.

The same procedure as for the RM has been performed for the existing nozzle layout. An optimized nozzle layout has been proposed in order to increase the impact while reducing the water flow rate.

As a result the impact could be increased from 0.84 N/mm<sup>2</sup> to 0.87 N/mm<sup>2</sup> (+3.6 %) while the water flow rate was reduced from 2,183 l/min to 1,759 l/min (-19.4 %) for each top and bottom header.

A summary of the existing and proposed nozzle layout and process parameters is shown in **Table 1**.

**Table 1.** summary of descaling system analyses results.

	RM		FM	
	Existing	Proposed	Existing	Proposed
Nozzle	DNX1525	6PJ.806	682.805	6P3.765
Filter/ Stabilizer	01F04	06P.353	064.253	06P.353
Quantity of Nozzles	18	18	22	22
Total Flow Rate (l/min)	2254	1786	2183	1759
Deviation	---	-20.8%	---	-19.4%
av. Max. Impact (N/mm <sup>2</sup> )	0.82	0.85	0.84	0.87
Deviation	---	3.7%	---	3.6%

#### 4. Implementation

The recommended roll cooling nozzle layout has been implemented as proposed. New headers have been designed and the new nozzle types have been installed. The new nozzle types reduced maintenance due to the rigid and self-aligning Lechler 6F-series nozzle type.

The revised descaling nozzle types could be implemented in the existing headers by simple nozzle and stabilizer exchange without any mechanical adjustments to the existing headers.

Both, the roll cooling and the descaling system upgrade, have been conducted during regular maintenance.

Therefore the total cost for implementation of the upgrades was low and could be realized from the regular maintenance budget.

#### 5. Results

The implementation of the revised roll cooling systems resulted in reduced work roll temperatures as predicted. Existing problems such as roll wear, strip surface quality problems and nozzle clogging have been strongly reduced or eliminated.

A significantly improved descaling performance in combination with reduced energy consumption for descaling operations has been achieved through the revised FM and RM descaling units.

The maximum water flow rate of the descaling operations has been reduced by 1784 l/min (107 m<sup>3</sup>/h). Assuming average operational times of the descaling system and nominal pump efficiencies this results in energy savings of 1,031 MWh/a. This will reduce the operating costs depending on the currently fluctuating energy prices. Also the carbon (CO<sub>2</sub>) footprint of the HSM will be decreased, which is another step towards “green steel”.

The product quality was increased at the same time by reducing the scale and roll surface quality problems.

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## Affecting Factors on Gloss Value for Galvanized Cold Rolled Sheets

Soğuk Haddelenmiş Galvanizli Sac Parlaklığına Etki Eden Faktörler

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#### Abstract

Flat steel products are coated with zinc to ensure decorative requirements and prevent the steel from corrosion. Galvanized cold rolled (GCR) sheets has three main characteristics for decorative requirements, these are metallic effect, spangle and gloss. High gloss value is one of effective parameter on the customer demand.

In order to define influencing factors on gloss value, GCR sheet samples, with different dimensions and produced with different parameters, had been taken. Influencing factors such as zinc coating mass, sheet thickness, chemical composition of zinc coating, line speed were investigated under constant zinc pot metallurgy conditions.

This study finds out increase in strip thickness and Al% content of zinc coating leads to increase in gloss value, increase in coating mass leads to decrease in gloss value and gloss-line speed data gives a Gaussian curve where the gloss value reaches a maximum magnitude at about 100 m/min.

#### 1. Introduction

Galvanization is the process of applying zinc coating on steel to prevent corrosion. In addition to corrosion inhibition effect, zinc coating gives aesthetic metallic surface to steel. This metallic surface is also used to meet decorative requirements and has become a customer request over the years for applications like roofing, culvert pipes, panels, building sidewall panels, flashing doors etc. There are three different decorative expectations; metallic effect, spangle and shine. Metallic effect is come from zinc color in any case. As the Zn coating on a steel sheet solidifies, dendritic crystals grow around a core of solidified Zn, and in some cases, a flower-like pattern called “spangle” forms on the surface of the galvanized sheet. [1]. Shine is the ability of light reflection through galvanized surface [2]. The appearance of the coating (matte grey, shiny, spangled) does nothing to change the corrosion protection of the zinc coating [3].

There are two different production types according to application of zinc to steel surface. One is hot dip galvanizing which structural steel pieces are dipped into a molten zinc bath, held there until the temperature of the steel

equilibrates with that of the bath and cooled down. The second is continuous hot dip galvanizing which is applicable to strip and where strip passes through a zinc bath as continuous.

Continuously galvanized steel sheets are defined in EN 10346-Continuously hot-dip coated steel flat products – Technical delivery conditions, but shine or gloss is not a specified characteristic of the product in this standard [4]. Also there is no quantitative specification to evaluate the appearance of galvanized sheet. Only, International standard ISO 147132:2009 divides coating characteristics into two groups relating to steel chemical composition: 1) Coating has a shiny appearance with a finer texture. Coating structure includes outer zinc layer. 2) Coating has a darker appearance with a coarser texture [5]. Whereas shine is a requested property for galvanized sheet by consumers in the market.

For example, shinier galvanized sheets are preferable for the producer of panels according to MMK Metalurji customer request analyse [6]. Because, it is known that “Consumers focus increasingly on the visual appearance of product features and often evaluate the product quality and performance based on this [7].

For some constructions the visual homogeneity is important. However, the ones, which are composed of galvanized sheet with different thickness and coating mass, have shine difference between parts of the body.



**Fig. 1** Shows a silo which has dull and shiny parts on the body.



In batch hot dip galvanizing, it is known how to make shine or dull appearance by the help of studies about this issue. In batch galvanizing, shiny surface is directly related to free zinc layer and this layer depends on steel chemistries (with a typical levels of silicon, phosphorus, manganese & carbon), zinc bath chemistries, cooling time and withdrawal speed [8].

However, study, about shine property of continuous galvanized sheet, had not been found during literature research. On the other hand, parameters of production may change shine of surface relatively like Fig.3. This difference between two images on galvanized surfaces is a significant visual variation which is big enough to effect customer's aesthetic expectations.

Although the human eye is still the most capable instrument, automated gloss measurement is needed for quantitative and reliable quality control in industrial settings [9]. Under this article's test and assessment method title, determination of the best proximate evaluation method is discussed.

In this study, gloss change of continuously galvanized steel surface was examined according to parameters like line speed, strip thickness, coating thickness and Al% content of coating.

## 2. Experimental Procedure

### A. Materials

DX51D+Z grade steel sheets samples were used in the study produced by MMK Metalurji hot dip galvanizing line. Mechanical and chemical specifications of DX51D steel grade are given in Table 1 and Table 2 respectively.

TABLE 1  
DX51D STEEL GRADE MECHANICAL SPECIFICATIONS

Tensile Strength (N/mm <sup>2</sup> )	Elongation (% ) Min.
270 - 500	22

TABLE 2  
DX51D STEEL GRADE CHEMICAL SPECIFICATIONS (MAX.)

C%	Si%	Mn%	P%	S%	Al%
0,18	0,50	1,20	0,12	0,045	0,030

### B. Devices and Equipment

Sheet samples used in the study were prepared with hydraulic punch press which has 75 mm x 75 mm cut dimension. AND brand GR200 model precision scales (0,0001g precision) were used for weighing samples. Samples thickness had been measured with Horex brand IP54 model thickness gauge. Composition of the zinc

coating was analysed with Varian brand ICP-OES 710-ES axial spectrometer. Gloss values were measured at 20 ° with BYK TRI-glossmaster device Fig. 2.



Fig. 2 Glossmaster™ Gloss Meter

### C. Chemicals

Analytical Grade %36,5-38 HCl (Sigma-Aldrich brand) and %99 Hexamethylenetetramine (Merck brand) as an inhibitor were used in order to solubilise zinc coating from samples. Mutli-element Standard Solution IV (Merck brand) was used to create a method with ICP-OES 710-ES axial spectrometer.

### D. Test and Assessment Method

Shine property measurement method and optical properties of different surfaces are widely studied especially by the glossmeter manufacturers from beginning of 20<sup>th</sup> century up to now.

Hunter R. S., in 1937 described six different kinds of gloss: (1) specular gloss, (2) sheen, (3) contrast gloss, (4) absence-of-bloom gloss, (5) distinctness-of-reflected-image gloss, (6) absence-of-surface-texture gloss. He indicated that both metallic and nonmetallic surfaces exhibit specular reflectance [10].

Linke B., in 2016 investigated the gloss measuring systems of different surfaces and also metallic surfaces for determination of quality defects on metal surfaces by gloss measurements. For her purpose she used specular glossmeters with the angles 60° and 20° [11]

In the technical catalogue of glossmeter suppliers it is indicated that gloss measurement is available at 20° angle for the metallic surfaces which have mirror effects [12, 13]

Considering studies above, 20° and 60° gloss measurements are done and the most compatible angle with human eye is decided. The photo on the left gives 97 GU at 60° and 207 GU at 20° and the one on the right which is shinier gives 116 GU at 60° and 423 GU at 20°. 20° angle is decided to use because of its distinctiveness even for small shine differences for human eye Fig. 3.



Fig. 3 A photo of a dull and a shiny galvanize samples

The dimensions of related galvanized steel test specimens were 75 mm x 75 mm. Minimum 5 test specimens had been prepared for each parameter. Gloss values were calculated as an average of 3 different points' measurement values by glossmaster device on each test specimen in accordance with EN 13523-2. Zinc coating mass analyses were done in accordance with EN 10346.

Thicknesses of test specimens were measured with calliper gage. Zinc pot metallurgy and coating compositions were analysed by in ICP-OES (inductively coupled plasma optical emission spectrometry) device in accordance with TS EN ISO 3815-2 [14].

Influencing factors such as zinc coating mass, sheet thickness, chemical composition of zinc coating, line speed were investigated under constant zinc pot metallurgy conditions Table 3.

TABLE 3  
ZINC POT METALLURGY OF MMK METALURJI

%Al	%Cd	%Fe	%Pb	%Sb
0,22-0,25	0,003	0,0400	0,0200	0,0040

### 1) Effects of Zinc Coating Mass on Gloss Value:

In this part, effect of zinc coating mass on gloss value was investigated with test specimens which have constant thickness 1.00 mm and variable zinc coating mass range between 80 – 300 gr/m<sup>2</sup> (Total Number of Samples: 25 ).

### 2) Effects of Sheet Thickness on Gloss Value:

Effect of strip thickness on gloss value was studied under constant coating mass 100 g/m<sup>2</sup> (Total Number of Samples : 50 )

### 3) Effects of Al% concentration of Zinc Coating on Gloss Value:

Al% concentration of samples with different strip thickness and coating mass were analysed and gloss value of each sample is recorded. (Total Number of Samples: 29)

### 4) Effects of Line Speed on Gloss Value:

In this part, effects of line Speed value was investigated on 36 test specimens which are randomly collected from HDG line products. The gloss values are measured and recorded.

## 3.Results

### 1) Effects of Zinc Coating Mass on Gloss Value:

Gloss value decreases by increasing coating mass as shown in table 4 and Fig. 4.

TABLE 4  
GLOSS VALUES OF DIFFERENT COATING MASS

Coating Mass (g/m <sup>2</sup> )	Average Gloss @20°	Sample Number
80	441	5
100	355	5
140	262	5
275	171	5
300	127	5

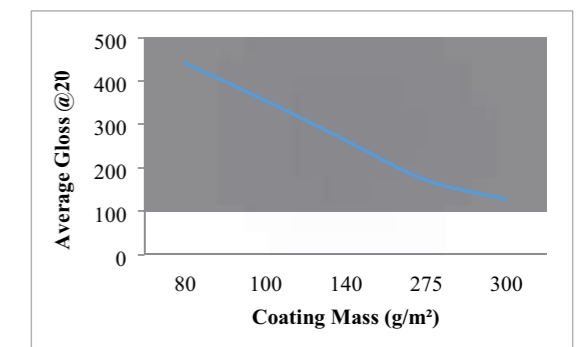


Fig. 4 Average Gloss – Coating Mass Graph

### 2) Effects of Sheet Thickness on Gloss Value:

Increasing coil thickness results an increase at gloss value as shown in Table 5 and Fig 5.

TABLE 5  
GLOSS VALUES OF DIFFERENT THICKNESSES

Thickness	Average Gloss @20°	Sample Number
0,43	249	5
0,50	222	5
0,60	288	5
0,80	332	5
1,00	261	5
1,20	447	5
1,35	467	5
1,40	384	5
1,90	530	5
2,00	467	5



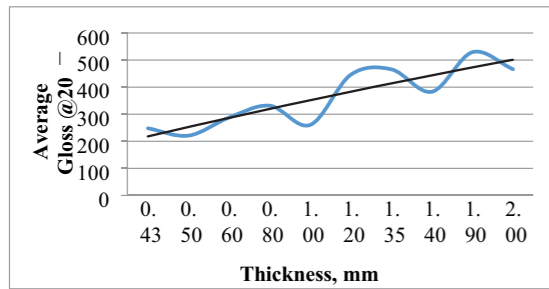


Fig. 5 Average Gloss – Sheet Thickness Graph

3) **Effects of Al% concentration of Zinc Coating on Gloss Value:** Increasing Al% content in the coating causes an increase on gloss value. The data regarding the effect is given in Table 6 and the graph in Fig. 6.

TABLE 6  
GLOSS VALUES OF DIFFERENT AL % CONCENTRATION OF COATING

Al % Conc. of Coating Mass	Gloss @20°
0,28	139
0,31	267
0,32	257
0,33	197
0,34	253
0,35	262
0,35	161
0,36	256
0,36	178
0,41	236
0,46	206
0,48	259
0,48	224
0,50	272
0,51	266
0,52	211
0,53	257
0,53	171
0,55	229
0,56	459
0,59	265
0,61	513

0,62	493
0,64	537
0,67	469
0,69	669
0,71	527
0,73	739
0,81	596

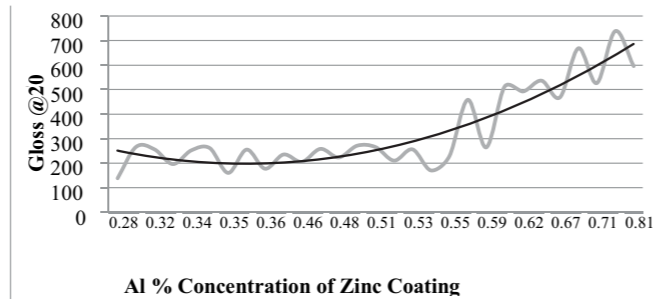


Fig. 6 Gloss – Al% Concentration of Zinc Coating Graph

4) **Effects of Line Speed on Gloss Value:** Line speed vs gloss values gives a Gaussian curve where gloss value increases up to a top magnitude at about 100 m/min and decreases then by increasing line speed, see, Table 7, Fig. 7.

TABLE 7  
AVERAGE GLOSS VALUES OF GALVANISED SHEETS PRODUCED AT DIFFERENT LINE SPEEDS

Average Gloss @20°	Line Speed (m/min)
210	55
336	77
529	99
288	134
253	180

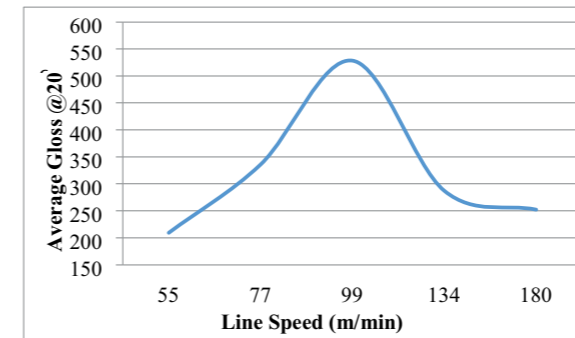


Fig. 7 Average Gloss – Line Speed Graph

#### 4. Conclusions

This study finds out that gloss value increases by increasing sheet thickness, increasing Al% in the zinc coating and decreasing coating mass. Also, line speed value is effective on gloss. The gloss of the galvanised sheet increases up to a certain line speed value like 100 m/min and tends to decrease on the line speeds bigger than 100 m/min.

Gloss is one of the leading decorative property on customer demand but unfortunately it depends on the customer order characteristics like sheet thickness, coating mass etc. which determines the line speed and Al% concentration of the coating during the galvanised sheet production.

According to the results of this study, in a conventional continuous hot dip galvanising line with the capacity 30 to 180 m/min line speed, 70 to 600 g/m<sup>2</sup> coating mass and 0,25 to 3 mm strip thickness, the most glossy (shiny) product can be obtained with the production parameters between 90 to 110 m/min line speed, 70 to 80 g/m<sup>2</sup> coating mass and 0,95 to 1,24 mm strip thickness.

#### 5. Acknowledgments

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## A Ferrous Study Investigating the Film Thickness and Lubrication Behaviour of Steel Cold Rolling Oils

Soğuk Hadde Yağlarının Film Kalınlığı ve Yağlama Davranışını İnceleyen Araştırma Çalışması

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### Abstract

This study will focus on ball-on-disc measurements to investigate the central film thickness, film forming and friction properties of the TOTAL range of steel cold rolling lubricants intended for steel cold rolling applications. These oils are designed to contain a variety of mixed esters and additive packages to aid their lubrication and film forming behaviour with the aim to minimise friction, roll wear and energy loss during the rolling process. The results will then be used to (1) calculate an approximated pressure-viscosity coefficient value for each tested lubricant and (2) verify the relationship between thicker films and lubrication profile changes based on our current internal friction testing methodology. It is anticipated this information will contribute towards predicting the ability of a lubricant to withstand increased rolling speeds, without compromising viscosity, to improve the accuracy of our lubricant screening process and aid their productivity within steel rolling mills. The three lubricants tested in the current study are designed with different properties and are compared from a research perspective.

### 1. Introduction

#### 1.1 Elastohydrodynamic lubrication

Lubricated contacts within many metal applications involve non-conforming surfaces which roll or slide together to create elastohydrodynamic (EHD) contacts<sup>1</sup>. The EHD lubrication regime is characterised by small contact areas which give rise to high Hertzian pressures; a form of pressure resulting from elastic deformation of the surfaces that arise due to the extent of pressure and shear stress within the contact<sup>2</sup>. Thus, the film thickness of a fluid within EHD contacts will depend heavily on two factors: (1) the dynamic viscosity of the lubricant, with higher viscosity fluids producing thicker films and (2) the entrainment speed, whereby the volume of fluid drawn into the contact area will be greater at higher speeds, resulting in thicker films<sup>3</sup>.

#### 1.2 Pressure-viscosity relationship of lubricants

Whilst the dynamic viscosity of a lubricant can be measured straightforwardly in a laboratory setting at a range of temperatures, it does not provide a conclusive representation of the pressure induced variation of viscosity that will inevitably occur in an industrial

rolling mill. EHD lubricated contacts in-situ do not typically operate in steady-state conditions and are often subject to extreme pressure and shear environments. In effect, as derived from Barus, the viscosity of a fluid will increase exponentially with pressure as shown in Equation 1<sup>4</sup>. The viscosity at pressure 'p' and atmospheric pressure are denoted by  $n_p$  and  $n_o$  respectively, and  $a$  is the pressure-viscosity coefficient.

$$n_p = n_o e^{ap} \quad (1)$$

The increased lubricant viscosity during the rolling process can lead to detrimental effects on lubrication performance as the fluid begins to adopt solid-like characteristics and flow rate is reduced. The prominent factors that affect a lubricants viscosity during the rolling process are temperature, pressure and shear stress (and these factors are a direct result of the friction, load, speed and mill operating conditions)<sup>5</sup>. Although highly sought after, the concept of determining this pressure-viscosity relationship for lubricants within the metal rolling industry is largely elusive because it is a difficult parameter to measure experimentally. It requires an extremely precise temperature-controlled, high pressure viscometer that is both rare and expensive to operate<sup>6</sup>. This lack of knowledge is therefore a major limitation in the lubricants industry. A plausible approach to investigate a lubricants pressure-viscosity relationship, is the use of mathematical models that rely on the assumption that the viscosity of a fluid varies with pressure.

#### 1.3 Calculating pressure-viscosity coefficient from EHD film thickness

Considering the EHD film thickness dependencies highlighted in section 1.1, many theoretical and experimental determinations of EHD central film thickness ( $hc$ ) and pressure-viscosity coefficient exist. It is therefore important to be aware that there will be different limitations for each approach. A detailed comparison of some of the most widely used models within literature are discussed by H van Leeuwen<sup>6</sup>. The model applied within this study was derived by Hamrock and Dowson and utilises the relationship in Equation 2<sup>7</sup>:

$$\frac{hc}{R} = k \left( \frac{U n_o}{E' R} \right)^a (\alpha E')^b \left( \frac{W}{E' R^2} \right)^c \quad (2)$$

$E'$  and  $R$  are the reduced Young's modulus and reduced radius of the interacting contacts, and  $W$  and  $U$  are the applied load and the entrainment speed. The overall geometry of the two surfaces determines the value of  $k$ , and  $n_0$  and  $\alpha$  are the lubricants dynamic viscosity at atmospheric pressure and the pressure-viscosity coefficient respectively. The indices  $a$ ,  $b$  and  $c$  are computational constants. In practice, measuring the film thickness of a homogenous lubricant within the EHD lubrication regime is well established throughout current industrial knowledge and can be easily achieved using optical interferometry<sup>8</sup>. The procedure can be optimised to investigate the film forming behaviour of fluids at a range of speed, temperature and load conditions. Therefore, at fixed values of  $E'$ ,  $R$  and  $W$ , this enables Equation 2 to be simplified to Equation 3:

$$h_c = k'(Un_0)^{0.67}(\alpha)^{0.53} \quad (3)$$

If two fluids are then tested using the same operating conditions, we can deem the values for  $k$  and  $U$  to be constant to yield Equation 4:

$$\left(\frac{h_{c1}}{h_{c2}}\right) = \left(\frac{n_{o1}}{n_{o2}}\right)^{0.67} \left(\frac{\alpha_1}{\alpha_2}\right)^{0.53} \quad (4)$$

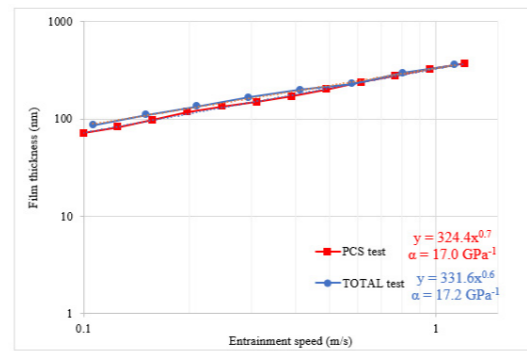
Simple rearrangement allows us to then calculate an approximated value for pressure-viscosity coefficient of one fluid in terms of the other, Equation 5:

$$\alpha_1 = \alpha_2 \left(\frac{h_{c1}}{h_{c2}}\right)^{\frac{1}{0.53}} \left(\frac{n_{o2}}{n_{o1}}\right)^{\frac{0.67}{0.53}} \quad (5)$$

By using a reference fluid with a known pressure-viscosity coefficient, we can indirectly determine the unknown pressure-viscosity coefficient of another fluid based on a comparison of the measured central film thickness and dynamic viscosity as shown in Equation 5<sup>9</sup>.

#### Reference fluid

A standard mineral oil with a known pressure-viscosity coefficient at 40°C (17 GPa<sup>-1</sup>) determined by PCS-Instruments, is used as a reference to enable pressure-viscosity coefficient determinations of steel cold rolling oils between entrainment speeds of 0.02 – 3 m/s. The dynamic viscosity for this fluid at 40°C is measured to be 57.4 mPa.s, and its EHD coefficient value at 20N is 324.4 as shown in Fig.1. This EHD coefficient value is to be used as  $h_{c2}$  in Equation 5 for all pressure-viscosity coefficient calculations. The EHD machine used for all measurements is supplied by PCS-Instruments. To test the reproducibility of the EHD measurements, the standard mineral oil was tested and compared to the results provided by PCS-Instruments, also presented in Fig.1. The TOTAL result correlates well and produces a reproducible pressure-viscosity coefficient ( $\alpha$ ).



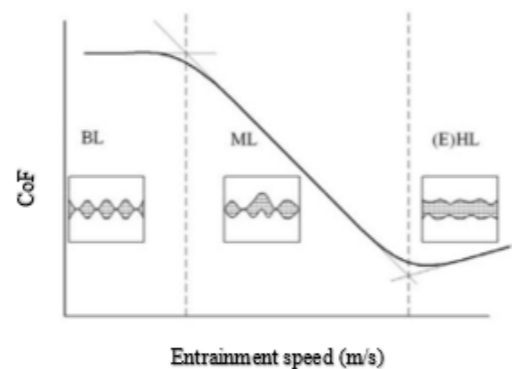
**Figure 1.** EHD coefficient for reference oil determined via the Power gradient of the film thickness measurements.

#### Limitations

All equations used in this study rely on the assumption that the fluids do not exhibit any shear thinning in the contact inlet. However, in practice extensive shear thinning within high pressure rolling EHD contacts occurs regularly for high molecular weight lubricants (or those containing polymeric viscosity modifiers)<sup>10</sup>. This results in thinner EHD films than expected when using their low shear rate viscosities, which complicates the calculation of pressure-viscosity coefficient using Equation 5; the opposing impacts of pressure-induced viscosity increase, and shear rate-induced viscosity decrease cannot be separated. It has been suggested that using dynamic viscosity measurements at higher shear rate would improve the accuracy of Equation 5.<sup>11</sup>

#### 1.4 Friction; estimation of Lambda Ratio

The primary purpose of a lubricant is to minimise friction between moving surface contacts. In practice, measuring the frictional properties of a fluid can be achieved using tribometers whereby the measured coefficient of friction is expressed in terms of entrainment speed; exemplar stribeck result outlined in Fig.2.

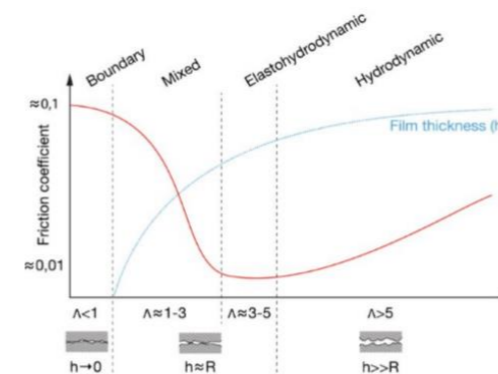


**Figure 2.** A stribeck curve expressed in terms of entrainment speed<sup>12</sup>.

The test is designed to begin at high speeds which gives rise initially to elastohydrodynamic (EHD) lubrication where thicker films are generated, and lower coefficients of friction are observed as there is little metal-metal contact. Within the EHD lubrication regime, the film thickness is much larger than the surface roughness and hence the EHD friction originates solely from the bulk rheological properties of the lubricant at high pressures and strain rates<sup>13</sup>. As speed is reduced throughout the duration of the test, we move through the mixed lubrication regime and transition into the boundary lubrication regime where increased metal-metal contact and thinner lubrication films are observed, resulting in higher coefficients of friction. An effective way to relate friction and measured film thickness of lubricants directly is via the use of the lambda ratio ( $\lambda$ ); a well-studied parameter that relates the ratio of lubricant film thickness ( $h$ ) to the surface roughness of the contacts ( $\sigma$ ), defined in Equation 6<sup>14</sup>.

$$\lambda = \frac{h}{\sqrt{\sigma_1^2 + \sigma_2^2}} \quad (6)$$

Therefore, if the test conditions for film thickness and friction measurements are kept constant, the stribeck curve can be converted to a plot of coefficient of friction vs lambda ratio as shown in Fig.3. This then analyses the friction properties of the lubricant during the transitions through the lubrication regimes and correlates them to the film thickness. Figure 3 outlines that the typical values for  $\lambda$  ratio within the hydrodynamic lubrication regime are greater than 5, the elastohydrodynamic regime range between 3 and 5. For mixed lubrication, the values range between 1 and 3, and boundary lubrication fall below 1.



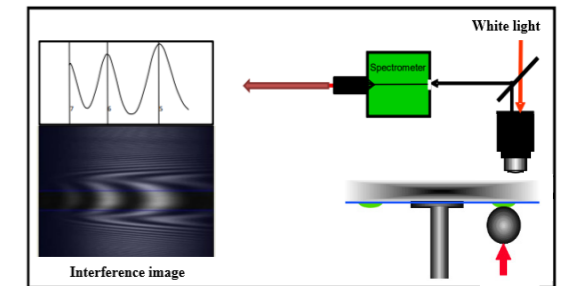
**Figure 3.** A stribeck curve result expressed in terms of lambda ratio<sup>15</sup>.

## 2. Experimental theory and procedure

### 2.1 Film thickness measurements

The EHD method applied in this study utilises the circular (pure rolling) contact formed between a

19.05mm steel ball ( $\sigma_1 = 20$  nm) and a highly reflective, rotating glass disc ( $\sigma_2 = 5$  nm) at 20N. The contact is illuminated by a white light source directed down a microscope and through a glass lens. Part of the light is reflected from the chrome layer on the disc, and part of the light travels through the silica layer (and any additive film) and is reflected from the steel ball. The measured wavelengths of the recombining light paths generate a film thickness map of the contact area – schematic of the experimental setup outlined in Fig.4.



**Figure 4.** Schematic of film thickness measurement<sup>16</sup>.

### Testing parameters

Prior to testing, all specimens (steel ball and reflective disc), test components and lubricant reservoir are cleaned thoroughly with iso-propanol and hexane. The lubricant test sample is added to the reservoir and set to desired temperature (40, 60, or 80°C). The ball is then half immersed into the neat lubricant test sample and loaded onto the reflective disc in static conditions to 20N. The disc cover is fitted, and the microscope/spectrometer is assembled and adjusted in order to obtain a clear spectral image. A spectral image/film thickness measurement is generated for each increasing incremental rolling speed from 0.1 - 3 m/s. The outputted results of the finished test are a logarithmic plot of film thickness (nm) vs entrainment speed (m/s). The EHD coefficient values required for the pressure-viscosity coefficient calculations will be determined from the Power gradient of each result in the same manner as the reference fluid outlined in Fig.1.

### 2.2 Friction measurements

The method for measuring the frictional properties of steel cold rolling oils used in this study uses an automated tribometer (mini traction machine). Our standard configuration uses the MTM-3D SLIM machine supplied by PCS-Instruments and measures the friction between a 19.05mm steel ball and a 46mm diameter steel disc; the ball is loaded against the face of the disc whereby each specimen is driven independently to create a mixed rolling/sliding ratio of contact. This 'ball on disc' mode is a model system to mimic the contact during steel rolling applications to allow a somewhat effective lab-to-field approximation in the screening and differentiation of rolling oil lubricants.



**Limitations of MTM**

Unlike the in-use field process whereby the steel strip is consistently replenished during rolling, the MTM works via rotation of the steel disc substrate. This means that upon one full rotation of the steel disc, the points of contact will be reused throughout the duration of the test. Furthermore, any plastic/elastic deformation or elongation that would occur on the metal sheet is also not simulated in the measurement.

**Testing parameters**

Prior to testing, all specimens (steel ball and steel disc) and test components are cleaned in an ultrasonic bath for a duration of 5 minutes in iso-propanol and hexane respectively. The lubricant pot is also cleaned with the same solvents. Once all specimens and components are clean and dry, they are assembled into position and 50mL of neat test oil is added to the lubricant pot – schematic of the test procedure is outlined in Fig.5. The pot cover is attached and locked into place. All measurements are then performed automatically based on the inputted MTM method. The MTM method uses an applied load of 20N for all temperatures (40, 60 and 80°C) and a slide/roll ratio of 50%. Decreasing incremental rolling speeds from 3 – 0.02 m/s are kept consistent for each test.

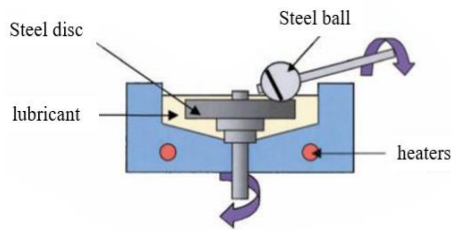


Figure 5. Principle of MTM measurement<sup>17</sup>.

**3. Results and discussion**

**3.1 Lubricant properties**

This study will consist of the lubrication and film thickness evaluation of three current steel cold rolling lubricants; each bearing their own individual formulations containing a variety of base oils, esters and metalworking performance enhancing additives. A summary of their bulk composition is presented in Table 1.

Table 1. Overview of test lubricants.

	1	2	3
Base stock	Synthetic Polyol ester/polyunsaturated vegetable triglyceride	Synthetic Polyol ester/saturated vegetable triglyceride	Unsaturated animal-based triglyceride

**3.2 Pressure-viscosity coefficient determination from measured EHD film thickness**

Three lubricants have been investigated, with the aim to determine their pressure-viscosity relationships and quantify their elastohydrodynamic film-forming capabilities. The initial phase of this task included measuring the film thickness of each lubricant at three temperatures (40, 60 and 80°C) with increasing speeds from 0.1 – 3 m/s at a constant load of 20N. The generated results, and thus their obtained EHD coefficients, are presented in Figs' 6-8.

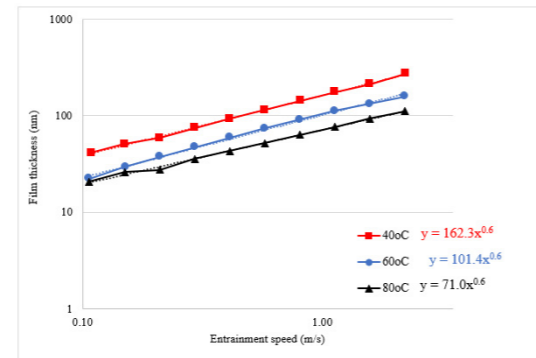


Figure 6. EHD coefficient determinations at all temperatures for lubricant 1.

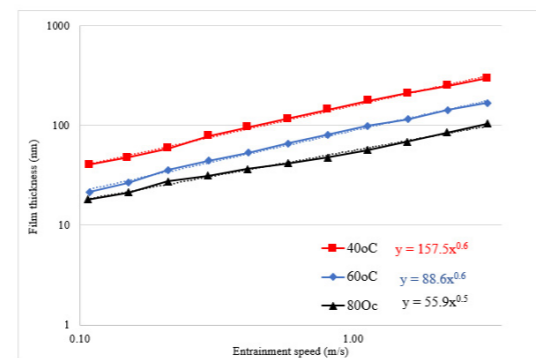


Figure 7. EHD coefficient determinations at all temperatures for lubricant 2.

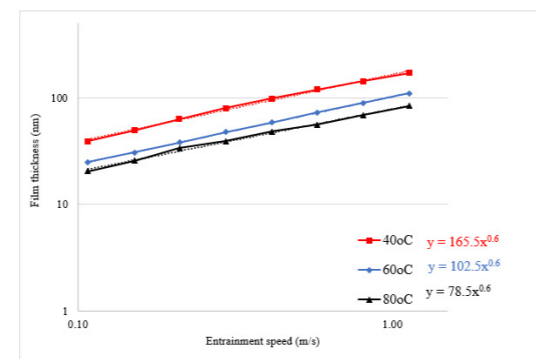


Figure 8. EHD coefficient determinations at all temperatures for lubricant 3.

It has been shown that increasing the entrainment speed, leads to incremental increases in film thickness for all tested lubricants at each temperature. Maximum film thickness profiles are exhibited for each lubricant at 40°C. This suggests that temperature changes, and the resulting dynamic viscosity effects, lead to clear differentiations in film forming behaviour - with lower temperatures, and higher fluid dynamic viscosities creating increased film thicknesses across all lubricants as speed is increased. These findings conform with the EHD film thickness theory discussed in section 1.1 which outlines that higher viscosity fluids and higher entrainment speeds are expected to produce thicker films. Upon completion of the film thickness measurements, the extrapolated power gradient for each individual plot yielded the EHD coefficient values; also highlighted in Figs'6-8. These values were then directly inputted into Equation 5. Approximations for pressure-viscosity coefficient values ( $\alpha$ ) for all lubricants has been achieved across the range of temperatures using the formulae discussed in section 1.3 – presented individually in Figs' 9-11, and collectively in Fig.12. The dynamic viscosity, EHD coefficient and pressure-viscosity coefficient values are presented in Tables 2-4.

Table 2. Dynamic viscosity, EHD coefficient, and  $\alpha$  values at 40°C.

Sample	Dynamic viscosity (mPa.s)	EHD coefficient	$\alpha$ (GPa <sup>-1</sup> )
Lubricant 1	32.6	162.3	9.4
Lubricant 2	29.3	157.5	10.2
Lubricant 3	38.7	165.5	12.6

Table 3. Dynamic viscosity, EHD coefficient, and  $\alpha$  values at 60°C.

Sample	Dynamic viscosity (mPa.s)	EHD coefficient	$\alpha$ (GPa <sup>-1</sup> )
Lubricant 1	17.3	101.4	8.7
Lubricant 2	14.9	88.6	8.1
Lubricant 3	19.9	102.5	10.2

Table 4. Dynamic viscosity, EHD coefficient, and  $\alpha$  values at 80°C.

Sample	Dynamic viscosity (mPa.s)	EHD coefficient	$\alpha$ (GPa <sup>-1</sup> )
Lubricant 1	10.3	71.0	8.5
Lubricant 2	8.7	55.9	6.7
Lubricant 3	11.8	78.5	8.7

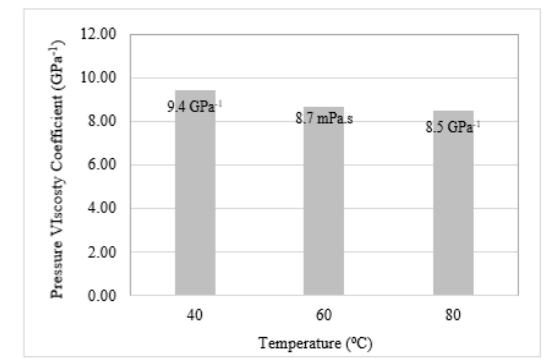


Figure 9. The effect of temperature on  $\alpha$  for lubricant 1.

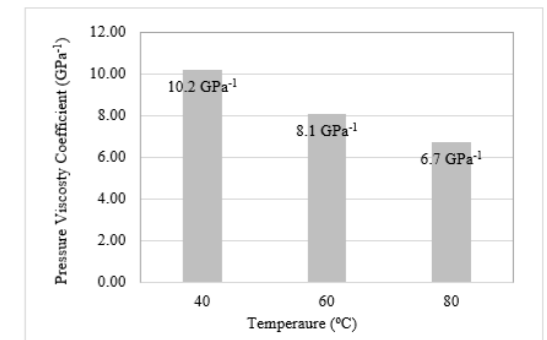


Figure 10. The effect of temperature on  $\alpha$  for lubricant 2.

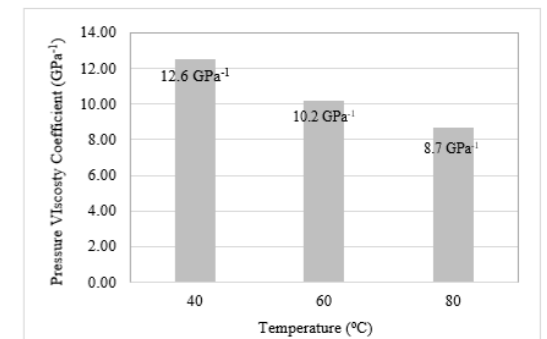


Figure 11. The effect of temperature on  $\alpha$  for lubricant 3.

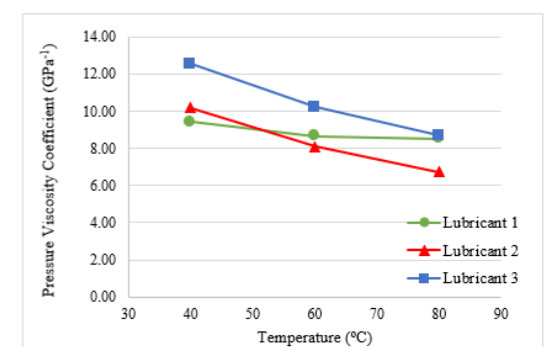
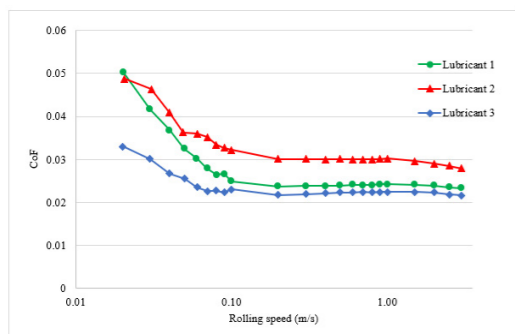


Figure 12. The effect of temperature on  $\alpha$  for all lubricants.

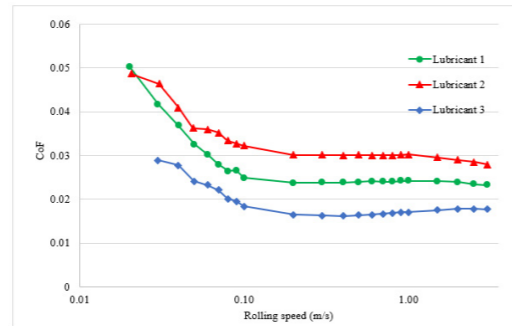
Observing Tables 2-4, the values for determined EHD coefficient correlate well with the measured dynamic viscosities. In each case, the calculated EHD coefficients are greater when dynamic viscosity is higher. This is to be expected as more viscous fluids tend to produce thicker films within the contact. The effect this has on the pressure-viscosity coefficient values is outlined in Figs'9-11, whereby it is shown that for each lubricant the value for pressure-viscosity coefficient,  $\alpha$ , decreases linearly as temperature is raised. This trend coincides well when compared to pressure-viscosity coefficient vs temperature studies within lubricant literature<sup>18,19</sup>. It is proposed that lower EHD pressure-viscosity coefficients is attributed to the lower film thickness ranges we observe at higher temperatures<sup>20</sup>. Overall it can be deemed that the method for calculating  $\alpha$ , derived by Hamrock and Dowson, has been successful (despite the slight inconsistency in trend at 40°C for lubricant 1 in Fig.9). A collective evaluation of the three lubricants, outlined in Fig.12, demonstrates that lubricant 3 produces the highest range of  $\alpha$  values consistently at all temperatures. This suggests that lubricant 3 has a better ability to retain its viscosity under high speed and temperature conditions within EHD contacts. Interestingly, the  $\alpha$  values for lubricant 1 decreases the least across the spread of temperatures as outlined by its almost flat plot in Fig'12; suggests a good capability of retaining viscosity as temperature is increased.

### 3.3 Coefficient of friction analysis

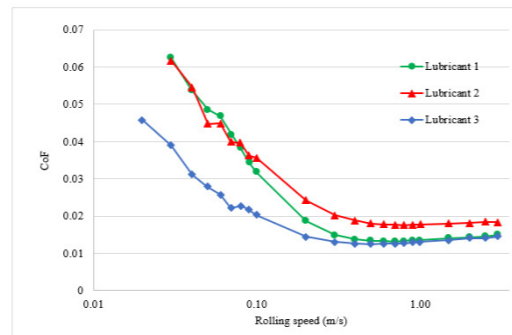
The second phase of this study asks the question if increased film thickness leads to visual lubrication improvements. The original stribeck curves for all lubricants at each temperature are displayed in Figs'13-15; providing an overview of the friction behaviour (CoF) and its dependency on entrainment speed. The plots of lambda ( $\lambda$ ) ratio, and hence the effect of film thickness and surface roughness on CoF, are presented in Figs'16-18 and these results will be the focus within the discussion. As the surface roughness for the test specimens are kept constant, the differences observed in Figs'16-18 are deemed to be largely influenced by the film thickness.



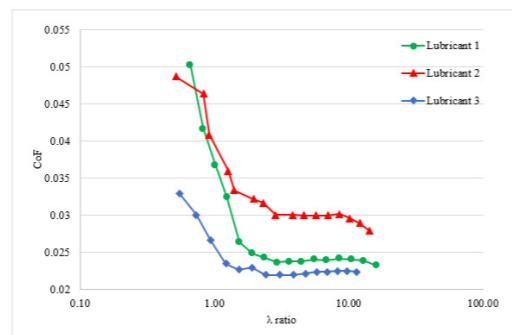
**Figure 13.** Entrainment speed vs CoF for all lubricants at 40°C.



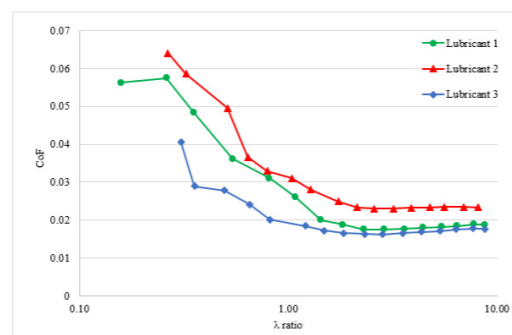
**Figure 14.** Entrainment speed vs CoF for all lubricants at 60°C.



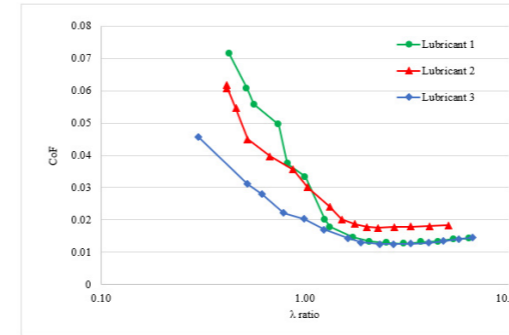
**Figure 15.** Entrainment speed vs CoF for all lubricants at 80°C.



**Figure 16.** The effect of  $\lambda$  ratio on the CoF for all lubricants at 40°C.



**Figure 17.** The effect of  $\lambda$  ratio on the CoF for all lubricants at 60°C.



**Figure 18.** The effect of  $\lambda$  ratio on the CoF for all lubricants at 80°C.

Focusing on Figs'13-15, lubricant 3 displays lower values for coefficient of friction (CoF) throughout each lubrication regime at all temperatures. At high speeds, the lowest values for CoF are observed which is characteristic of (EHD)hydrodynamic lubrication. The transition into the mixed lubrication regime outlines a gradual increase in CoF values, demonstrating classic friction behaviour as we begin to reduce entrainment speed and metal-metal contact is increased. As discussed in section 1.4, we can analyse the stribeck curves more attentively if we know the film thickness of the lubricant at each speed measurement. Figures 16-18 outline the CoF results plotted versus the specific film thickness ( $\lambda$  ratio). In all cases, it is shown that the lowest CoF values arise when  $\lambda$  ratio is high. The CoF values are shown to rise with decreasing  $\lambda$  ratio. Increased  $\lambda$  ratios can be attributed to high speed conditions and hence higher film thicknesses, thus the trends observed for all lubricants conform with the standard friction theory discussed in section 1.4.

Figures 16-18 show that at each temperature, lubricant 3 exhibits the lowest CoF values consistently throughout the individual lubrication regimes; this is most significant at 40°C. As temperature is raised through to 60°C and 80°C, the behaviours of lubricant 3 in the elastohydrodynamic (EHD) and hydrodynamic (HD) regimes begin to overlap with lubricant 1, and hence its superior lubrication benefit is most prominent in the mixed to boundary lubrication regime transition. It is observed that lubricant 2 exhibits the largest CoF values predominantly at high speed conditions within the EHD and HD lubrication regimes across all temperatures. Specifically, in figure 18, the lubrication behaviour of lubricant 2 begins to compete with lubricant 1 upon transition to the boundary lubrication regime.

### 3.4 The relationship between thicker films and improved lubrication

When the EHD film thickness results for all lubricants are directly compared to the friction results, there is a definitive relationship between increased film thickness and improved lubrication. There is of course a limit to this as we must consider the efficiency losses in-situ if

the lubricant becomes too thick. As outlined in section 3.2, lubricant 3 yields the highest dynamic viscosity values across all temperatures and thus results in larger EHD coefficients derived from the film thickness plots. The calculated pressure-viscosity coefficients were also higher in all cases. This concurs with its improved EHD lubrication properties evidenced by its tendency to generate lower CoF values across all temperatures as outlined in the stribeck curves (Figs'16-18). On the contrary, lubricant 2 is shown to have the lowest range of dynamic viscosities across all temperatures which resulted in the lower generated EHD coefficients. The calculated pressure-viscosity coefficients for lubricant 2 were also shown to be lower (apart from the slight deviation at 40°C). The low film-forming characteristics are reflected also in the stribeck curves, evidenced by its tendency to produce higher CoF values within the high-speed lubrication regimes at all temperatures. Lubricant 1 is defined to be the median across all EHD and pressure-viscosity coefficient results and is shown to compete well when observing its pressure-viscosity coefficient and CoF values at high temperature, whereby its high  $\alpha$  and low CoF values compete directly with lubricant 3.

### Conclusion

The EHD film thickness for a selection of steel cold rolling oils has been measured over a range of temperatures at a constant load. A collective overview of the results suggests that at increasing temperatures, the value for the pressure-viscosity coefficient is reduced. This can be attributed to the significantly lower EHD coefficient values observed at higher temperatures. The Hamrock and Dowson derived equation for calculating pressure-viscosity coefficient has proven to be a positive choice as the results discussed in this study conform with EHD theory and lubricant studies within literature. Clear differences have been observed between the lubricants of varying base stocks, with lubricant 3 providing the highest pressure-viscosity coefficient values across all temperatures. There are however some small discrepancies at low temperature (40°C) where the model appears to lose accuracy. Hence, it could be suggested that further testing of these lubricants at higher temperatures (100, 120, 140°C) should be conducted to build a wider range of results. This would also correlate with more realistic mill temperatures in-situ. It has also been demonstrated in this study that there is a direct relationship between increased film thickness and improved lubrication properties, in terms of reduced friction whereby lubricant 3 consistently displayed lower CoF values across the range of lambda ratios at all temperatures, which coincides with its tendency to form thicker films. From a research perspective, the methods used, and combined results have proven to be effective in providing a respectable initial screening of lubricants and will be applied to a wider selection of steel cold rolling oils in the future.

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## Energy Efficiency with Special Lubricants in Steel Industry

Çelik Endüstrisinde Özel Yağlayıcılar ile Enerji Verimliliği

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KLÜBER LUBRICATION • Brazil

### Abstract

This article aims to present specific success case in cold roll mill application in the steel industry. To achieve that, were utilized reliable methodology to determine the energy benefits, proving that it is possible to implement energy conservation measuring in motor powered systems installed and mapping the main process variables that influences the energy consumption. The reduction of energy consumption and positive financial result was accomplished changing the lubricant, mineral oil, for a special lubricant. The result reached was 4,1% less energy consumed with a payback of 20 months and additional operational benefit of reduction of oil temperature in 15°C, which allowed the operators to increase the production speed.

### 1. Introduction

The objective is to show results in steel rolling mill equipment process, demonstrating occurrence of energy saving with the substitution of mineral oils, currently widely used in the industry in most applications, by synthetic oils evidencing the financial viability of the use of seemingly more costly solution coupled with other mechanical benefits increasing the return. The operational and mechanical improvement may even become a better argument than the energy efficiency itself.

The theoretical argument is that a high performance special synthetic lubricant from Klüber Lubrication increases the load bearing capacity and efficiency of a machine or a set of gears due to the lower coefficient of friction.

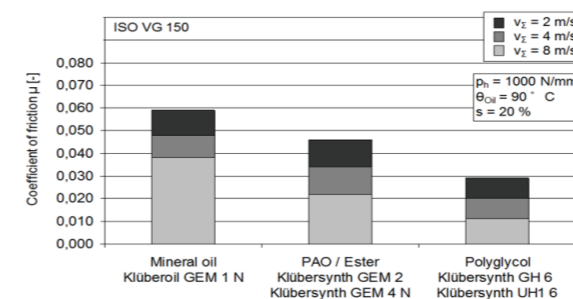


Figure 1. Friction Coefficients for Base Oils

Using the oil with lower coefficient of friction, almost half of the conventional mineral oils, the synthetic lubricant PAO (polyalphaolefin) and PG (polyglycol) have the capacity to

increase mechanical efficiency, which theoretically results in lower energy consumption due to lower losses caused by friction.

To validate this theoretical argument, measurements and methodologies were adopted following the International Measurement and Verification Protocol (IPMVP- EVO 10000 - 1: 2018), which is recognized by main international organizations. The trial was made in a steel plant in Brazil and results were confirmed by the technical sector of that company.

The greatest motivation for this study and the application of our proposal is the fact that according to a 2018 IEA (International Energy Association) report, on average, more than 60% of the energy consumption of the equipment in the industry comes from electrical motors. This motors drive air compressors, machines moved by geared motors (rolling mill process has the biggest electrical motors within a steel plant that drive gearboxes), chains that continuously move material during the manufacturing process as the main. As a rule, the application of lubricants is required, with that, following the concept of replacing mineral oil based lubricant in these machines, at least 4% reduction of electrical consumption can be reached.

The equipment we display in this article is of great relevance in the use of lubricants and is responsible for 80% of the energy consumption of the plant.

The retrofit and measurements were carried out at the ArcelorMittal (AM) Vega in São Francisco do Sul, Brazil, and the processing of the data obtained was done at Klüber Lubrication in Brazil.

### 2. Project Details

The measurements to determine the variables involved in the quantification of results were performed directly on the selected equipment. In addition to the measurements of the energy consumed, the production of the equipment was taken into account to determine the specific consumption (KWh/ton). It is imperative to consider that there are other variables with a strong influence on energy consumption such as production process conditions, electrical and mechanical interventions.



For comparison accuracy, all these variables and conditions must be the same in the baseline (mineral oil lubricant) and post-retrofit (Klüber synthetic lubricant) periods. The measurement limit to assert the results is restricted to the powertrain equipment involved, through the continuous measurement of the energy consumed by it, the production of the equipment and other variables of influence.

**Table 1.** Equipment information and products used

COLD ROLLING MILL	OEM: SMS -DEMAG
Number of Gearboxes	4 to drive the Mills + 2 Coilers
Oil Sump Volume (centralized system)	25,000 liters
Electrical Power (nominal of all motors)	27,000 kW
Oil in use (Baseline)	Mineral ISO VG 320 Temperature of Operation: 80 °C
New oil replaced (PAO basis)	KLUBERSYNTH GEM 4-320 Temperature of Operation: 65 °C

- Baseline (Mineral oil): 01/Jan to 31/May/2019
- Retrofit (Oil Change): 09/Jun/2019
- Post – retrofit ( Synthetic Oil): 16/Jun to 15/Nov/2019

The variables analyzed with high influence on the energy consumption were:

- Electric Motor Power (kW) per stand;
- Oil temperature (°C);•
- Oil flow (7 bar - 1036 liters / min)
- Speed (stands # 1, # 2, #3 and #4)
- Production (ton / hour);
- Product (bar code);
- Thickness between stands;
- Cross section (thickness x width);
- Time of production of coil
- Torque
- Weight of the steel coil

Were analyzed 39 product codes representing 85% of the portfolio produced in volume (tons) manufactured.

**2.1. Methodology used**

The measurements to determine the variables involved in the quantification of the results were carried out in the field, for each lubricant, directly at the installation site, using data from AM Vega’s data base systems. The measurements were made with the duration interval of 10 seconds of rolling of each coil and analyzed the same way. This data base was used to compare the power consumption profile of the main engines after the change from

mineral oil to synthetic oil, this period is called post-retrofit. The baseline and post-retrofit measurement period was each, 150 days.

In order to carry out the energy efficiency assessment of the oil replacement of the centralized lubrication system, it is necessary to build a model of energy consumption for the equipment responsible for the rolling power. For this, a set of equipment and production variables with mineral oil was first collected to build and validate a mathematical model.

Due to the high number of variables with influence, the complexity level for comparison was high. To solve this, a mathematic model was built, so a comparison with high level of accuracy could be performed. The coefficient of precision found for this model was 0.997 (or 99.7%).

With this, it was possible to predict the power consumed when data of the production was given (the independent variables).

Returning to the mill, we have a dependent variable which is the Power for each roll and 24 more independent or explanatory variables, in this case the regression analysis is widely used as a descriptive method of data analysis without requiring any assumptions about the processes and other variables influence that allowed the data to be generated. The baseline was represented by a function / mathematical model that describes the efficiency of the Power unit and determined through regression analysis as a function of the variables X, Y, Z, up to N:

$$Power = f(X, Y, Z, \dots N) \dots \dots \dots (1)$$

Once the coefficients for each independent variable was determined, it was possible to predict what the value of the dependent variable would be for any value read / known, respecting the limits where these values were obtained. With this, one can explain the phenomenon observed in a single mathematical equation, applying the coefficients. We can explain, or better, predict the value of the power for the baseline with only one equation.

$$Power_t = V_{1t} \times Coef_1 + V_{2t} \times Coef_2 + \dots + V_{nt} \times Coef_n$$

These coefficients multiplied the values read for each coil / line / instant from the database to the corresponding “Channel” (independent variable) in the other periods, respecting the limits of “minimum and maximum values as well as the validation conditions”. With this, it was possible to make the "prediction" of what the value of the "Total Power" of the current period would be for each coil, with no need to measure this variable, just calculate. With this method, after changing the oil to Klüber Lubrication’s oil, it was possible to say “what would have been the power read using Mineral oil if the change was not performed”.

This procedure was repeated for each stand (#1 to #4), respecting their own boundary measurement, in order to confirm the accuracy and results.

**Table 2.** Coefficients for Mill #2

Channel	GenLSFitCoefficients
Tempo Laminacao	1.33
Producao (ton/hora)	4.17
ESP_SAIDA	-6.32E+03
LARG_SAIDA	1.96
COMPRIMENTO_METROS	-0.544
PESO_SAIDA	138.81
REDUÇAO	-105.89
TCM_ESPESSURA_ENTRADA	764.90
VEL_MED_ENTR	-33.45
TCM_ESPESSURA_CAD_1	4980.65
VEL_MED_CAD1	29.43
TCM_ESPESSURA_CAD_2	-3.43E+03
VEL_MED_CAD2	-3.97
TCM_ESPESSURA_CAD_3	-2.21E+03
VEL_MED_CAD3	4.21
TCM_ESPESSURA_CAD_4	2064.16
VEL_MED_CAD4	33.42
VEL_MED_SAIDA	-24.05
TCM_FORÇA_CAD_1	0.203
TCM_FORÇA_CAD_2	0.111
TCM_FORÇA_CAD_3	0.194
TCM_FORÇA_CAD_4	-0.151
TCM_TORQUE_ENROLADEIRA	88.88

**ResultStatStdError: 4.82 kW ou 0.06 %**



**Figure 2.** Accuracy of Model (green line)

In the comparison between the averages, the error was 4.82 kW or 0.064% of deviation, using a determination coefficient (R<sup>2</sup>) equal to 0.997. Applying student’s t-test, was achieved a result with 99% of confidence when compare to the means.

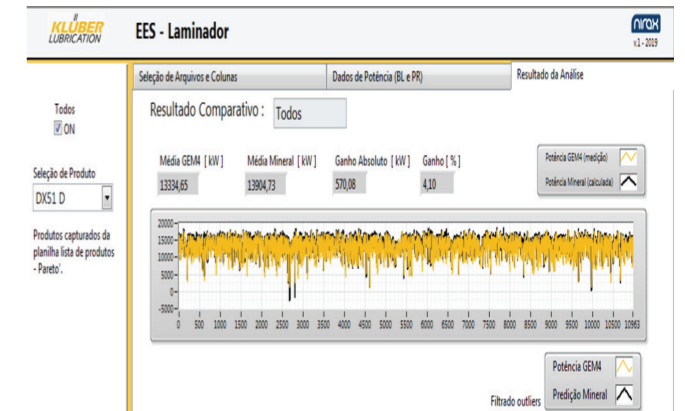
Because of the high number of product codes and repetition of the analysis, it was developed a software called EES using the algorithm proposed in order to do the calculations and comparisons for each case “Product Code and # of Stand” in separate.

The accuracy of the results stayed high, with 99% of confidence, and determination coefficients (R<sup>2</sup>), above 0.9, for every calculation executed.

**3. Results and Discussion**

Using the methodology defined and described in item 2.1, was made comparison between the data measured in the Post Retrofit and in the Baseline. It was possible to see graphically the “before” x “after” (black line is mineral oil, orange line is Klüber Lubrication’s oil) perceiving differences in Powers under exactly same conditions / values for all variables during post retrofit period.

The first result showed below is a dashboard of EES for “all stands and all products”, the result achieved was 4.1 % saving or 570.08 kW of less power demand in absolute value.



**Figure 3.** Results from software EES (all products & all stands)

For the calculation of each stand separately was followed similar procedure, resulting in savings of 4.06 % in weight average or 564.32 kW.

**Table 3.** Results for each rolling stand

All products Analysis	Power Reduction	Savings
Rolling stand #1	140.99 kW	5.183 %
Rolling stand #2	182.87 kW	4.021 %
Rolling stand#3	189.00 kW	4.419 %
Rolling stand #4	51.46 kW	2.188 %
<b>Total</b>	<b>564.32 kW</b>	<b>4.06%</b>

Another analyses was made for all products and for each stand (#1 to #4), so that the comparison considers also the hardness and other physical properties of each product under the same process conditions.

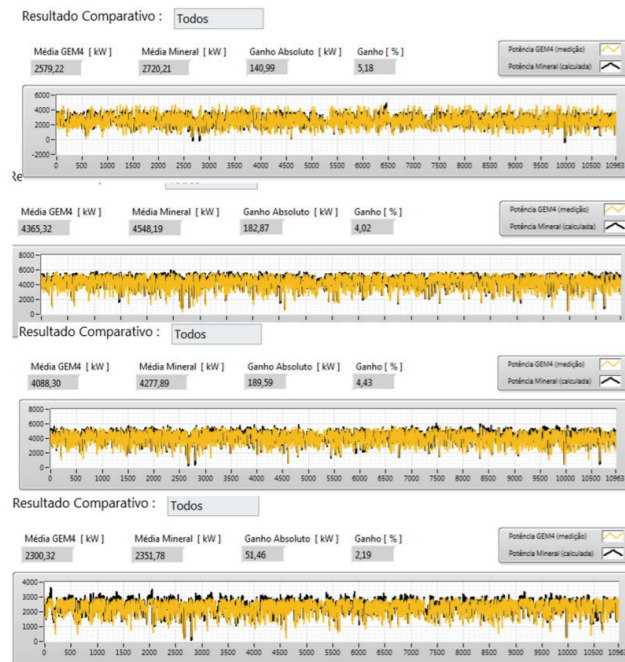


Figure 4. Results from software EES in each stand.

A procedure was also made for each product code separately, the results are summarized in the table below. The average was a reduction of 589,0 KW or 3,85 %. Because of the large number of products (many rows), this table is available in png file to give more details for readers.

Table 3. Results for all products and each Roll Mill

CODAÇO	PR	Cadeira 1				Cadeira 2				Cadeira 3				Cadeira 4				Total		
		Méda GEM4 [kW]	Méda Mineral [kW]	Ganho Absoluto [kW]	Ganho [%]	Méda GEM4 [kW]	Méda Mineral [kW]	Ganho Absoluto [kW]	Ganho [%]	Méda GEM4 [kW]	Méda Mineral [kW]	Ganho Absoluto [kW]	Ganho [%]	Méda GEM4 [kW]	Méda Mineral [kW]	Ganho Absoluto [kW]	Ganho [%]			
DX51D	15,57%	206,47	2089,15	15,35	0,49%	4471,6	4635,94	158,34	3,39%	4594,6	4326,54	268,06	5,83%	2079,96	2361,25	281,29	13,53%	5235,17	5358,34	123,17
SAE 1008	13,96%	2476,74	27114	206,46	0,75%	4623,08	4928,35	305,27	0,61%	4298,42	4638,42	340,00	7,79%	2063,9	2647,05	583,15	22,35%	14631,12	14884,2	253,08
USBOR 1600	10,24%	1205,59	2081,62	281,67	13,51%	3861,9	4462,87	600,97	13,46%	3623,25	4133,3	510,05	13,95%	2776,19	2897,3	121,11	4,36%	10294,49	10388,52	94,03
ARCO4HDG	6,39%	210,52	3296,52	100,08	3,72%	4286,02	4582,65	306,63	0,71%	4063,59	4371,48	307,89	0,71%	2398,84	2491,74	92,90	3,84%	10897,71	10538,59	359,12
SAE 1006	6,04%	1082,05	2359,69	127,64	5,39%	4952,11	4788,85	163,26	0,34%	3890,96	4392,59	501,63	1,31%	2492,57	2299,47	193,10	8,48%	10886,67	10323,2	563,47
ARCO9HDG	4,15%	3704,6	3788,77	34,37	0,91%	4622,25	4784,26	162,01	0,34%	4075,36	4371,81	306,45	0,70%	2494,96	2621,69	126,73	5,09%	15336,87	15642,36	305,49
BH220HDG	4,29%	2102,34	2389,05	286,71	12,22%	4682,77	4714,14	31,37	0,07%	4486,67	4683,46	196,80	0,42%	2103,17	2081,96	21,21	1,01%	15459,45	15794,64	335,19
HSLA30RDH	3,47%	2063,1	2363,01	300,00	12,60%	4084,42	4362,94	278,52	0,63%	3712,66	3853,46	140,80	0,37%	2594,21	2771,38	177,17	6,47%	10366,89	10242,49	124,40
SAE 1010	2,35%	1704,44	1868,25	163,81	8,99%	4773,45	5328,05	554,60	1,16%	4581,69	4893,62	311,93	0,68%	3396,51	3694,25	297,74	8,48%	14799,61	15033,57	233,96
HSLA20BF	2,23%	1889,65	2124,68	235,03	10,99%	3782,87	4162,38	379,51	0,90%	3881,19	3388,67	542,52	16,02%	2683,59	2881,21	197,62	7,26%	10102,78	10774,75	671,97
ARCO11HDG	1,90%	3141,46	3366,45	224,99	6,69%	4324,4	4664,42	340,02	0,72%	4079,95	4365,25	285,30	0,65%	2329,84	2366,09	36,25	1,54%	10883,13	10923,65	40,52
Q235PHDG	1,82%	2072,8	2098,80	26,00	1,24%	4253,36	4069,62	183,74	0,44%	4469,71	4638,62	168,91	0,36%	2278,63	2244,69	33,94	1,50%	10589,72	10735,64	145,92
HSLA30BDF	1,69%	2364,74	2721,69	356,95	13,03%	4284,42	4362,94	78,52	0,18%	4275,56	4463,46	187,90	0,43%	2288,78	2362,44	73,66	3,18%	10186,15	10376,77	190,62
ARCO6BF	1,60%	3494,38	3738,2	243,82	7,00%	4694,05	4881,1	187,05	0,40%	4326,61	4589,69	263,08	0,58%	2370,77	2395,98	25,21	1,06%	10260,61	10481,77	221,16
DP 600	1,37%	1896,4	2122,45	226,05	12,46%	3783,68	3380,95	402,73	11,17%	3070,11	3022,21	48,90	1,61%	2084,1	2266,40	182,30	8,27%	10298,15	10512,22	214,07
ARCO4BF	1,34%	1824,6	2021,8	207,20	11,37%	4453,61	4632,12	178,51	0,38%	4333,69	4532,36	198,67	0,44%	2293,99	2462,46	168,47	7,34%	10084,94	10266,39	181,45
ARCO1-BF	1,14%	1025,69	1081,01	55,32	5,39%	4482,97	4634,68	151,71	0,33%	3601,74	4025,16	363,42	1,01%	2249,4	2386,01	136,61	5,82%	10575,54	10734,98	159,44
HSLA20HDG	1,24%	2772,2	2881,98	109,76	3,82%	3878,9	4075,9	197,00	0,48%	4275,56	4463,46	187,90	0,43%	2376,71	2366,61	10,10	0,43%	10522,77	10563,56	40,79
ARCO9HDG	0,95%	1891,9	402,25	163,99	8,13%	4461,6	4742,24	280,64	0,65%	4001,02	4812,2	811,18	20,25%	2274,6	2361,01	86,41	3,79%	10438,29	10595,89	157,60
		2.127,25	2.172,72	45,47	2,09%	3540,60	3727,17	176,57	0,47%	3218,01	3484,11	266,10	0,77%	1930,86	1946,69	15,83	0,81%	10894,71	11030,70	136,00
		2.634,19	2.690,50	56,31	2,09%	4.394,26	4.615,40	221,13	0,47%	4.108,72	4.314,41	205,69	0,47%	2.353,85	2.406,61	52,76	2,23%	13.491,04	14.030,92	539,88

The methodology analyzing “each stand & each product” presents greater detail, as it analyzes each stand considering the interference within the set between each mill and by separate product, technically the most accurate result because it involves more variables in the analysis. With this methodology the result was savings of 573.52 kW or 4.101 %.

As the product codes portfolio was very similar for both periods, we can assume that it's not necessary to analyze them separate, decreasing a lot the efforts and time for next projects. The confirmation for this was obtained after doing a student's t-test with confirmed independence of the samples and accuracy of results with 99 % of confidence.

T-Test

[DataSet2]

Paired Samples Statistics				
	Mean	N	Std. Deviation	Std. Error Mean
Pair 1 Potencia Total LB	6269,019893	729743	4549,633224	5,3256905
Potencia Total PR	5903,224902	729743	4724,645381	5,5007528

Paired Samples Correlations				
	N	Correlation	Sig.	
Pair 1 Potencia Total LB & Potencia Total PR	729743	-.002	.044	

Paired Samples Test									
		Paired Differences			95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Potencia Total LB - Potencia Total PR	365,7949912	6566,792653	7,6872027	350,7263305	380,8616519	47,595	729742	.000

Figure 5. T-test results ran in SPSS Statistics Software

Out of conservatism and to increase the reliability (repetition), for financial evaluation the lowest absolute value verified (in kW) will be adopted as the final result of the analysis, this was with the methodology by product with all rolling mill as shown on Figure 5.

Result Adopted: Average reduction of 564.32 kW or 4.06%

This result was achieved using same methodology in different ways of process in order to do cross check and confirm the size order of the saving verified. The statistical analysis (t-test) also can be used in the simplest way to reach the final results.

The more detailed analysis, using all variables of the process, eliminates all doubts about the comparison in same conditions, despite the big variation among them.

3.1. Financial analysis

Financial analysis found a payback of 20 months, that is a very attractive investment with fast return.

Parameter	Value	Unit	Parameter	Value
Nominal Power	27.000	kW	Internal Rate	15%
Average Load	49,4%		Operation Time / year	7500
Oil Reservoir	20.000	Liters	Service Life (years)	10
Energy Price	0,03	Euro / kWh	# Gear Boxes	6
Amount of Analysis	1		Temperature	65
			Mineral	1,80 Euro
			KLUBERSYNTH GEM 4 -320	10,50 Euro
Oil Price ( in taxes )				
Energy Saving				4,06%
Power Demand Reduction				564 kW
Energy Saving / year				4.232.400 kWh
Economic attractiveness				
Expenditure to replace Oil	36.000,00 Euro		210.000,00 Euro	
Annual Expenditures ( Oil + Reposition )	5.760,00		27.300,00	
Annual Energy Saving	€ 0.00		€ 126.972,00	
Simple Payback				20 Months

Figure 6. Financial analysis of the saving achieved

It is important to consider also the sustainability benefits. The use of synthetic oils manufactured by Klüber Lubrication enabled the mill line, with comparable volume of steel produced, to reduce significantly its CO2 emissions.

Sustainability Analysis			
Category	Mineral	Klubersynth GEM 4-320 N	Saving per year
Lubricant FootPrint ( Oil Sump )	307.500 kWh	415.110 kWh	-107.610 kWh
Lubricant Consumption per Year	166.050,00 kWh	107.928,60 kWh	58.121 kWh
Water Consumption	675 liters / year	325 liters / year	420 kWh
	810,00 kWh	390,00 kWh	
Labor Force	2,36 kWh	0,21 kWh	2,15 kWh
Parts	96.000,00 kWh	24.000,00 kWh	72.000,00 kWh
Transport	5.500,00 kWh	2.648,15 kWh	2.852 kWh
Energy		4.232.400,00 kWh	4.232.400 kWh
Total Emissions Reduction	4.365.795 kWh		
	420,75 ton CO2 / year		200 Trees / year

Figure 6. Sustainable benefits consolidated in kWh eq. (Brazilian carbon conversion: 1 MWh = 96 kg CO2)

4. Conclusion

The result of 4.1% reduction of energy consumption in rolling mill, represents a financial benefit that should not be ignored by companies that seek to increase energy efficiency in their processes and shows that the practice of adopting high performance synthetic lubricant is a very good alternative among the energy efficiency solutions available.

This concept can be applied to any other gearbox with the same benefit, but in different order of magnitude. In the steel industry,

in which its machines work with peak loads closer to the nominal capacity, the result of replications could be even better.

It should be emphasized that financial gain with energy could be secondary for the company, since in many cases, the gain in productivity turns out to be far more relevant.

In addition to the financial benefits with the reduction of specific consumption there are other operational benefits obtained with the reduction of friction:

- Increased efficiency of gear pairs;
- Less wear of gear pairs, less maintenance costs.
- Increased efficiency through better agitation of the oil
- Reduced operating temperature;
- Increased lubricant life (5 times longer than mineral oil)
- Greater oxidation stability, less waste in the tank

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 Nicolas David, Head of Global Business Heavy Industry, Klüber Lubrication.

## Hot Rolling Roll Bite Lubrication (RBL)

Sıcak Haddedeleme "Roll Gap" Yağlama

Mike Cook

QUAKER HOUGHTON • Holland

Hot Rolling Mills can Lubricate the "Roll Bite" This lubrication is already utilized on a number of Hot mill Finishing Stands - With the main benefit seen on stands 1 to 5

The reason to Lubricate is as follows

- Increase Work Roll Life / reduction in roll changes and better roll surface and potential for Productivity Gains from less roll changes and longer rolling campaigns
- Energy Conservation and reduction of Carbon Footprint - reduction of roll forces by 10-30% achievable depending on mill stand and energy reduction
- Quality improvements- less strip defects from work rolls and less scale reported
- Enhanced mill capability - lighter gauges can be rolled with existing equipment and mill less prone to vibration

The Development of the oil takes two key aspects

- Dispersion Properties and plate out
- Intrinsic neat oil Lubrication tests

For the Dispersion properties Quaker Houghton have developed a high speed plate out tester that can simulate the application process and gives guidance for future modifications

Intrinsic Lubrication is normally undertaken by a "PLINT" test utilizing a steel ball or cylinder onto a steel test piece - the results are from analysis of the friction forces and visual inspection of the plate that can indicate the wear pattern.

There are a number of application methods for the "RBL" all are in current use on different mills and have the desired outcome

- Work Roll application - In this application the equipment is in a very vulnerable location and comes easily damaged from mill cobbles - If the application is above the wiper than the entry cooling water needs to be switched off - If the application is below wiper then good wiper condition is required - Otherwise uneven lubrication and banding type defect will occur
- Back - Up application - here the headers apply onto the back up roll and the oil is transferred onto the work roll - The selection of the timing on/off needs to be fine tuned to come on early enough to take into account the roll diameters -

Regular checks and Maintenance is required for both application types

There are a few types of application systems but Quaker Houghton use a MIDAS system - This MIDAS consists of a dosing pump for the neat oil - this feeds the oil to a static mixer situated close to the header at the mill - where after the static mixer it is mixed with water before being fed into the headers - We can utilize separate dosing pumps for top and bottom headers if required. The dosing pumps are very accurate and normal application rates range between 25ml/min - 150ml/min per header

This RBL lubrication can also be transferred to use on Edger roll to prevent roll wear and rolled in SEAM defect on light gauges - and also significantly reduce roll wear and extend the campaign length. We also utilize on Section/ rail mill operations





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## Imaging & Measuring Systems Görüntüleme ve Ölçüm Sistemleri

### Online Condition Monitoring System on Hot Rolling Mills

Sıcak Haddehane Tesisinde Online Durum İzleme Sistemi

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#### Abstract

Hot rolling mill section is literally the heart of the steel plant. The section produces vast amounts of sheet steel with different sizes and qualities which are used extensively on automotive, white good and domestic appliance industries. With respect to these high production rates, machinery reliability is of utmost importance for the plant. Rolling mills which needs to work continuously without a flaw, are the machine type that needs be the most reliable asset of the plant. Rolling mills can be divided in three main categories; Rougher mill, Edger mill and Finishing mill. Each of these divisions contain nearly the same machine elements which are mainly the main drive motor, a gearbox to reduce speed and increase the load and a pinion stand to get a double output which are turning in different directions to drive the milling stands. Each of these machines have very critical parts like rolling bearings and gear teeth that have to be perfectly and continuously monitored in order to prevent developing failures. The article contains the detailed structure of the online condition monitoring system which is implemented on the hot rolling mill plant in Isdemir – Iskenderun/TURKEY. In the last section of the article a bearing failure which has been detected with the help of the online system has been shared.

#### 1. Introduction

There are a couple of selection criteria that helps engineers choose the proper monitoring device for their assets. These criteria can be listed as below:

- Asset value
- Impact to the process in case of the unscheduled shutdown
- Health and safety risk in case of a catastrophic shutdown
- Health and safety risk of reaching out to the machine (during offline measurement)
- Length of the P-F curve
- Dynamics of the machinery

In this study regular criticality analysis was included and each item is marked with a proper value to be used as an

overall machinery grade. The overall criticality grade then reviewed against to the criticality limits to decide the type of the monitoring methodology.

Monitoring methodology for the vibration monitoring can be “offline” or “online”. If the criticality grade is low according to the predefined limits, then the offline vibration monitoring can be implemented. If the grade is high, then machineries should be monitored with online devices. In our case, it was obvious to monitor the hot rolling mill machines with online devices as the impact to the process in case of any unscheduled shutdown is big and the value of the machines are high. In addition to these properties, the dynamics of the machines have high complexity as there are more than one gear stages and the machine speeds and loads are continuously changing according to the material milled.

Measuring vibration levels with online device grants privileges like the ability to see all dynamic behaviour of the machine in conjunction with process parameters. Vibration level changes can be observed against speed, load and process states. Machinery faults are also able to be diagnosed with respect to load and speed parameters.

To maintain control on the machinery increases the reliability of the plant and provides knowledge about adverse effects caused by the hard material milling and mishandling of the machines which can be further improved.

#### 2. Properties of the Online Device and a Case Study

This section provides technical details about the online vibration monitoring and analysis system and at the end of the section a case study presented which has been formed with the help of the online devices installed in the hot rolling mill plant in Isdemir.

##### 2.1. Technical Properties

The online devices installed to the hot strip mill site are named as Vibguard© by Prüftechnik (see Figure 1) which have 20 analog channels that can collect data simultaneously. Channels should be configured according to the sensors will be used as voltage or current analog input before the installation. On the hot strip mill (HSM) project, low-to-mid frequency ICP type accelerometers has been used that can be seen in the Figure 2. As the nominal motor

speeds are not higher than 600 RPM, frequency response of the machines are pretty low in frequency (between 0-400 Hz).



Figure 1. Prüftechnik Vibguard - Advanced Condition Monitoring Device

Dynamic range for all channels is 110dB which is the consequence of 24-Bit ADC. This high level of dynamic range provides good quality diagnostic data. Each channel is capable of collecting data with 102400 spectral lines which is the highest spectral line value on the market. Spectral line setting is crucially important when the analyst's deals with the low speed machinery as it provides crystal clear spectrums that are easily analyzed.



Figure 2. Prüftechnik VIB 6.172 accelerometer installed on the bearings

It is possible to collect two different speed data at the same time with two tacho channels. On top of that four digital input channels can also be used for triggered data collection. These auxiliary channels help analysts to perform complex data acquisition tasks which will be seen in the examples of the next section.

Capability of the Modbus TCP communication protocol, helps with collecting process parameters from the production layers which are essential for the vibration analysis. For the milling line that has been studied in this

article process parameters like line speed, motor loads, motor bearing temperatures, material input signal are collected. These process parameters are used for conditional acquisition and divide the data to different operating states. Conditional acquisition feature of the Vibguard online system helps analysts to get rid of the unnecessary vibration, temperature and process data that might cause to increase the database sizes. Operating states feature provides an option to divide collected data into different states of the machinery for example load regions that change the vibration behavior significantly. On top of these properties, adaptive storage capability reduces data sizes significantly by eliminating similar data sets.

Temperature sensors has been used for each gearbox and pinion bearings to monitor the temperature values with the vibration values together. Temperature sensors installed on the bearings stated has been shared in Figure 3. Sturdy construction of the sensors made it suitable for that kind of harsh environment.



Figure 3. Emko temperature sensors installed on the bearings of gearboxes and pinions

As the machines that are monitored have highly dynamic working behavior and continuously changing speeds, it is mandatory to monitor the machine speed. Machine speeds has been collected with 10 inductive tacho sensors which are strategically located to ease the analysis process. It can be seen the tacho sensors used in the Figure 4



Figure 4. Tacho sensors used on site

It is appropriate to mention that the site that online devices work is significantly harsh. The bearing temperatures reach to 50°C and especially the pinion area can sometimes be very greasy. Despite this harsh environment, online devices working isolated with full performance.

All of these data collected from site assemble to build the big data which can be processed to extract a meaningful and

refined knowledge of the line. The data is sent to the analysis software called Omnitrend Center® by Prüftechnik which is located in the main server PC.

Analysis process is carried out every 15 days periodically to analyze and monitor possible machinery faults.

2.2. Measurement Points and Tasks

The entire line is monitored with 75 accelerometers, 48 temperature sensors, 10 tacho sensors and 24 process parameters. All sensor locations have been shared in Figure 5.

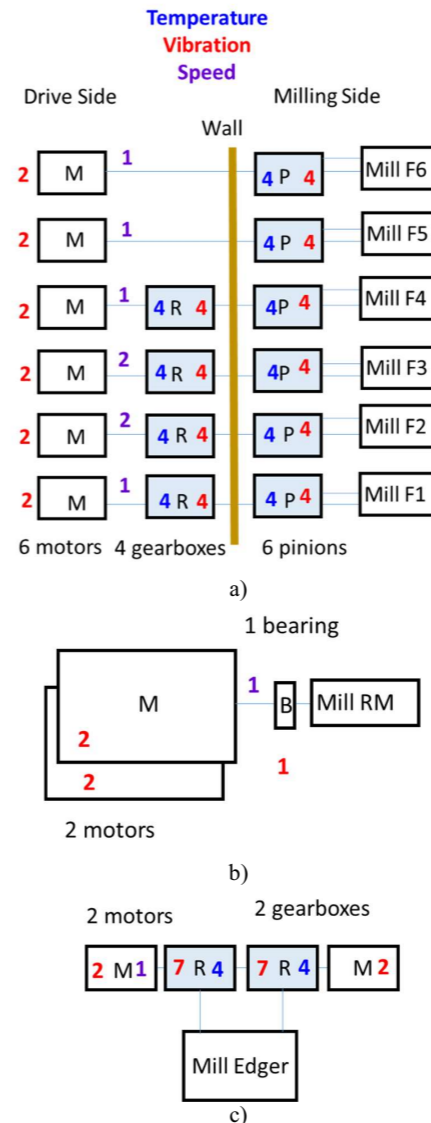


Figure 5. a) Finishing Mill area b) Rougher Mill area c) Edger Mill area

Each bearing on the machine has at least one vibration sensor and is monitored continuously. On finishing mill area, accelerometers have been installed with horizontal direction on to the motor bearings and vertical direction on the gearbox and pinion bearings. Each gearbox and pinion bearing have its own temperature sensor. On edger mill area, motors have one sensor per bearing on horizontal direction. Edger gearboxes have complex internal mechanism, so it has been monitored with seven sensitively chosen measurement locations. They're chosen to be able to catch any bearing or gear related issues on the early stages. There are 4 temperature measurement locations per edger gearbox. In Figure 6, vibration measurement locations can be seen for fine milling gearboxes, pinions and edger gearboxes.

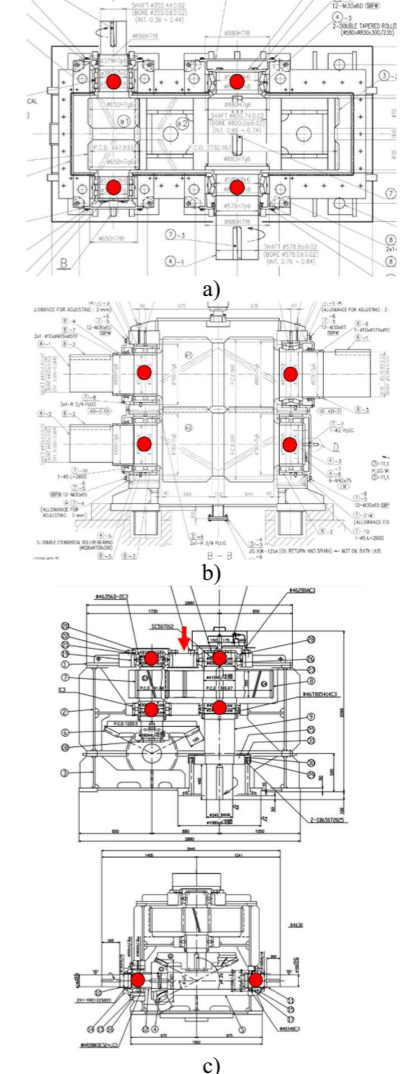


Figure 6. a) Finishing Mill gearbox b) Finishing Mill pinion c) Edger Mill gearbox measurement locations



As the milling stands changed two or three times per day, it has been decided not to monitor them with fixed online system.

On each vibration measurement location, two sets of data collection group have been implemented. The first one is "overall vibration" group which includes velocity and acceleration overall values. These values are collected continuously together with temperature readings regardless of process parameters. Second group of measurements is "diagnostic group" which collect data depending on conditions which are defined in regard to the process parameters. These process parameters will be discussed in the next section. Velocity spectrum, envelope spectrum, acceleration time waveform and acceleration spectrum measurement tasks have been included.

Details of these measurement tasks have been shared in the Table 1 below [1]. It can be seen that the measurements in Finishing Mill area are more detailed than Rougher and Edger Mills. The reason of that is the milling duration is much more limited in rougher and edger mills than the fine milling area. The milling duration affects measurement times as the measurements have to be collected during loaded operation which reveals existing faults more clearly. Rougher and edger mills have nearly 6-8 seconds milling duration contrary to fine mills which have average of 20-30 seconds.

Finishing Mill Area				
	Velocity Spectrum	Acceleration Spectrum	Envelope Spectrum	Time Waveform
Fmax [Hz]	400	12800	400	50000
LINE [Nr]	6400	102400	6400	*
dF [Hz]	0,0625	0,125	0,0625	*
T [s]	16	8	16	10
HP filter [Hz]	*	*	2000	*
LP filter [Hz]	*	*	10000	*
Fsampling [Hz]	*	*	*	131000

Rougher & Edger Milling Area				
	Velocity Spectrum	Acceleration Spectrum	Envelope Spectrum	Time Waveform
Fmax [Hz]	400	12800	400	50000
LINE [Nr]	1600	51200	1600	*
dF [Hz]	0,25	0,25	0,25	*
T [s]	4	4	4	6
HP filter [Hz]	*	*	2000	*
LP filter [Hz]	*	*	10000	*
Fsampling [Hz]	*	*	*	131000

Table 1. Measurement tasks details

2.3. Process Parameters

Process parameters which are already collected by automation system are extracted to the main server. To be able to monitor all machines in the right operating states, process parameters should be collected properly.

For finishing mill area process parameters like line speed and material input signals are collected to be able to trigger the diagnostic measurement groups mentioned in the former section. In the right moment as line speed is between proper values and material input signal comes, analyzer fires the trigger which starts the acquisition for the required measurement tasks. Machine load parameter is used as operating states signal which sorts the measurements to different load layers. This sorting function helps analyst to analyze the data more precisely; data collected in different load layers can be analyzed as a group.

In the rougher and edger mills, addition to the parameters in the finishing mill, pass sequence parameter is also collected as a trigger signal. Within the right machine speed band, right pass sequence number (It is decided as 5<sup>th</sup> pass) and when the material input signal comes the analyzer starts acquisition. Machine load signal is collected in rougher and edger mills like in the finishing mill section as operating parameter. An example to the process parameters, a trend graph can be seen in the Figure 7.

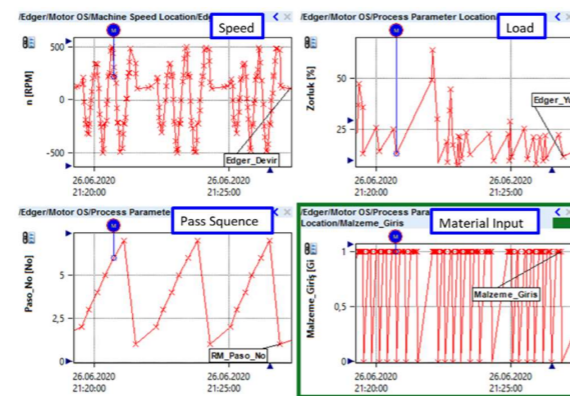


Figure 7. Process parameters collected in Rougher and Edger Mills

2.4. A Bearing Fault Case Study

In September 2019 bearing fault signals has been detected on 4<sup>th</sup> bearing of the F3 finishing mill gearbox. The overall acceleration 0-Pk levels were ~2g and it has been decided to continue monitoring this fault. At the end of November, the 0-Pk acceleration values reached to ~7-8 g. It is decided to replace this bearing as soon as possible. In Figure 8, broken cage of the bearing can be seen clearly. It has been concluded that excessive forces during milling caused this bearing fault. Vibration graphs showing before and after the overhaul can be seen in Figure 9.



Figure 8. Process parameters collected in Rougher and Edger Mills

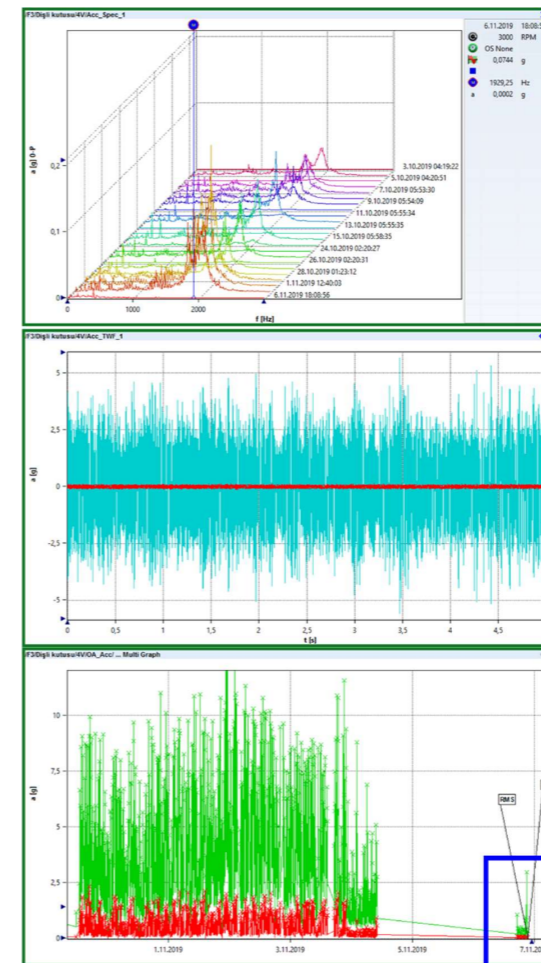


Figure 9. Vibration levels before and after overhaul

3. Results and Discussion

Directly after the installation and periodical analysis service, the online system helped analyst and maintenance engineers on site to understand the behavior of the milling stands. This realization stage supported thoughts to develop new methods to change the milling characteristic to be able to have lesser milling forces in order to have more reliable machinery.

4. Conclusion

A proper online system to the critical machinery proved its benefits nearly 6 months after installation as it is seen in the case study in the former section. It is obvious that a continuous monitoring system is a must for that kind of critical line. But it has to be stated that the conditional data collection property should be implemented to have extract "smart" data. With further developments on milling characteristics the reliability can be increased rapidly.

References

- [1] Mobius institute CAT III course notes
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## Online Yüzey Kontrol Sistemi

Online Surface Control System

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KARABÜK DEMİR ÇELİK • Türkiye

### Abstract

Being able to compete at the international level in the globalizing world is of great importance for both developed and developing countries. In such an environment, it is only possible to ensure the continuous improvement and development by combining the quality, cost and efficiency aspects of the enterprises in the best way. In this study, it is explained that the products passing through rolling mills at Rail and Section Rolling Mill in Kardemir with a temperature of approximately 900°C and 4-6 m/s speed are subjected to surface defect control online with three-dimensional cameras and lasers. The data obtained from three-dimensional cameras were transferred to the computer and converted into numerical data and graphics. Thus, the defective product from the rolling stands can be detected immediately. Thanks to this system, both the surface defect and the source of the problem can be detected in a short time. The establishment of the online surface control system has reduced the amount of scrap in production, energy and labor loss, and increased the competitive possibilities of our company.

### Özet

Küreselleşen dünyada uluslararası düzeyde rekabet edebilmek, gerek gelişmiş gerekse de gelişmekte olan ülkeler açısından büyük önem taşımaktadır. Böyle bir ortamda rekabet gücünün sağlanabilmesi ancak işletmelerin kalite, maliyet ve verimlilik unsurlarını en iyi şekilde bir araya getirerek sürekli iyileştirme ve geliştirmeyi sağlamakla mümkün olmaktadır. Bu çalışmada, Kardemir'de ki Ray Profil Haddehanesi'nde hadde tezgâhlarından yaklaşık 900°C sıcaklık ve 4-6 m/s hızla geçen mamullerin üç boyutlu kamera ve lazerlerle online olarak yüzey kusur kontrolüne tabi tutulması anlatılmaktadır. Üç boyutlu kameralardan elde edilen veriler bilgisayara aktarılarak sayısal verilere ve grafiklere dönüştürülmüştür. Böylelikle hadde tezgâhlarından çıkan kusurlu mamul anında tespit edilebilmiştir. Bu sistem sayesinde hem yüzey kusuru hem de sorunun kaynağının tespiti kısa sürede gerçekleştirilebilmektedir. Online yüzey kontrol sisteminin kurulması, üretimdeki hurda

miktarının, enerji ve işçilik kaybının azalmasını sağlayarak, firmamızın rekabet imkânlarını artırmıştır.

### 1. Giriş

Cumhuriyetimizin kurulduğu ilk günden bugüne demir-çelik sektörü Türk sanayinin temel bileşenleri arasında gösterilmekte ve gerek üretimde gerekse kapasite kullanım oranında gün geçtikçe çitayı yükseltmektedir. 1939 yılında kurulan ve Türkiye'nin tek ray üretimi yapan şirketi Kardemir, sektörün ray gereksinimlerini kalite anlayışıyla karşılamakta ve bu konuda gerekli tüm donanımlara sahiptir. Bu çalışmada da, Ray Profil Haddehanesi'nde kurulan online yüzey kontrol sistemi ile hataların nasıl tespit edildiği anlatılmaktadır.

### 2. Ray Üretimi

Ray ve Profil Haddehanesi'nde yarı mamuller öncelikle tavlama işlemine tabi tutulmak üzere tav fırınına alınmaktadır. Fırından tavlana çıkarak yarı mamuller üzerlerinde oluşan tufal tabakasının temizlenmesi için yüksek basınçlı su ile çalışan temizleme ünitesinden geçirilmektedir. Yarı mamul daha sonra birinci ve ikinci kaba hadde tezgâhlarında haddelenmektedir. Buradan, hassas haddeleme için en üst düzeyde hassasiyetin sağlandığı, kompakt sistem prensibine göre dizayn edilmiş, bilgisayar kontrolü ile çok sıkı toleranslar arasında çalışan tandem hadde grubuna transfer edilmektedir. Malzeme, üniversal haddeleme ile haddelenerek istenilen mamule dönüştürülmektedir. Tandem grubunda haddelenmiş malzemeler soğutma ızgarasında hava fanları ile soğutulduktan sonra üretim hattında olan dikey ve yatay doğrultma tezgâhlarında doğrultma işlemine tabi tutulmaktadır. Doğrultma tezgâhından çıkan profiller, ilgili hatta istenilen boylara kesildikten sonra paketleme ünitesinde paketlenerek, müşteriye teslim edilmektedir. Ray üretiminde ise, doğrultma ünitesinden geçen raylarda ultrasonik test sistemiyle içyapı kusurları tespit edilirken eddy current test sistemiyle de yüzey kusurları tespit edilmektedir. Ardından raylar, müşteri talebine göre boy kesimi ve delik delme işlemleri yapılarak teslim edilmektedir.

### 3. Durum Tespiti

Ray ve Profil Haddehanesi'nde tandem grubundan çıkan haddelenmiş mamuller lazer ışın destekli görüntüleme yöntemi ile (Lazer Gauge) ölçü kontrolü yapılmaktadır. Ölçü kontrolü yapılırken mamul sıcaklığı yaklaşık 900°C ve mamul hızı 4-6 m/s'dir. Ölçü kontrolünden geçen mamuller 78 m uzunluğundaki soğutma ızgarasında hava fanları ile 20-30°C'ye soğutulmaktadırlar.



Şekil 1. Ölçü kontrolünden sonra mamullerin soğutulduğu ızgara.

Mamuller soğutulduktan sonra mamul yüzeyleri yüzey kusurları (çizik, yara, kabuk, oyuk, iz vb.) açısından kalite uzmanları tarafından gözle kontrol edilmektedir. Bir mamulde yüzey kusuru bulunduğu, diğer mamullerde ayrıntılı şekilde kontrol yapılmaktadır.

Tandemden çıkan 900°C'deki bir mamulü kontrol etmek için yaklaşık 1 saat süreye (mamul sıcaklığının yüzey kontrolü yapılabilecek seviyeye düşmesi için geçen süre) ihtiyaç duyulmaktadır. Yüzey kusur kontrolü online ve sürekli yapılmadığından, bir mamulde yüzey kusuru tespit edildiğinde, kusurlu malzeme sayısı 30'a kadar ulaşabilmektedir. Mamulün kusurlu olduğunu anlamak ve üretimi durdurmak için geçen sürede 6-30 adet mamul 1 ve 2 no'lu ön, ara ve tandem hadde tezgâhından geçirilmiştir. Mamullerdeki yüzey kusuru belirlenen tolerans sınırını aştığında ise 6-30 adet mamul hurdaya ayrılmaktadır. Bu durum üretim, enerji işçilik ve verim kaybına sebebiyet vermektedir.

Yaptığımız araştırmalara göre dünyada mevcut çalışan haddehanelerde, haddelenen mamullerin (Ray ve Profil) yüzey hata kontrolü mamul soğutulduktan sonra iki boyutlu kameralarla veya firmamızda olduğu gibi gözle kontrol edilmektedir. Mamul soğuk olduğu için mamul yüzeyinde meydana gelen hatayı ton farkından ayırt etmek

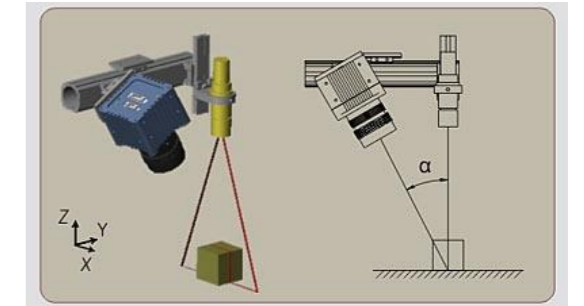
kolaydır. Mamul sıcakken kızıl renkte olacağından dolayı ton farkından yüzey kusurlarını ayırt etmek oldukça zordur. Ayrıca, yine yaptığımız araştırmalara göre dünyada hadde tezgâhlarından çıkan mamulün yüzey kusur kontrolünü, mamul sıcakken online yapabilen bir sisteme rastlanmamıştır. Bu çalışmada mamul sıcakken online yüzey kusur kontrolü yapan bir sistem deneysel olarak incelenmiştir.

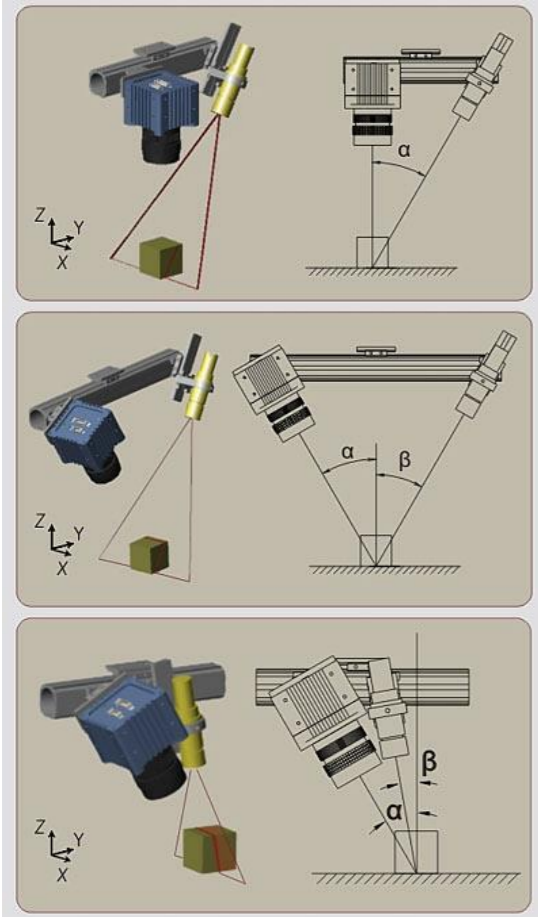
### 4. Deneysel Çalışmalar

Deney düzeneği; bir takım üç boyutlu kamera ve lazer ışık kaynağı, lazer ve kameraların soğutulmasını sağlayan soğutma ünitesi, verilerin (görüntülerin) işlenmesi için hazırlanan program, üzerine yapay kusurlar oluşturulan numunelerden oluşmaktadır. Deneysel çalışmalar iki aşamada gerçekleştirilmiştir:

- Dairesel kesitli ortam sıcaklığındaki bir numunede deneyin yapımı,
- Tav fırınından geçirilmiş ve haddeleme işlemi tamamlanmış bir ray numunesi yüzeyine değişik ölçülerde yapay kusurlar oluşturularak kusurların tespiti.

Kamera ve lazer yerleştirilirken Şekil 2'de gösterilen kamera ve lazer yerleşim düzeneklerine göre kamera ve lazer açıları denenmiştir. Kamera ve lazerler mamulden 300 mm uzaklıkta konumlandırılmıştır. Mamul yüksek sıcaklıklarda kızıl renkte olacağından mamul üzerinde ton farkı oluşturmak için lazerle ışık perdesi meydana getirilmiştir. Kamera, lazerin mamul üzerinde taradığı alanın görüntülerini üç boyutlu olacak şekilde bilgisayara aktarmıştır. Elde edilen veriler bir yazılım sayesinde analiz edilerek grafikler ve sayısal çıktılar oluşturulmuştur. Oluşturulan grafikten, mamulde yüzey kusuru olan noktalar tespit edilmiştir. Kameralar sadece lazer izdüşümünün olduğu alana odaklanmıştır.

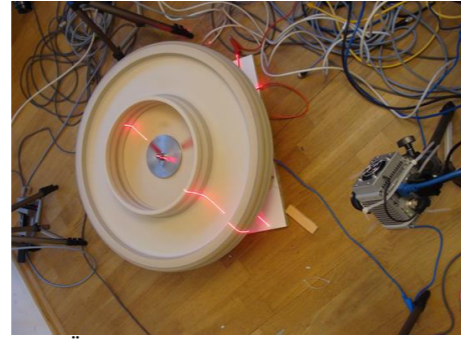




Şekil 2. Kamera ve lazer yerleşim düzenekleri.

#### 4.1. Ortam sıcaklığındaki dairesel kesitli numuneye ait deney düzeneği

Deney düzeneğinde 40 cm çapındaki dairesel kesitli disk üzerine yapay kusurlar oluşturulmuştur. Disk bir elektrik motoruna bağlanarak kendi etrafında döndürülmüştür. Disk üzerine farklı büyüklükte yapay kusurlar oluşturulmuştur. İlk denemede diskin dış yüzeyine 0,7 mm et kalınlığında etiketler yapıştırılmıştır. Yapay kusurların olduğu yüzey 5 m/s hıza ulaşacak şekilde elektrik motoru ile döndürülmüştür. Disk ile kamera arasında 80 cm mesafe kalacak şekilde üç boyutlu kamera ve lazer diskin etrafına konumlandırılmıştır. Kamera ile lazer arasındaki açı Şekil 2'de verilen konumlarından biri seçilerek yerleştirilmiştir. İkinci denemede diskin dış yüzeyine 0,3 mm et kalınlığında yapay kusurlar eklenmiştir. Birinci denemede olduğu gibi yapay kusurların olduğu yüzey 5 m/s hıza ulaşacak şekilde elektrik motoru ile döndürülmüştür. Disk ile kamera arasında 80 cm mesafe kalacak şekilde üç boyutlu kamera ve lazer diskin etrafına konumlandırılmıştır.



Şekil 3. Üzerinde yapay kusurlar oluşturulan dairesel kesitli numuneye ait deney düzeneği.



Şekil 4. Disk üzerine oluşturulan yapay kusurlar.

Üçüncü denemede disk üzerine girintiler açılmıştır. Disk üzerine açılan kusurların ölçüleri  $5 \times 3 \times 0,5$  mm ve  $5 \times 3 \times 0,25$  mm'dir. Diğer denemelerde olduğu gibi yapay kusurların olduğu yüzey 5 m/s hıza ulaşacak şekilde elektrik motoru ile döndürülmüştür. Disk ile kamera arasında 80 cm mesafe kalacak şekilde üç boyutlu kamera ve lazer diskin etrafına konumlandırılmıştır. Kamera ile lazerin mamul üzerinde taradığı alanın görüntülerini üç boyutlu şekilde alınarak bilgisayara aktarılmıştır. Elde edilen veriler Matlab programında oluşturulan bir yazılım sayesinde analiz edilerek grafikler ve sayısal çıktılar oluşturulmuştur. Hazırlanan grafikten, mamulde yüzey kusuru olan noktalar tespit edilmiştir.

#### 4.2. Tav sıcaklığındaki ray numunesine ait deney düzeneği

Deney düzeneği Ray/Profil üretim hattı üzerine kurulmuştur. Son hadde tezgâhı ve ölçü kontrol ünitesi sonrasında üç boyutlu kamera (1 adet) ve lazer ünitesi yerleştirilmiştir. Hattan geçirilen ray ile kamera ve lazer ünitesi arasında ~70 cm mesafe kalacak biçimde kamera ve lazer konumlandırılmıştır. Deney düzeneğine ait resim Şekil 5'de verilmiştir.

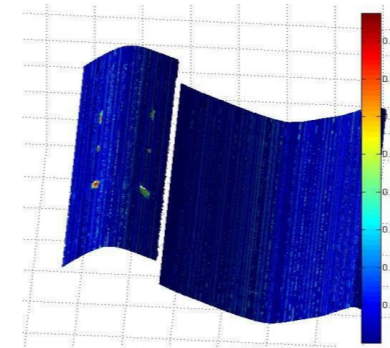


Şekil 5. Ray/Profil üretim hattına konumlandırılan deney düzeneği.

Deneylerde tandem tezgâhından çıkan 76 m uzunluğundaki ray üzerinde yüzey kusuru tespit edilmeye çalışılmıştır. Yüzey kusuru tespit edilmeye çalışılan raylarda sıcaklık ~950°C ve rayın hızı 4~6 m/s'dir. Ölçüm sırasında  $300 \times 300$  mm alanı tarayan kamera ve lazer kullanılmıştır. Rayın tüm çevresini tarayabilmek için en az 6 adet kamera ve lazere ihtiyaç duyulacağı düşünülmektedir. Yaptığımız deney çalışmasında yalnız 1 yüzeyi taramak için 1 adet kamera ve lazer kullanılmıştır.

#### 5. Sonuçlar ve Tartışma

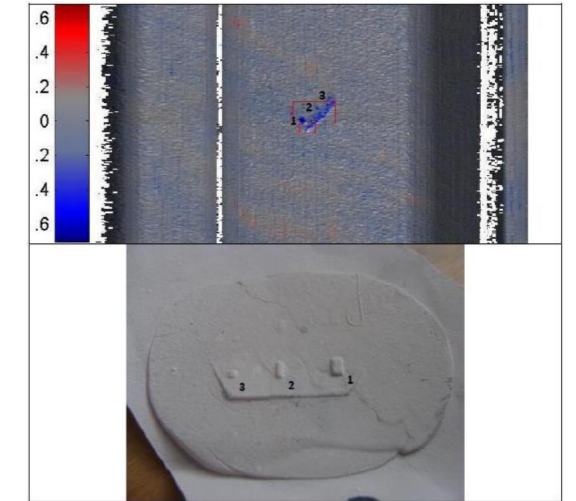
Dönen disk üzerine oluşturulan yüzey kusurlarını belirlenmesi çalışmasında, disk 5 m/s hızla döndürülürken lazer ile disk üzerinde ton farkı oluşturulan bölgeden üç boyutlu kamera ile veriler alınmıştır. Üç boyutlu kameradan alınan veriler, matlab paket programında hazırlanan görüntü işleme yazılımıyla analiz edilmiştir. Yazılım çıktısı olarak elde edilen grafik Şekil 6'da gösterilmiştir.



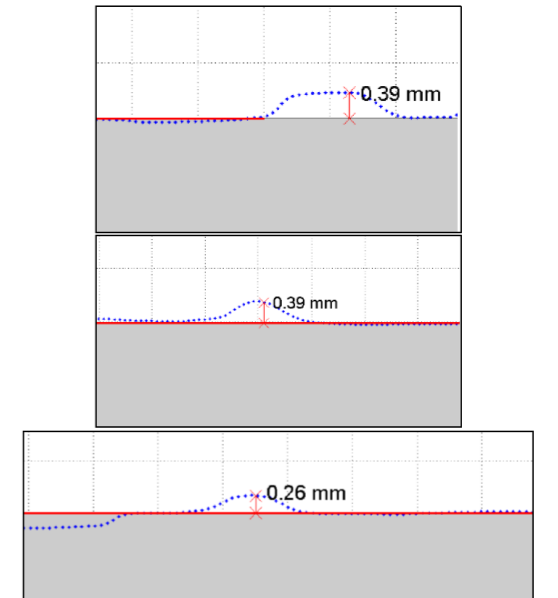
Şekil 6. Disk üzerinden elde edilen yüzey kusur görüntüleri

Disk üzerine oluşturulan 6 adet yüzey kusuru disk 5 m/s hızla dönerken tespit edilmiştir. Yüzey kusurunu oluşturan noktaların derinliği, demir yolu rayı üretiminde uyulması gereken standartlarda üzerinde durulan bir parametredir. Deneysel çalışmada 0,5 mm ve 0,25 mm derinlikteki kusurlar grafikte tespit edilmiştir.

Haddemeleme işlemi tamamlanmış sıcak ray üzerinde oluşturulan yapay yüzey kusurları belirleme çalışmasında ise rayın yüzeyine oluşturulan yüzey kusur ölçüleri Calipri marka ölçüm cihazıyla belirlenmiştir. Ölçüm cihazının doğruluğu  $\pm 0,05$  mm'dir. Yüzey kusuru için Calipri marka ölçüm cihazı ile elde edilen yüzey kusur değerleriyle, online yüzey kusur ölçüm cihazından elde edilen değer arasındaki farklar Şekil 7'de görülmektedir.



Şekil 7. Ray üzerindeki üç adet yapay yüzey kusuru tespiti.



Şekil 8. Ray üzerindeki üç adet yapay yüzey kusuru ölçü belirleme.



**Çizelge 1.** Ray üzerindeki yapay kusurların karşılaştırılması.

Kusur Tanımı	No	Derinlik (mm)	3D görüntüsü	Kırmızı kutuyla belirlenebilirliği
Yapay kusur	1	0,39	Var	Evet
Yapay kusur	2	0,39	Var	Evet
Yapay kusur	3	0,26	Yok	Evet

Çizelge 1’de görüldüğü üzere online yüzey kusur kontrolü için hazırlanan yazılım 0,3 mm derinliğin üzerindeki kusurları tespit ederek yüzey kusuru olarak tanımlamıştır. Yapay kusur 3’deki 0,26 mm derinlikteki yüzey kusuru için 3D görüntüsü elde edilmiş fakat yazılımda hata olarak tanımlanan kırmızı kutu içerisinde gösterilememiştir. Bu sonuç geliştirilen online yüzey kusur kontrol sisteminin istenilen derinlikteki kusurları tespit edebildiğini göstermektedir.

## 6. Sonuç

Deneysel çalışmaların sonuçları doğrultusunda üretilen mamul üzerindeki hataların görüldüğü tespit edilmiştir. Buradan yola çıkarak Ray Profil Haddehanesine “Online Yüzey Kontrol Sistemi” kurulmuş ve şu anda aktif olarak çalışmaktadır.

2010 ve 2011 yıllarında bu konuyla ilgili yaptığımız istatistikî çalışmalarda aylık ortalama 40 farklı zamanda mamullerde yüzey kusuru hadisesi meydana geldiği görülmüştür. Ayrıca, farklı zamanlarda meydana gelen bu yüzey kusuru vakalarının her birinde ortalama 6 tane rayda periyodik kusurlar olduğu tespit edilmiştir. Üretilen mamule göre farklılık göstermekle birlikte bir adet rayın kütlesi yaklaşık 4 tondur. Haddehaneden çıkan nihai mamul kusur olmaksızın müşteriye satıldığında birim fiyatı yaklaşık 2.000 TL/ton iken mamulde yüzey kusuru var ise (hurda malzeme) birim fiyatı yaklaşık 500 TL/ton’a düşmektedir. Bilindiği gibi raylarda ikinci sınıf malzeme söz konusu olmayıp standartta belirtilen toleransların dışında rayda yüzey kusuru tespit edildiğinde mamul hurda olarak çelikhaneye gönderilmektedir. Bu ise enerji ve işçilik kayıplarına neden olmaktadır. Online yüzey kusuru kontrol sisteminin kurulmasıyla hurda mamul miktarı 6 yerine 2’ye düşmüş yılda yaklaşık 11.520.000 TL kazanç sağlanmıştır.

Ray ve Profil Haddehanesinde farklı ebat veya türde ray üretimine geçildiğinde, tandem hadde tezgâhından çıkan ilk mamul soğutma ızgarası üzerinde soğuması için yaklaşık bir saat bekletildikten sonra gözle yüzey kusur kontrolü işlemine tabi tutulmaktadır. Mamulde yüzey kontrolü yapılması da yaklaşık 10 dakika alacağı için toplamda 1 saat 10 dakika üretim kaybı

gerçekleşmektedir. Tüm bu işlemler yapılırken tav fırını çalışmaya (yakıt tüketmeye) devam etmektedir. Haddehanemizde mamul tür/ebat değişimi ayda ortalama 15 defa yapılmaktadır. Fırının saatteki kok gazı tüketimi 3.500 Nm<sup>3</sup>’dür. Bu değer yıllık yaklaşık 400 ton kömür eşdeğeri enerjiye karşılık gelmektedir. Online yüzey kusuru kontrol sistemiyle mamul tür/ebat değişimi esnasında beklenmediği için yılda yaklaşık 120.000 TL yakıt tasarrufu sağlanmıştır. Özetle çalışmanın sağladığı katma değer toplamı yaklaşık 11.640.000 TL/yıldır.

Kurulan sistem sayesinde yüzey kusurundan dolayı ortaya çıkan hurda mamul sayısı minimuma düşmüştür. Ayrıca, haddehanede mamul tür/ebat değişimi esnasında gözle yüzey kusur kontrolü için beklenmemektedir. Online yüzey kusur kontrol sistemiyle hurda mamul sayısı minimuma inmiş (hurda malzemeyi geri kazanmak için çelikhane ve haddehanede ekstra herhangi bir yakıt tüketilmemektedir) ve mamul tür/ebat değişimi esnasında üretim olmaksızın fırın çalışmadığı için yılda yaklaşık 400 ton kömür eşdeğeri enerji tasarrufu sağlanmıştır. Yapılan yakıt tasarrufuna bağlı olarak yıllık yaklaşık 200 ton CO<sub>2</sub>’nin atmosfere salınmasının önüne geçilmiş ve sera gazı azaltımına katkıda bulunulmuştur.

## Teşekkür

Yapılan bu çalışma sonrasında Ray Profil Haddehanesinde kurulan Online Yüzey Kontrol Sistemini destekleyen Kardemir A.Ş. Yönetim Kurulumuza ve Yönetimimize teşekkür ederiz.

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## Production Optimisation due to Real Time Information of Profile and Surface Defects on Rolling Products

Haddeleme Ürünlerinde Profil ve Yüzey Hatalarının Gerçek Zamanlı Bilgiye Dayalı Üretim Optimizasyonu

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LAP LASER • Germany

### Abstract

This paper addresses the need of rolling mills, especially hot rolling mills, to produce high quality products under rising industrial challenges. By implementation of profile measuring gauges not only for process monitoring but for automated control, the product quality rises in terms of tolerance limits and root cause analysis for surface defects.

### Introduction

The metal industry, especially steel industry, faces challenges regarding delivery time, production costs and product quality driven by high requirements from e.g. the automotive industry [1]. One measure to address these challenges is striving for production automation with comprehensive understanding of material behaviour under certain control action in the rolling production line of long products. Contactless inline measuring systems play a key role in production optimisation.

Laser based systems are the solution for sound information about the product geometry and its surface condition with high accuracy. The detection of deviations of profile and surface, as well as the analysis of its source regarding the calibre is crucial for taking the right control actions in the rolling line. Smart evaluation and data processing allow real time detection of product parameters and the supply of significant details for the process control system and the operator, respectively. In times of digitalisation the minimisation of the time gap between detection and execution of a control action is tangible by automation.

### Challenges in Hot Rolling Mills

Hot rolling mills are the last production step to influence the product quality and production costs significantly [2]. Wear, damages, adhesive scale and defects on the rolling calibre as well as production process condition changes like temperature changes, unforeseen production interruptions or strain variation at the calibre influence the quality of the rolled products. The consequences on the rolling product are profile deviations, break-outs, splitting and bursting, dents, scratches and cracks [3].

Tight tolerance demands require shortest reaction time on production condition changes. Manual process

control for rolling mills is still common and results in challenges for product quality and production costs [4].

Especially in wire production mills the wire gets turned and twisted by usage of a layer head. This production set-up causes high difficulties to identify distinct calibre information in order to control the finishing block accurately.

### Laser Based Solutions

**Shadowing Systems.** The contactless measuring principle for shadowing systems is the shadowing principle. A laser scan is emitted and received in a single axis measuring range. An object in the measuring range interrupts the scan so that the size of the object can be measured by interruption time. Up to 6 axes can be used in a measuring range of 500mm and more in the LAP shadowing gauges CONTOUR CHECK ROUND & EDGE. This system principle is already established for over 25 years on the market.

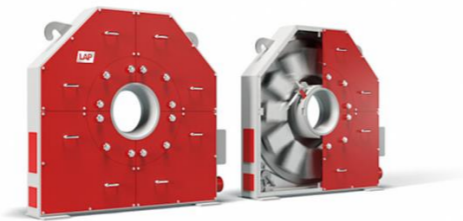


Figure 1: CONTOUR CHECK ROUND & EDGE system

**Light Sectioning Systems.** The contactless measuring principle for the light sectioning systems is the triangulation principle with a laser line. A laser line is projected and traced by a camera in a certain measuring range. The laser line is distracted by income of an object and is detected as object profile information by the camera. The complete profile is measured by usage of at least 4 sensors in a measuring gauge. Up to 6 sensors in a measuring range of up to 900mm are used in the LAP light sectioning gauge CONTOUR CHECK SHAPE.

In the application of profile measurement including the identification of rolling defects and rolling gap this system principle has been established since 2015. The newest application (2019) is profile measurement in

combination with surface defect detection on hot rolling products in one single measurement gauge.



Figure 2: CONTOUR CHECK SHAPE system

**Benefits in Hot Rolling Mills.** These systems are mainly used in hot rolling mills for long products, rebars and pipes, especially for valuable materials like SBQ.

The LAP shadowing system CONTOUR CHECK ROUND & EDGE provides profile information at the implemented axes like diameter and ovality for round products.

The LAP light sectioning system CC SHAPE can identify and visualise rolling defects regarding the position of the calibre to each other and its filling factor.

Especially in wire rolling mills with layer heads the identification of the rolling gap and the relation of the measured information to the gap solves a crucial production challenge.

In productions with high material surface requirements the CC SHAPE is additionally used for surface defect detection. Surface defects down to 100µm depth or height and 200µm width can be identified over the length of the material. The surface defect length depends on the production speed. The detectable surface defects can differ between convex and concave shapes as well as steps. The surface defects are evaluated in defect classes based on their length over the rolling product.

The comprehensive LAP measuring software SMART CORE PRO gives the operator the possibility to receive the most important information at one glance by high level of usability to react on certain events. The

software displays real time calibre related information via numerical, graphical and 3D elements.

In order to fulfil industrial requirements for tight production tolerances closed loop control systems for rolling mills are becoming more important. Such size control systems require usually a laser light sectioning gauge at the exit of the finishing block for subsequent feedback control [2]. In order to enhance the production tolerance range even more the additional use of a measuring gauge at entry position of the finishing block is needed. The information density for such additional feedforward control can sufficiently be generated by the LAP shadowing gauges. LAP provides measuring gauges for both feedback and feedforward control with the same real time set-up and defined communication architecture.

### Summary

In order to meet the requirements of the industry, rolling mill directors have to gather as much information about their products as possible. LAP systems fulfil current requirements of rolling mills, especially hot rolling mills and SBQ mills. Shadowing systems are used in one or several upstream positions before the finishing block. Light sectioning systems are positioned after the finishing block. These systems provide the necessary information for production optimisation regarding rolling and surface defects as well as tight production tolerances.

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## Poster Presentations Poster Sunumlar

### Integration of Laboratory Information Management Systems with SAP in an Iron-Steel Company

Demir Çelik Sektöründe Laboratuvar Veri Yönetim Sisteminin SAP ile Entegrasyonu

İbrahim Göçer, Erdiñç Soylu, Özgür Karakaş, Pınar Özkan, Mesut Yılmaz

MMK METALURJİ • Türkiye

#### Abstract

Today, with the developing technology, enterprises manage many processes such as order taking, human resources, production, quality control and planning integrated with the ERP software SAP. Laboratories of production facilities often use software such as Labware, My-Lab and Enlab to manage their own data. In their study, Krzysztof Żabala and Bartosz Gałda applied the laboratory data management system in the SAP standard module and identified some disadvantageous aspects in this application [1]. By the help of this study, some of these disadvantages identified by the researchers were solved with the software developed apart from the standard module in SAP, thus eliminating the need for a different software, providing a fast and secure data flow, reducing the need for labor in reporting and eliminating personnel errors. Most importantly, laboratory data is made available to departments that use SAP extensively, such as quality control, planning and operation. body should contain abstract, introduction, experimental studies, results and conclusion parts after the set of title, author name(s), affiliation(s) and keywords. Further parts (and subheadings) are under the initiative of author(s) in accordance with the content integrity. The manuscript is in two column formatting after the keyword line.

#### 1. Introduction

Laboratory analyzes are very sensitive and must be maintained safely. However, no matter how sensitive the analyzes are performed, issues such as storage, reporting and confidentiality of the results of the analysis may be at risk if appropriate tools are not used. Because of this sensitivity, there are solutions that include many manually created measures and control mechanisms. These can cause serious workload and time losses hence work inefficiencies [2].

In order to avoid these situations, a data management system is required in laboratories. In addition, laboratories wishing to be accredited must comply with data information security and management procedures in terms of accreditation processes [3].

Laboratory data management system is a complex of hardware and software components that support the management of collection, processing, storage, distribution

and information presentation procedures used with the information obtained as a result of laboratory activities [4].

Today, laboratories use software such as Labware, my-Lab, EnLab to manage their data. There are companies that use these software separately from ERP systems, as well as companies that integrate only the results reports into ERP systems.

ERP, which means enterprise resource planning, refers to the product set that companies use to carry out processes such as finance, accounting, supply chain operations, sales, maintenance, quality and laboratory, procurement, project management and risk management. ERP systems define a large number of business processes within this integrity and provide data flow between business processes.

SAP, which is an ERP system, plays an important role in the management of thousands of companies from every sector today [5].

K.Żabala and B.Gałda's study, they analyzed the laboratory management system based on the standard functionality of SAP's QM module. In addition to the advantages in their studies, they identified some disadvantages. As disadvantages, they determined that there is no specific business plan for the tests to be carried out, these tests can only be analysed by batch number and the information workflow is lacking [1].

#### 2. Studies

In this study, besides the SAP-QM standard structure, all operational operations from sample acceptance to delivery of the result report to the relevant person were combined into one system (SAP), avoiding workload such as managing different systems, integration problems between systems and maintenance costs of different systems.

Laboratory unit operating in MMK Metalurji, which is designated as the site of study, is grouped as follows.

#### a- Raw Material Input Control Analysis :

Raw material input control analyzes are the analyzes performed to check whether the raw materials and materials purchased meet the specifications required for production.

### b- Process / Routine Analysis:

Control analyzes are performed to test the intermediate/end products during production, to control the targeted product process and to help the chemicals used during production to meet the process requirements.

### c- Non-Routine Analysis (Internal/External Customer):

It covers sample analyses that do not come in a specific order and are specifically requested. (Except for the 'Analysis Frequency List' prepared for process/routine analysis and/or come from third party analyzes)[6]. Work flow charts have been prepared for each of these identified study areas. SAP-QM standard module for Raw material Input Control has been configured and made available. Since the standard module for the other two work areas could not meet the demands, the control of all work areas was gathered under the roof of SAP with additional improvements.

### 2.1. QM Modul

Raw material input controls are carried out by the Coordination of many units (stock control, Production Planning, Purchasing, operation, Quality Control and laboratory) based on the technical specifications prepared. Compliance checks are carried out according to the technical specifications prepared.

For each specification, a control plan was created within the SAP-QM module and material numbers were defined according to these control plans. The purchase of the materials requested by the production lines is carried out according to the material numbers. The SAP-QM module determines the relevant raw material according to the material number and transmits the raw material information (raw material name, company, parameters to be checked with the specification, location of raw material and amount of raw material) to the laboratory unit via e-mail. In accordance with this information, the laboratory unit starts the analysis by taking samples from the incoming raw material.

After the end of the analysis, the results are entered in the analysis results section in the SAP-QM module. SAP-QM automatically sends the analysis results to the e-mail addresses of the previously defined contact persons for each specification. Notification of raw materials whose analysis results are within the relevant specification limits is transmitted as "Acceptance" and opened to the use of the Production through the system. If the results of the analysis are outside the limit values, the raw material statement is transmitted as "Rejection". In this case, this raw material is automatically blocked through the system and closed to use. The relevant production operating officer states the final decision on SAP-QM based on the process and raw material status. In case of accepting the raw material, stating the

reason and makes the decision as "Accept even though it is wrong" to remove the block. In case of "rejection" decision, notification is sent to the relevant unit and necessary actions are initiated. While the parameters in the specification are related to whether the raw material can be used technically in production, some parameters (coating area in paints etc.) are of commercial importance, not technical. It is stated in the specifications that laboratory results outside the limits of this parameter will be considered as "Conditional Acceptance". Since the use of a raw material within the scope of conditional acceptance will cause an increase in the production costs of the company, this amount of increase is calculated according to the difference in the parameters specified in the specification and compensated from the supplier. Due to the continuity of production, samples of raw materials that are required to be consumed are taken without waiting for the completion of the analysis. However, even if the use decision is rejected, it will not be put into blocked stock. Raw materials in this case (coal, lime, etc.) are considered optional.

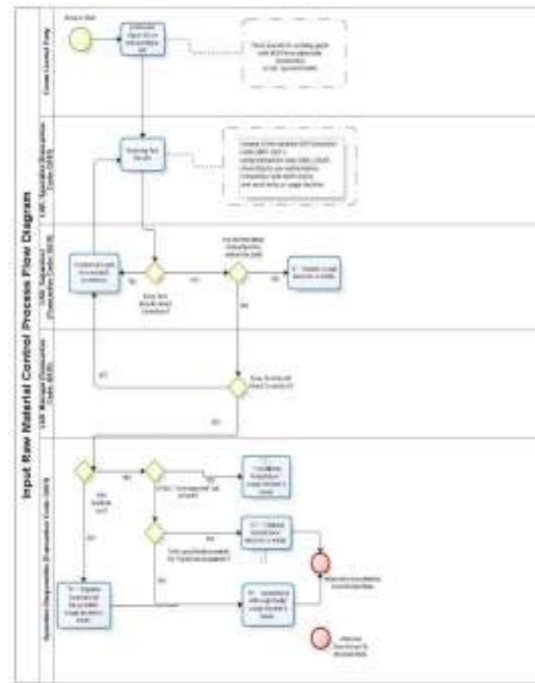


Figure 1. QM Module System Flow Diagram samples

### 2.2. Process / Routine Analysis

The internal control processes are subject to regular follow-up in a healthy way which this analysis of work to be done/can be made reliable and easy, since the repetition of the analysis and ensure the feasibility of all steps to be reportable on the basis of the predetermined unit is a frequency analysis list structure is based on the integration SAP system [6].

The customizing of the process/routine Analyses to the SAP system begins with the creation of material cards by assigning them to the material type specially opened for each type of analysis. The control plan for these materials is created and recorded to the system which analyses will be performed with these control plans. Based on the periods in the analysis frequency list, registration of the sample samples taken to the system is entered into the system by the analyst. After starting the analysis of the sample in the laboratory, the results of the analysis are entered into the system by the controllers.

After the result entries are completed, the system automatically sends the results of the analysis to the related people by mail. If there is at least one out of limit value in the analysis results, the control decision is indicated as "Not Appropriate" in the mail content and the out of limit value/values are highlighted in red. If all values are within the limit, the control decision is indicated in the mail as "Appropriate".

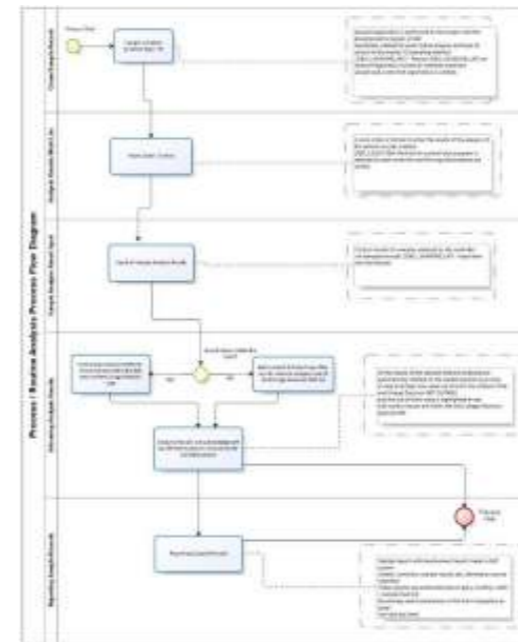


Figure 2. Process/Routine Analysis Flow Diagram

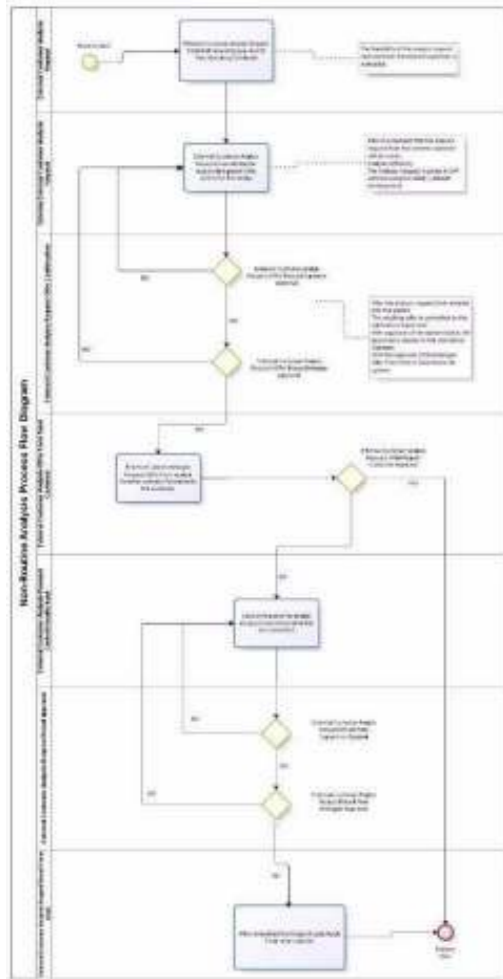
### 2.3. Non-Routine Analysis (Internal/External Customer)

Non-routine analysis is evaluated in two areas: internal customer analysis and external customer analysis. In both areas, improvements and additional programs made in SAP are used, completely different from the QM module standard.

Analysis requests from the process for analyses not defined in the Analysis Frequency List as internal customers; all analysis requests from third parties are defined as external clients.

All non-routine analysis (internal-external customer) requests are received by e-mail and sample records are created in SAP. "Rejection" or "Acceptance" decision is made by examining the feasibility of the analysis requests for the sample record. The analysis request for which the "Rejection" decision is made is forwarded to the requester via SAP via e-mail. The decision to accept the analysis request is notified to the relevant laboratory personnel by e-mail as a work order. In this statement, if the required analysis parameters are to be performed according to which standard, the results are entered into SAP by the controller. The Laboratory Supervisor can accept or reject the result by examining the result statement from SAP. Rejected analysis results are processed according to the reason of rejection specified in SAP (Repeat Analysis, Incorrect Result Input, etc.). When the result is accepted, the results of the desired analysis are automatically sent to the requester via e-mail in excel format.





**Figure 3.** Non-Routine Analysis System Flow Diagram

### 3. Results and Discussion

These methods based on information technology directly affect product quality in iron and steel companies. Fast delivery of data with this system is important for product quality. The system enables all business processes to be carried out on a single system, preventing human factor errors and keeping data safe and processable in iron and steel companies using SAP. The advantages of the study are that the tests carried out with a specific business plan can be analyzed independently of the batch number and the information is complete at each stage. The disadvantages are the lack of cost calculation of the tests and no prioritization is made for the analyses.

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## Effect of Web Based Employee Suggestion System Software Application on System Performance: MMK Metalurji Case

WEB tabanlı, Çalışan Öneri Sistemi Uygulamasının, Sistem Performansına Etkisi; MMK Metalurji Örneği

Özgür Karakaş, Alper Akün

MMK METALURJİ • Türkiye

### Abstract

Over the last 10 years Employee suggestion systems (ESS) have been extensively used by industrial companies all over the world to improve their operations/business processes in. ESS increases workers' sense of belonging and confidence, cost saving, product quality, process efficiency, new revenue, workplace safety, etc. The success of ESS depends on individual attributes of employees, organizational factors and system features like administration quality, publicity, rewarding policy, feedback and evaluation philosophy, ESS structure and many others., MMK

Metalurji ve Liman İşletmeleri A.Ş. (iron and steel producing company), started using an ESS based on suggestion boxes checked by an evaluation group in 2015 and revised its ESS to be based on a software application and a single expert evaluation in the beginning of 2018. The revised procedure also changed some system features. This study compares and discusses the performance of the previously and currently used ESS systems, focusing on the web-based software usage effect and improved system features benefiting the company. According to the collected data, the usage of the revised web-based ESS software has contributed to the drastic increase in the number of received suggestions (45 times exceeding the amount of suggestions collected using suggestion boxes; at that, the suggestions' review and application time was decreased, the suggestion flow speed accelerated and the ESS accessibility, publicity, feedback speed etc. was improved.

### 1. Introduction

Industrial ESSs trace their origin back to the 19th century; in 1880, William Denny, a Scottish shipbuilder asked his employees to offer suggestions in order to build ships in better ways but simultaneously at lower cost [1]. The Kodak company became a pioneer in ESSs with its program being introduced in 1896 [2]. So, in the business world, formal and structured suggestion schemes were first introduced as a modern practice more than one hundred years ago.

Today, the industrial enterprises tend to include employees' beneficial opinions regarding their workplaces and favor them to provide mind power for optimizing operation processes and increasing productivity [3]. Employee suggestion system (ESS) is one of the most favorable tools

targeting this aim for industrial organizations [4]. ESS is described as a formalized mechanism that encourages employees to contribute constructive ideas for improving the organization they work for [5] A suggestion scheme should elicit suggestions from employees, classify them, and dispatch them to the experts for evaluation. Thereafter, suggestions might be implemented, in which case the suggesting employees may be well rewarded [6].

Many studies were conducted to determine and assess the success factors for an ESS of any organization to achieve the targeted results like cost saving, new revenue, customer and employee satisfaction, product quality increase etc. [7], [8], [9]. F. Lasrado, M. Arif and A. Rizvi et al. carried out one of the comprehensive reviews about the main success factors of ESS [10]. The authors have indicated that the success factors can be grouped as organizational and work environment factors, individual attributes and system features.

This study investigates and discusses the effect of employee suggestion *system features* on entity's performance and success based on an iron and steel producing company application case sample where the organizational & work environment factors and individual attributes kept constant while the system features were changed.

### 2. Company profile and methodology of the study

#### 2.1. Second-level subheading

MMK Metalurji ve Liman İşletmeleri A.Ş. [11] (company), a large-scale iron and steel producing company invested by Russian MMK Group with 12,7 million tons of crude steel production and USD 8,214 million sales in 2018 in Turkey [12]. Company has started up the flat steel production in 2010 with a totally 2.4 million tons/year of crude steel production capacity in two locations. The main production plant includes a sea port and administrative departments located in the south and the second in the north of Turkey. Company profile is given in Table 1.

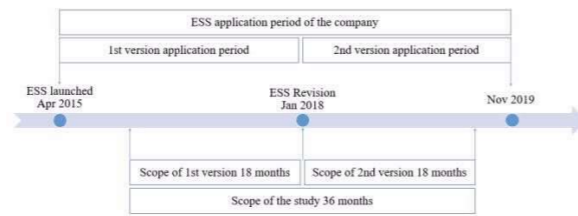
**Table 1.** Company profile

	Main plant	2nd plant
Number of total employees	820	334
Number of workers (Blue collar)	638	270
Number of expert/engineer (White Collar)	182	64
Port Capacity (M Tons/y)	11	No
AEF Capacity (M Tons/y)	2.4 (not operating)	No
HSM Capacity (M Tons/y)	2.4 (not operating)	No
CPL Capacity (M Tons/y)	1.2	No
CRM Capacity (Th Tons/y)	750	No
HDGL Capacity (Th Tons/y)	450	450
CCL Capacity (Th Tons/y)	200	200
Cutting Slitting Line Capacity (Th Tons/y)	50	50

In 2015 company launched the ESS in both locations to increase the innovation culture and provide related benefits. After more than 2.5 years of ESS implementation, top management of the company was not satisfied with the results and asked the R&D department to analyze the ESS implementation and revise it to achieve more satisfactory results. Required revisions were done by the experts and the revised ESS was put into operation in the beginning of 2018, and is being currently used.

## 2.2 Methodology of the study

ESS was launched in April 2015 and revision was done in the beginning of 2018 on the system features. The organizational/work environment factors and the individual attributes of the employees are not changed during the old and new ESS version application period. The scope of this study covered the results of the last 18 months of ESS application before revision (1st version) and results of the 18 months of the ESS application after revision (2nd version) to avoid from the initial effects of learning period of 1st version and also to equalize data collection periods of both versions. Time schedule of the application and the scope period of the study is illustrated in fig 1.

**Fig 1.** Study scope period

This study is based on the data collected during 36 months of the ESS usage before and after the revision. Some feedback information about the ESS application is obtained from the blue collar employees, white collar employees, suggestion evaluation and implementation responsible persons. This information is also used as a data set. Both versions of ESS are characterized and a comparison chart is created based on the system features of the basic characteristics of each version. Then the application results of both versions are analyzed, compared and discussed from the view point of the success factors related to system features.

## 3. Characterization of ESS versions

Characterization of version 1st and version 2nd are done comparatively based on the basic success factors related to system features: publicity, administration, structure, evaluation, rewarding and feedback.

### 3.1. Publicity

#### 3.1.1. Publicity of 1st version

ESS operation procedure, rewarding rules and suggestion forms are created and declared to all employees via e-mail. Suggestion entry forms were printed and sent to the department managers, the forms were also available on intranet of the company for the employees. 21 suggestion boxes are located in the most crowded areas of the plants like dining hall, main entrances, administration building etc.

#### 3.1.2. Publicity of 2nd version

ESS operation procedure and rewarding rules are revised, suggestion forms and all other hardcopy documentation was transferred to web-based ESS software. The revised procedure and rewarding instruction sent to all employees via e-mail. Promotional posters were prepared and hanged to some central parts of both company locations to announce the new version's start up. A logo was designed for ESS of the company and used for illustrating the system where needed. The logo with a link to ESS web site was set

in the intranet of the company, also the logo and introducing information is published in the company magazine.

A training program about the new version of ESS including system usage, system structure, rewarding rules etc. was prepared and presented to the managers, evaluation responsible personnel, implementation responsible personnel and to blue collar workers.

## 3.2 Administration of ESS

### 3.2.1. Administration of first version

1st version of ESS was managed manually. According to procedure, the suggestion entries were done with suggestion forms. The employees were requested to fill the suggestion forms and put them to the suggestion boxes. A suggestion secretary was responsible from collecting forms every week and record them. The suggestion forms received by e-mail was also recorded. The suggestions were evaluated by a committee of related directors/managers once a month. The suggestion submitted employee (SSE) was informed if the committee rejected. Accepted suggestions were projected by a team. Economy department calculates the estimated yearly income of the projected suggestion and the result of this calculation was accepted as a base for rewarding of the suggestion. The project was sent to general managers' approval. Approved projects were sent to the related department for implementation.

In the 1st version all the steps were followed by a suggestion secretary manually on hardcopy forms. Directors of human resources, finance, production, quality etc. were responsible for evaluation, general manager was responsible for final acceptance, related department managers were responsible from implementation and administrative department was responsible from rewarding. The communication between steps was via manual e-mailing.

### 3.2.2. Administration of 2nd version

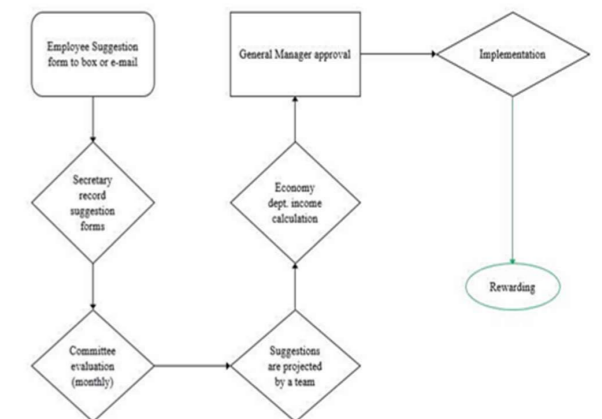
According to the revised procedure, 2nd version has been operated on web-based ESS software. Suggestion entries have been done on PC, mobile phone or any device which can connect to internet. A suggestion coordinator has been acting as an admin and directing the accepted entries to the relevant departments' expert or supervisor assigned to evaluate the suggestion technically by the department manager before. The SSE has been informed instantly with an automatic email service including the rejection rationale in the case of rejection. After technical evaluation, the evaluation result is approved by the related departments' manager and directed to the implementation department by the suggestion coordinator. Implementation has done and

the data regarding the application results are submitted to the system by the implementation responsible. If monetary profit was obtained, the data transferred to the economy department and the final reward calculation based on this calculation results. In the 2nd version all the steps run on software automatically. SSE has been informed instantly about the movement of the suggestion and was allowed to check the status of the suggestion in his profile. Any hardcopy has not used and any manual mailing has not needed during the administration of the 2nd version of ESS in the company. Technical evaluation has performed by a single expert who has assigned before and from the implementation and follow up stage a single person has been responsible as well.

## 3.3. Structure

### 3.3.1. 1st version ESS structure

The structure scheme of the 1st version of ESS (fig 2.) had 7 steps: recording, evaluation, projecting, economic calculation, approval, implementation and rewarding. There was a unique evaluation step consisted of a group of high level members. Accepted suggestions were converted to project again by another group. To be implemented, the projected suggestion should have been approved by the top level managing authority, general manager. The rewarding was done one time and at the end of all steps.

**Fig 2.** ESS 1st version structure scheme

### 3.3.2. 2nd version ESS structure

The structure scheme of the 2nd version of ESS (fig 3.) had 4 steps: review and routing, technical evaluation, implementation and follow up the results and rewarding. There was a review step which the submitted ideas were checked if the shape requirements of being a suggestion was met. The content of the suggestion was evaluated in the technical evaluation step by a single expert and the decision of the expert was approved by the manager of the expert. Implementation was done by the related

department and the economical income calculations were done according to the realization results of the implementation. Rewarding was done three times after each step.

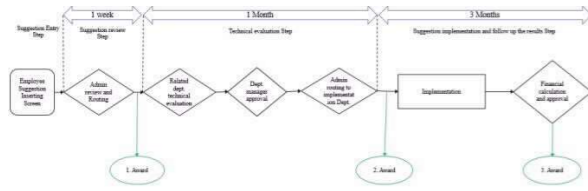


Fig 3. ESS 2nd version structure scheme

3.4. Evaluation

3.4.1. Evaluation in 1st version

Evaluation was done by a committee consisted of financial director (committee leader), human resources (HR) and administrative affairs director and purchasing manager, technical director, economy department manager, HR supervisor (committee secretary). Committee met every month and might have been included related managers if needed. Committee evaluated the suggestions due to the suggestion forms recorded and collected during the previous month. If a clear decision could not be taken the committee leader took the votes of the committee members and gave the final decision about the suggestion.

3.4.2. Evaluation in 2nd version

There are two step of evaluation, review and technical evaluation. In the review step, the semblance of the submitted idea of the employee was evaluated by the suggestion coordinator (admin) according to the predetermined criteria like, the idea should have not been about any of the following: salaries, out of core business of the company, worker union related subjects, the ideas should have included a solution to any problem or an offer for an improvement but should have not been a complaint or grumble. In that way, review step aimed to select the suggestions in an idea pool for a further detailed evaluation step.

The second evaluation was the technical evaluation and done by an employee who was expert on the subject of the suggestion or supervisor of the related department of the suggestion subject. The technical evaluation responsible (TER) employees are predetermined by the department managers and suggestion subject-responsible technical evaluation employee matching was done by the suggestion coordinator on the software.

3.5. Rewarding

3.5.1. Rewarding of 1st version

There is one reward at the end of all steps. The reward was %2 of the yearly profit provided by the suggestion

implementation which was calculated before implementation by the economy department. For group suggestions each group member was rewarded with the same ratio of the yearly profit, 2% for each member. The suggestions with nonmonetary benefits were awarded by a fixed amount of money.

3.5.2. Rewarding of 2nd version

The 2nd version of the ESS had a stepwise growing amounted 3 rewards after passing each step. 1st award was a small gift, 2nd award was a shopping card and the 3rd award was 2% of the yearly profit provided by the suggestion implementation where the data regarding implementation results submitted to the software and approved by the economy department. Also 3rd level rewards for the group suggestions decreased for per member of the group by increasing number of group members. So the given money amount by the company for 3rd award per suggestion increased but the gained amount of money for each group member was decreased to avoid from the unrealistic grouping. In the 2nd version all the calculations and management of the rewarding is processed on the web based software. The structure of rewarding in 2nd version is given in Table 2.

Table 2. Rewarding structure of 2nd version of the ESS

	1st award	2 <sup>nd</sup> award	3 <sup>rd</sup> award	
			Implemented	
	Pass review	Pass technical evaluation	Monetary value added	Nonmonetary value added
Single Employee Suggestion	Small Gift	Shopping Card	2 % of yearly benefit	Shopping Card
Two Employees Group Suggestion	Small Gift	Shopping Card	1.5 % of yearly benefit for each group member	Shopping Card for each group member

3.6.1 Feedback

3.6.1. Feedback system of 1st version

The feedback to the SSE about the status of his/her suggestion was sent via a manual e-mail by the ESS secretary in the 1st version. This feedback was consisting of an informative email message about the acceptance or rejection of the suggestion. If the suggestion was deserved to be rewarding, the e-mail also indicated the award details.

3.6.2. Feedback system of 2nd version

All the feedback information was sent via an e-mail message to the SSE automatically after each step by the software. When any action was taken on the suggestion status, software triggered the e-mail sending, to all participants related to the suggestion. For example, when a suggestion passed the review and directed to a TER;

a. a mail sent to SSE informing that his/her suggestion (including the name and the number of the suggestion) passed the review, directed to the TER (including name and department of the TER) and he could take his award from awarding responsible.

b. a mail sent to TER informing that he/she was appointed as a TER for a suggestion (name and number of the suggestion was included). The manager of the TER was also received that e-mail.

c. a mail sent to awarding responsible informing that a suggestion (including, the name of SSE, the name and the number of the suggestion) passed the review and reserved

for awarding.

The SSE could also sign in and follow the status of his/her suggestion in his/her profile screen on the ESS software.

3.7. Summary of characterization of the ESS versions

Version 1st and version 2nd of ESS of the company are characterized based on the basic success factors related to system features: publicity, administration, structure, evaluation, rewarding and feedback. Fundamental attributes of the versions are given in Table 3 comparatively.

Table 3. Summary of the attributes of versions

	ESS of the company	
	1 <sup>st</sup> version	2 <sup>nd</sup> version
Publicity	<ol style="list-style-type: none"> <li>ESS procedure emailed to employees</li> <li>Suggestion entry forms put to intranet</li> <li>21 suggestion boxes are located</li> </ol>	<ol style="list-style-type: none"> <li>ESS procedure emailed to employees</li> <li>Promotional posters were hanged</li> <li>ESS logo was designed</li> <li>A link given to ESS web site on intranet</li> <li>ESS advertisement in company magazine</li> <li>A training program to related employee</li> </ol>
Administration	<ol style="list-style-type: none"> <li>Administration was manual</li> <li>Coordinated by suggestion secretary</li> <li>All records were on forms</li> <li>Teams and departments were on duty</li> <li>General Manager was on charge</li> </ol>	<ol style="list-style-type: none"> <li>Administration was run on software</li> <li>Inter-step flow was automatic</li> <li>Coordinated by admin</li> <li>Single person and some departments were on duty</li> </ol>
Structure	<ol style="list-style-type: none"> <li>7 steps</li> <li>Complex structure</li> </ol>	<ol style="list-style-type: none"> <li>4 steps</li> <li>Simple structure</li> </ol>
Evaluation	<ol style="list-style-type: none"> <li>No review for suggestion selection</li> <li>Evaluation was done by a team</li> <li>Team members were directors</li> <li>Evaluation was done once a month</li> <li>Evaluation in a limited time</li> </ol>	<ol style="list-style-type: none"> <li>Idea semblance were reviewed</li> <li>Single expert technical evaluation</li> <li>Instant and on time evaluation</li> </ol>
Rewarding	<ol style="list-style-type: none"> <li>Single award at the end of all steps</li> <li>Nonmonetary benefits were also rewarded</li> <li>For single and group suggestions rewarding ratio was same</li> <li>Rewarding was followed manually</li> </ol>	<ol style="list-style-type: none"> <li>3 increasing valued awards</li> <li>Nonmonetary benefits were also rewarded</li> <li>Rewarding was incentive for group suggestions</li> <li>Rewarding was designed to avoid fake grouping</li> </ol>
Feedback	<ol style="list-style-type: none"> <li>Feedback was sent to SSE manually by e-mail</li> <li>Single e-mail to SSE for each suggestion</li> <li>Feedback include only the result and award</li> <li>Feedback was sent only to SSE</li> </ol>	<ol style="list-style-type: none"> <li>Feedback was sent to SSE automatically by instant e-mail</li> <li>E-mail to SSE for each step of each suggestion</li> <li>Feedback include all details about each action</li> <li>All the participants were informed</li> <li>SSE could follow the status of each suggestions via internet based software</li> </ol>



#### 4. Results of 1st and 2nd ESS version application and discussion

Usage of a web base software in the 2nd version completely changed the relevance of the employees to the system comparing to the 1st version which was based on hard copy forms and manual application, such that total number of suggestions submitted to the system was 45 times more than the 1st version. 28 total suggestions were received from 15 different employees to the 1st version and 1252 suggestions were received from 371 different employees to the 2nd version. The more the number of suggestions and the more the employees included to the system actively brought a functioning system perception in the company both for employees and system responsible personnel. ESS and suggestions submitted to the system were started to be spoken among the workers and managers and became an agenda topic of work places after initialization of the 2nd version.

The evaluation process times shortened and the number of total processed suggestions increased drastically with the 2nd version. During the application period of the 1st version, the members of the evaluation team were high level directors and the work density of their schedule was not allowing them to share time for the suggestion evaluation activity. In the 1st version period of 18 months, the evaluation team members able to meet for three times and could be able to discuss only on 11 of 28 received suggestions. In the same time period of the 2nd version the number of processed suggestions was 827 of 1252 submitted suggestions. Long response time of the 1st version blinded the employees' desire to make suggestion. In the last 18 months of application period of the 1st version, 2 of 8 accepted suggestions were implemented. The number of implemented suggestions for the first 18 months of the 2nd version was 172 of 368 accepted suggestions. 2 suggestions were rewarded during the 1st version's application period. On the other hand, all of the 999 suggestions which have passed the review were rewarded with the first level award in the application period. Also, 368 were rewarded with second level and 172 with third level awards. So, 631 suggestions were rewarded with first level award, 368 both first and second level awards and 172 all three of the awards.

The provided monetary income quantities for the company from the 1st and the 2nd version ESS applications in the scoped periods are not indicated in this study because of privacy but as might be predicted, the revisions on the 1st version and especially the effect of shifting the system to web based software caused a huge increase on company's monetary income, 122 times.

The summary of the results of the ESS versions are given in Table 4.

**Table 4.** The summary of the results of the ESS versions applications

Quantity	1 <sup>st</sup> version			2 <sup>nd</sup> version		
	Quantity	Ratio (%)	Suggestion per employee	Quantity	Ratio (%)	Suggestion per employee
Total Employees	1154			1154		
Total Suggestion Submitted Employees	15	1.3		371	32.1	
Total Suggestions	28	100	0.024	1252	100	1.085
Waiting for Review	-	-	-	0	0.0	0.000
Waiting for Revision	-	-	-	47	3.8	0.041
Rejected at Review	-	-	-	206	16.5	0.179
Waiting for Technical Evaluation	17	60.7	0.015	135	10.8	0.117
Rejected at Technical Evaluation	3	10.7	0.003	496	39.6	0.430
Waiting for Implementation	8	28.6	0.007	196	15.7	0.170
Implemented Suggestions	2	7.1	0.002	172	13.7	0.149

Some of the managers indicated that after some time of initiating the application of the 2nd version, they observed increase of innovation culture in some of their workers' behaviors where they began to discuss about some traditional applications which were used for years. Some managers and supervisors suffered from the extra work load they had faced for evaluation and implementation of the suggestions after the 2nd version was started. Another displeasing issue for them was the low qualified suggestions bombardment of some employees who were over focused on suggesting something.

#### 5. Conclusion

The revision of the company's employee suggestion system features like publicity, administration, structure, evaluation, rewarding and feedback drastically changed the success of the system from the view point of the number of suggestion received, number of employees actively involved to the system, evaluation speed and performance, number of awarded suggestions, income of the company from the suggestion implementation and innovative behavior of the workers. The improvement on the output performance of the ESS increased the satisfaction of both the employees and the management from the system. The web-based software paved the way for all these changes on the features of the ESS and so the increase on the output performance of the system. The increased satisfaction from the speed and performance of the new version encouraged the tendency to suggest for the employees. This tendency provided some positive effects on the innovative behavior of some employees, while on the other hand causing some attempts and tendency to misuse of the system by some employees and reactions by managers and supervisors. A further study may have done to analyze the problematic areas of the new version and to offer solutions to increase performance of the system.

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## Investigation of the Effects of Dry Film Thickness and Peak Metal Temperature on Surface Effect on Polyester Wrinkle Coil Coatings

Kuru Film Kalınlığının ve Pik Metal Sıcaklığının Polyester Kırışık Efektli Bobin Kaplamalarının Yüzeyi Üzerindeki Etkisinin Araştırılması

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### Abstract

Particle and textural structure of polyester wrinkle paints gives a special decoration on coil coated flat steel products' surfaces. However, it is difficult to achieve the same wrinkle effect continuously because of sensitivity of the texture to the fluctuations of some production parameters.

In this study, the effect of dry film thickness and peak metal temperature on color deviation and wrinkle surface texture of wrinkle polyester paint application flat steel products were investigated. In order to understand the effect of the thickness, different dry film thicknesses of RAL 3009 paint were applied on DX51-Z100 grade galvanized steel sheet by keeping the peak metal temperature constant. The dry film thickness of the paint was kept constant and the peak metal temperature was changed in an acceptable range and the effect on the texture was investigated. Increasing dry film thickness caused a noticeable change on the texture whereas effect of change in peak metal temperature was negligible.

### 1.Introduction

Paint is a coating applied to any object to give color or to protect. It is a chemical component that protects the surface against physical and chemical effects by forming a film layer on the applied surface and provides a decorative appearance at the same time.

Painted sheets can be classified as follows according to types of polymers which play a binding role in the content of the paint used [1].

- High Durable Polyester
- Wrinkle Polyester
- PUR-PA
- Polyurethane

- PVDF
- Plastisol

Wrinkled coatings have high resistance to atmospheric effects and good bendability because of high durable polyester resin. On the other hand due to the textured surface, snow piles can not hold on to the roof and the surface can easily be cleaned. These advantages provide this product to be highly preferred in the roofs of constructions placed in northern or high altitude regions in many countries.

With the use of pigments causing specific images, unique visual effects like matt brightness (1-10 gloss) can be obtained.

In UV classification, product is considered as RUV3.

With the use of special chemicals, during drying process, a solvent evaporates and as a result a thin layer of the film contracts by volume, forming the wrinkle effect. A rapid curing is seen in the upper layers of the film compared to the lower layers. While the lower layers are still fluid, the upper layers have less fluidity. This crust forms a wrinkle effect.

Factors like curing, film thickness, catalisors, type and amount of crosslinkers are some of the factors that have an influence on the mechanism and final Appearance of the wrinkle. Other paint components like pigment and solvent also have a big effect on the texture of the wrinkle. Therefore, it is possible to get different sized wrinkles for different colours of paint.

With small modifications in the parameters of productions lines, wrinkling process can be applied smoothly as in standard paint applications.

Wrinkled polyester products, that provide a fine and rough surface effect, are highly preferred for roofing and siding applications. When compared with ceramic roof tiles, Wrinkled Polyester has many advantages; As they are much lighter than tiles, covering the roofs is much easier and much faster. Repairs can be operated and concluded easily due to big pieces of steel sheets. They are suitable for covering flatter roofs without any water leakage through joints. Snow easily slides down from the roof and the roof is less sensitive to any kind of dirt. The look in the roofs or sidings is very esthetic. Another usage of wrinkle applications is in garage doors [7].

Curing temperature, dry film thickness, catalysts in the dye content, type and amount of crosslinker; These are the factors that directly affect the effect by affecting the crease mechanism [1]. In this study, the effect of dry film thickness and curing temperature on the color deviation of Wrinkle Polyester RAL 3009 dye and the size of the wrinkled surface effect was investigated.

### 2. Experimental Studies

#### 2.1 Materials

All samples used in this study were produced by MMK Metallurgy Dörtüyl galvanizing line. Samples were pre-treated with Cr<sup>6+</sup>, coated with 0.45 mm, 100g / m<sup>2</sup> zinc and passivated in DX51D steel grade. After galvanizing process, 5 µm chromate-free white primer [SP (CF)] was applied on the dyeing line and made ready for wrinkle application. The lined sheets were sized 15 x 20 cm in the laboratory and SP Wrinkle RAL 3009 was applied on them.

#### 2.2 Devices and Equipment

Rds 24, RDS 28, RDS 30, RDS 32, RDS 38, Sheen 1850, Sheen 1836 applicators were used to apply SP Wrinkle RAL 3009 paint on the lined sheets used in the study. Reatec temperature-indicators (PMT band) for curing control, Alborh Furnace for curing, Erichsen Paint Borer 518 MC for dry film thickness measurement, Erichsen TRI-GlossMaster (65°) for brightness cone, X-Rite Ci7800 (d/8 geometry, spin) for color control.

### 3. Conclusion

In order to understand paint thickness effect; samples, produced in coating line with 5 µm primer, were painted by applicators in different wet paint thicknesses. Since the guaranteed dry film thickness of wrinkle coatings is 18-22µm [1], 20 µm paint thickness was aimed in the range ±6µm. The paint was cured at 232°C in the furnace according to the technical data document recommended by the paint manufacturer [6].

The determination of dry film thickness of samples prepared by applying as wet paint in the laboratory and cured in the oven was made in accordance with the ISO 2808 standard 6B method [2]. Brightness measurements were made in accordance with EN 13523-2 standard [3] and color measurements were made in accordance with EN 13523-3 standard. [4]

In order to understand the effect of curing temperature; the wrinkle RAL 3009 paint was painted with 20 µm thickness and was cured at different temperatures in the range of 199-260°C.

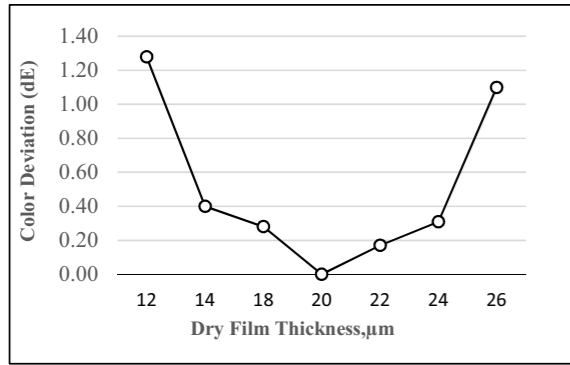
#### 3.1 Change of Color Deviation with Dry Film Thickness

The color deviation measurements of samples are measured according to standard color panels which is cured at 232 °C and has thickness 20 µm. all samples were cured with peak metal temperature (PMT) 232 °C.

**Table 1:** Change of color deviation (dE) at constant temperature with dry film thickness

Temperature, (°C)	Dry Film Thickness, µm	Color Deviation,(dE)
232	12	1,28
232	14	0,40
232	18	0,28
232	20	0,00
232	22	0,17
232	24	0,31
232	26	1,10





**Figure 1:** Change of color deviation (dE) at constant temperature with dry film thickness

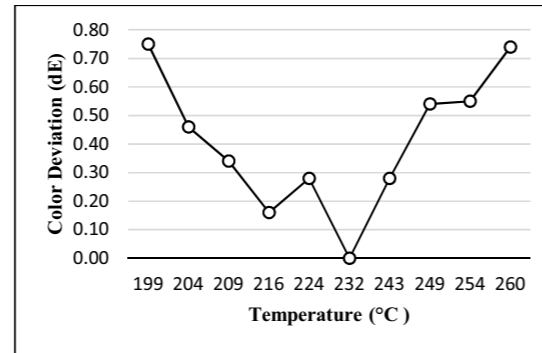
The color deviation due to dry film thickness (dE) between 14-24  $\mu\text{m}$  is not much whereas the color deviation of low and high thicknesses (12,26  $\mu\text{m}$ ) is high.

### 3.2 Change of Color Deviation with Temperature

One panel with a dry film thickness of 20  $\mu\text{m}$  and a peak metal temperature of 232°C PMT is stored as standard on the color spectrophotometer instrument. The color deviation of samples cured at different temperatures have same paint thickness 20  $\mu\text{m}$  and their color are measured according to standard panel. (Table 2)

**Table 2:** Change of color deviation (dE) at constant dry film thickness with temperature

Dry Film Thickness, $\mu\text{m}$	Temperature, (°C)	Color Deviation, (dE)
20	199	0,75
20	204	0,46
20	209	0,34
20	216	0,16
20	224	0,28
20	232	0,00
20	243	0,28
20	249	0,54
20	254	0,55
20	260	0,74



**Figure 2:** Change of color deviation (dE) at constant dry film thickness with temperature

According to the measurement results, the effect of temperature change on color deviation is less than the effect of thickness change on color deviation.

### 3.3 Change of Brightness with Dry Film Thickness

The brightness measurement of the samples applied in different thicknesses are given in Table 3. All panels are cured at a peak metal temperature of 232 °C (PMT). According to the data in Table 3, it was observed that the brightness does not change with dry film thickness, specific to this paint.

**Table 3:** Change of brightness (%) at constant temperature with dry film thickness

Temperature, (°C)	Dry Film Thickness, $\mu\text{m}$	Brightness (%)
232	12	3
232	14	3
232	18	3
232	20	3
232	22	3
232	24	3
232	26	2

### 3.4 Change of Brightness with Temperature

The panels, which are applied as 20  $\mu\text{m}$  (standard), are cured at different temperatures. The brightness of the panels applied and the change in temperature are given in Table 4.

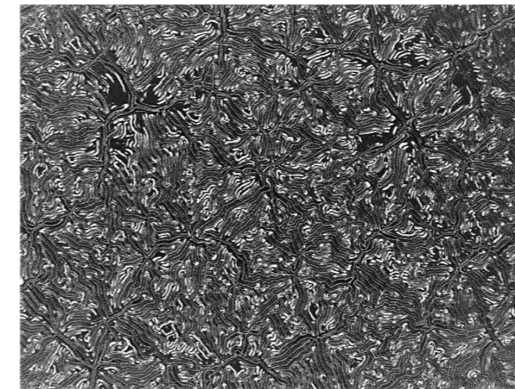
According to these data, it has been observed that the brightness does not change with temperature in relation to this paint.

**Table 4:** Change of brightness (%) at constant dry film thickness with temperature

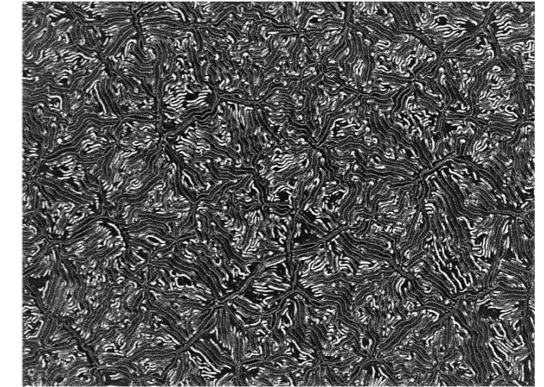
Dry Film Thickness, $\mu\text{m}$	Temperature, (°C)	Brightness (%)
20	199	2
20	204	2
20	209	2
20	216	2
20	224	2
20	232	3
20	243	3
20	249	3
20	254	3
20	260	3

### 3.5 Change of Wrinkle Effect with Dry Film Thickness

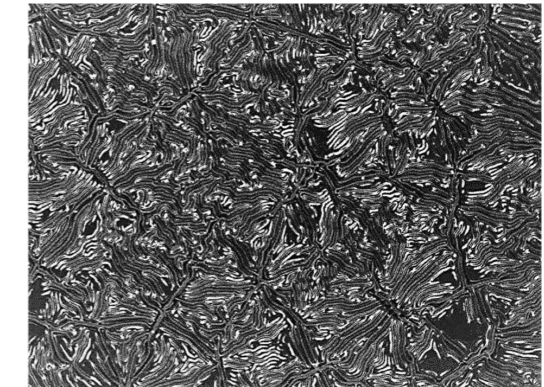
In order to understand the effect of thickness change on the wrinkle effect, all panels applied with different thicknesses were cured at a peak metal temperature of 232 °C (PMT)



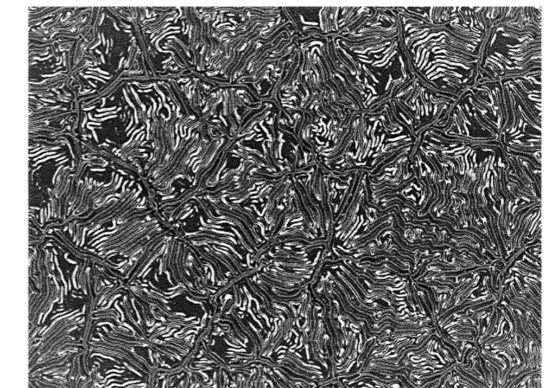
**Figure 3.** 12  $\mu\text{m}$ , PMT (232°C)



**Figure 4.** 14  $\mu\text{m}$ , PMT (232°C)



**Figure 5.** 16  $\mu\text{m}$ , PMT (232°C)



**Figure 6.** 18  $\mu\text{m}$ , PMT (232°C)





Figure 7. 20  $\mu\text{m}$ , PMT (232°C)

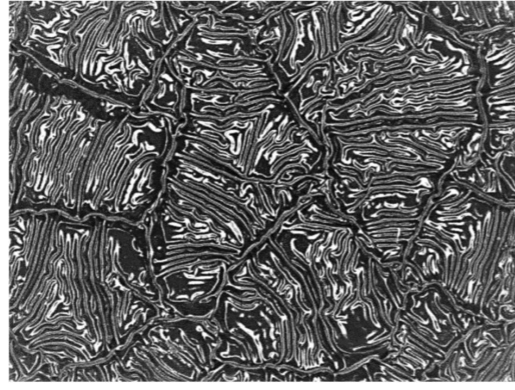


Figure 10. 26  $\mu\text{m}$ , PMT (232)

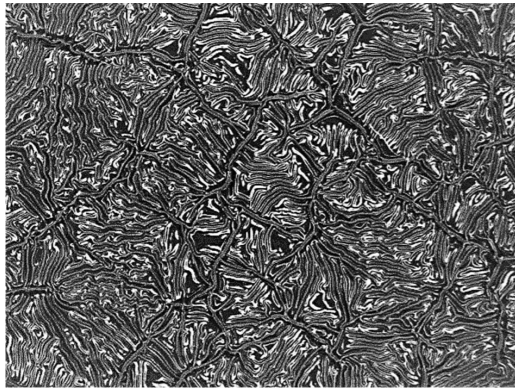


Figure 8. 22  $\mu\text{m}$ , PMT (232°C)

The standard application thickness of wrinkle paints is 20 microns. When the surface pictures were examined, it was seen that the wrinkle effects increased as the dry film thickness increased. In the winding process after the production, the stigmas of the big effects are deformed by rubbing on the bottom surface.

### 3.6 Change of Wrinkle Effect With Temperature

All panels applied standard 20 microns and cured at different temperatures.

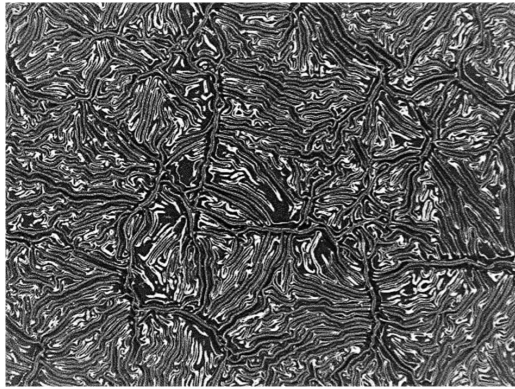


Figure 9. 24  $\mu\text{m}$ , PMT (232°C)

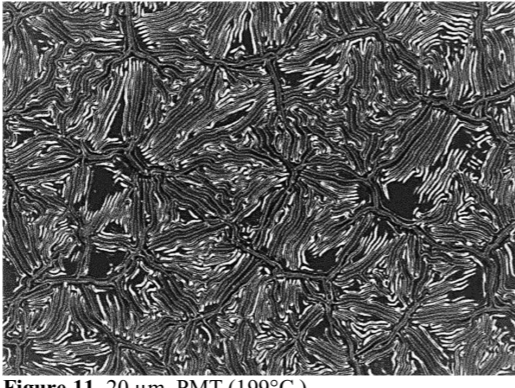


Figure 11. 20  $\mu\text{m}$ , PMT (199°C)

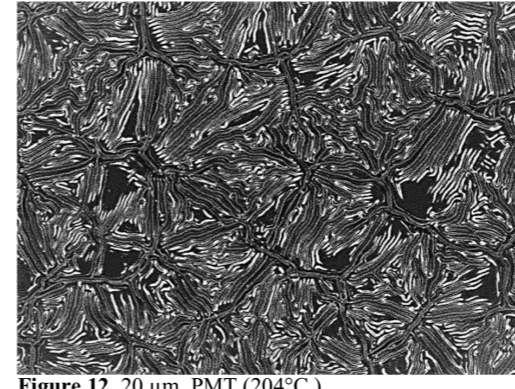


Figure 12. 20  $\mu\text{m}$ , PMT (204°C)

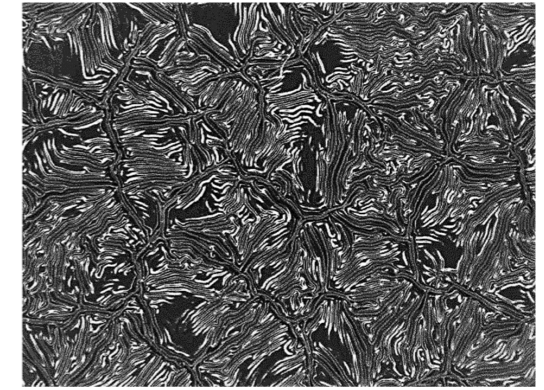


Figure 15. 20  $\mu\text{m}$ , PMT (224°C)

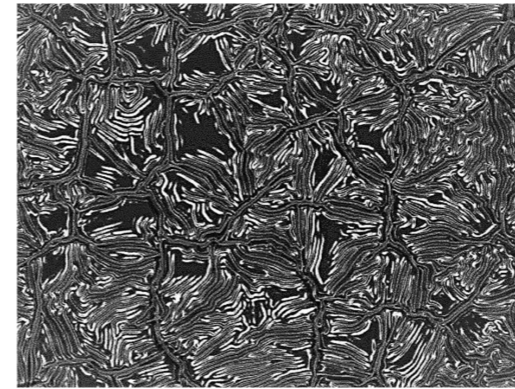


Figure 13. 20  $\mu\text{m}$ , PMT (209°C)

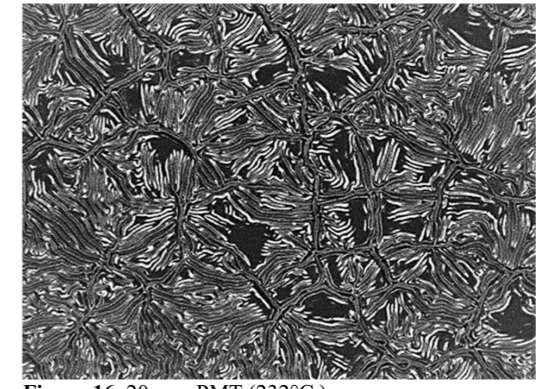


Figure 16. 20  $\mu\text{m}$ , PMT (232°C)

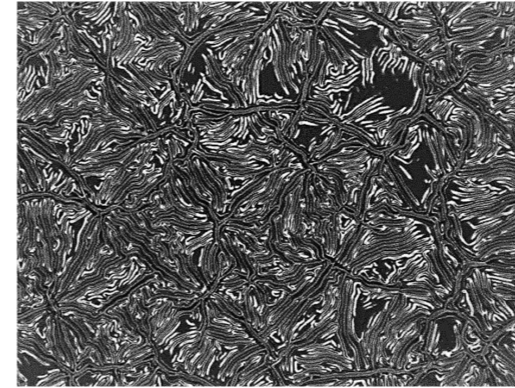


Figure 14. 20  $\mu\text{m}$ , PMT (216°C)

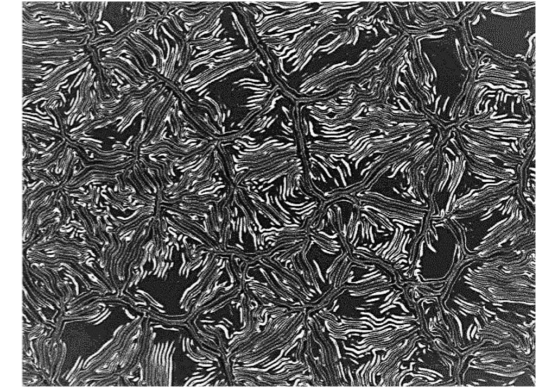


Figure 17. 20  $\mu\text{m}$ , PMT (243°C)



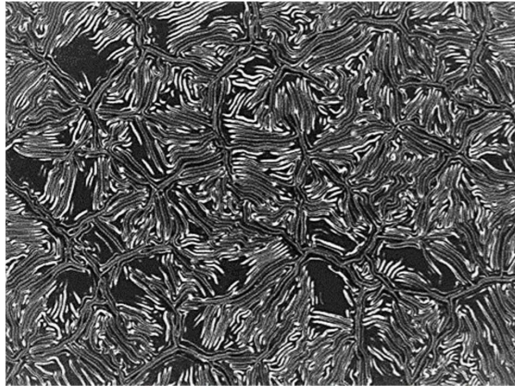


Figure 18. 20  $\mu\text{m}$ , PMT (249°C)

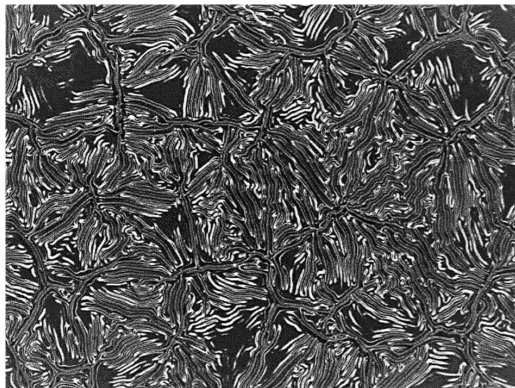


Figure 19. 20  $\mu\text{m}$ , PMT (254°C)

When the surface pictures are examined it was observed that increasing the curing degree had no effect on the wrinkle effect for this sample.

#### References

- [1] MMK Metalurji, Product Catalog, 2019
- [2] ISO 2808 Paints and varnishes - Determination of film thickness
- [3] EN 13523-2 Coil coated metals - Test methods - Part 2: Gloss
- [4] EN 13523-3 Coil coated metals - Test methods - Part 3: Colour difference - Instrumental comparison
- [5] Shimokawa, M., Yoshida, H., Komatsu T., Omachi, R., Kudo, K. Emergence of Wrinkles During the Curing of Coatings, (2018)
- [6] AkzoNobel Coil Coatings, Technical Datasheet For Wrinkle Polyester Topcoat
- [7] MMK Technical Bulletin

## Recent Hot Strip Mill Technology Highlights

H. Longze, T. Takeguchi

PRIMETALS TECHNOLOGIES JAPAN • Japan

### Pair Cross Technology

It is a basic and common understanding that shape and crown control in hot strip mill are exceedingly important for both product quality and material yield. Primetals Technologies was the first in the world to develop a pair cross mill with high strip shape control capability. It achieves excellent crown controllability by crossing work roll and back-up roll in pair. Since 1984, Primetals Technologies has made numerous improvements to this system based on our extensive experience in the industry.

#### Features:

- High strip shape control capability
- Simplified mill mechanical structure
- Achievement of high rolling reduction
- Reduced mill vibration through the use of a mill stabilizing device (MSD)

### SmartCrown® Technology

SmartCrown® work rolls feature a modified, sine-shaped contour. By selecting the correct contour coefficients and shifting the work rolls by the same amount in opposite directions, the resultant unloaded roll gap is always cosineshaped, regardless of the actual shifting position of the rolls.

#### Features:

- Significantly enhanced crown and flatness control range compared to work roll bending
- Higher adjustment range for narrow products
- Single work roll contour per stand for all products
- Facilitated production planning
- More flexible pass schedule design
- Thinner gauges can be achieved
- Contour control and higher-order flatness control in conjunction with work roll bending

### Endless Rolling

Endless rolling involves the joining of the tail end of a preceding transfer bar with the head end of the following transfer bar after the roughing stands by Super Deformation Joining (SDJ) machine. Primetals Technologies, Ltd. is a pioneer in this innovated HSM, with most experience developing and implementing unique technologies.

#### Features:

- Expansion of product lineup. Production of thinner, wider and harder steel sheets; Stable rolling of thin and hard-to-roll materials
- Increase in productivity. Great reduction in mill idle time, and constant rolling speed with reduction of mill acceleration and deceleration time
- Improvement of product quality. Improvement in accuracy and uniformity of strip thickness, crown, and width
- Energy savings. Reduction of the mill acceleration and deceleration frequencies

- Increase of yield. Minimization of miss-rolling of thin and hard-to-roll materials; Application of tension at head and tail parts of bar

#### Mill stabilizing device (MSD)

At today's demanding condition, maintaining stable operation of rolling mill is becoming difficult. MSD is a hydraulic cylinder installed to mill housing window and press a roll chock against the opposite side with constant force. MSD eliminates gap between roll chocks and mill housing, keep rolls in proper position and stabilize rolls.

##### Features:

- Enables stable rolling at demanding rolling condition.
- Stabilizes threading.
- Reduces housing window gap control work. (Easier maintenance)
- Prevents problems occurring from roll skew between WR and BUR.
- Can be applied to existing mill

#### Online Roll Profiler (ORP)

Primetals Technologies have been a pioneer in the field ever since we developed the world's first system capable of roll grinding inside the mill stand (ORP) and have enhanced this technology based on our extensive experience in the industry.

##### Features:

- Extending the roll life
- Eliminating roll surface defects
- Extending the length of same-width rolling
- Permitting to widen out without roll change

#### Looper Shape Meter (LSM)

The measurement of strip shape between mill stands on a strip mill has previously been rather difficult and unreliable. Primetals Technologies has developed a looper shape meter (LSM) for continuous and accurate measurement of interstand shape.

##### Features:

- The load on the segment roll is measured by a torque meter without any influences of hysteresis of the mechanism, unlike when using a load cell
- Measurement by torque meter enables higher accuracy and increased measurement reliability without any influences caused by changing mechanical condition
- Easily interchangeable with existing loopers. Because LSM has low moment of inertia, existing looper drive system can be reused
- Easy replacement of segment roll for maintenance

#### Power cooling®

For cooling and advanced “in-line” metallurgical treatment of new materials, Primetals Technologies developed “Power Cooling®” technologies. This combines the advantages of normal laminar cooling or “low pressure cooling” and “high power cooling” with the highest cooling rates for flexible operation.

##### Features:

- Reducing alloying costs by substitution of hardening elements with hardening achieved by higher cooling rates
- Providing extremely high cooling rates (up to 40K/s @ 25.4mm)
- Providing extreme flexibility with an adjustment range from 10% to 100%
- Used for the complete product mix by operating in two modes, laminar and Power Cooling. Installed in running mills and new mills in combination with laminar cooling or as transfer bar cooling or as interstand cooling
- Perfect solution for two-step cooling patterns e.g. needed for DP-grades
- Perfect for de-bottlenecking of short cooling lines

#### Advanced Down Coiler

Primetals Technologies have developed an advanced down coiler, incorporating improvements in high speed coiling, heavy gauge steel coiling and easy maintenance, derived from our vast amount of experience.

##### Features:

- Wedge & link step less expanding type Mandrel for better coiling quality & reliability
- Plug-in design for quick mandrel replacement
- Automatic Jumping Control for preventing top-marks on inner wraps
- Accurately controlled side guide & pinch rolls for stable operation & coil quality

#### Modular Coil Shuttle System (MCS)

Primetals Technologies has developed an innovative modular coil-logistics system that relies on self-driving, remote-controlled shuttle cars traveling on dedicated rail tracks. The cars have built-in motors and are orchestrated by an automation system that ties in perfectly with existing plant automation and enables streamlined interaction between the coil-transport setup, the plant's cranes, and all involved coil-treatment stations.

##### Features:

- Highly customizable coil logistics
- Low investment and operational costs
- Fast erection and commissioning
- “Plug & Play” type installation and removal of shuttle cars
- High operational flexibility
- Outstanding reliability
- Low maintenance with close-to-zero wear on the tracks and extended spare-part service life
- Simple integration into existing automation systems
- Reliable tracking of all active shuttle cars even in the event of a power outage
- No deterioration of the coils' surface and edges during transport
- Easy and low-cost system extension
- Smart and fully automated design (including crane handling)



## Monitoring Technology for Downstream Processes on the Example of Hot Strip Camber, Strip Edge Inspection and Mechanical Properties Measurement

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### Abstract

With worldwide experience and many installations Primetals Technologies is an experienced supplier for mechatronic products for checking parts in down-stream processes.

Original products from Primetals Technologies are the culmination of several years' experience in engineering, design, manufacturing, operations, and maintenance.

Specialization on specific measurement technologies is not enough to keep pace. So, the solution often is a combination of measurement technologies, measurement and control technologies of different physical fields. Optical measurement devices in the production area are valuable tools to further improve production reliability and product quality. Starting with hot strip mill strip guidance in the roughing mill as well as in the finishing mill is decisive in order to achieve constant and perfect product quality.

As well as the applications differ significantly the measurement technology used is related: Watching the measurement situation with cameras and let algorithm decide about quality of the seen – hot transfer bar in the hot rolling mill, identify the camber and strip alignment and automatically control the mill stands on the one hand – strip edge surface after side-trimming in order to speed-up set-up processes for side trimmers and avoid defects like knife breakouts and saw-tooth on the other hand.

In order to not only get an impression about the outer (visible) characteristics of an object other methods are necessary. This is shown at the example of electromagnetic measurement for characterizing the material properties.

In this respect, our aim is to set up the most modern mechatronic products available on the market. It will allow for more control at the heart of the plants.

### Introduction

The paper describes the image processing technology of the applications and the opportunities that come out from that by use of these products. The focus lies on the plant status monitoring on the one hand – but not only, it is optimized technology for the operators and process engineers to either automatically control or derive improvement actions for process optimization easily.

#### *Hot Strip Mill – ShapeMon*

An optical measurement device is watching the material from the bird's view. It records the glowing strip and measures the camber and the alignment on the roller-table. The novelty in this case is the evaluation algorithm with a statistical and predictive approach that only allows reliable measurement in this harsh environment. This is the precondition for the Primetals Technologies Strip Steering Expert, a fully automatic control device.

This not only ensures better wedge and profile of the hot strip, it also reduces the cobble-rate caused by camber significantly.

Interesting are also applications on the billet and bloom caster for controlling the torch cutter with respect to length and weight of the final product.

#### *Pickling, Annealing, Galvanizing – EdgeMon, PropertyMon*

EdgeMon is installed closely after the side trimmer. An image processing sensor is watching the strip edge surface. The innovation of this product lies in the algorithm that do not only prepare the image for

visualization (magnification, elimination of strip vibrations, brightness scaling...) it also rates the image in order to provide high-level evaluation that makes it easy to identify wrong trimmer settings or defects like saw-tooth or knife breakouts.

The requirements on product quality increase steady. This makes it necessary to observe process steps that were of less interest a couple of years ago. So, material properties are becoming more and more interesting. Modern products request highest stability: tailor blanks and other small stamped part need homogeneous material for dimension stability, electrical elements (Si-steel for motors and generators) need best electromagnetic behaviour in combination with mechanical properties.

PropertyMon serves both. It is used for characterizing mechanical properties in steel plants. The new optimized sensor allows direction related measurement to characterize longitudinal and transversal behaviour. The small measurement spot also informs about variations across the strip width.

The same sensor can additionally be used to measure the magnetic losses and the polarization at the same time with the same characteristic. Again, the direction related measurement allows an important insight in GO and NGO materials where it is not necessary to renounce on the mechanical properties that are measured simultaneously.

### 1. ShapeMon for improvement of camber and strip guidance

For measuring the geometry of hot rolled slabs or transfer bars there are a lot of methods described in literature. All are very similar in its basic principle except some special ideas that allow focusing on special interests. What is common for most is that they cannot reach the requested reliability in the harsh environment between the mill stands of a hot strip mill.



Figure 1: HSM - finishing mill section

The huge water load on the surface (e.g. coming from the scale breaker) and the according vapor interfere with the measurement significantly. This may lead to missing measurements (best case) or wrong measurement (worst case).

The design requirements for the present technology was the capability for a usage in a control unit.

Arrangement of measurement device:

An optical sensor is placed to the top of the mill stand watching the area in between. The signal is transferred to an evaluation unit and processed.

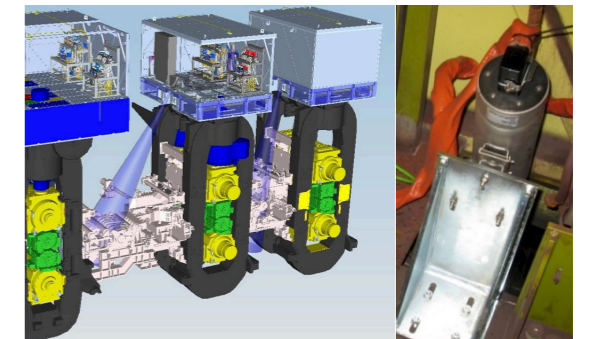


Figure 2: Installation in the FM, sensor

Due to the harsh environmental situation the core technology lies in the evaluation unit in order to achieve highest robustness. Therefore the first step of evaluation, the extraction of the strip edges from the raw images is crucial.



Figure 3: Scale breaker causes huge water and steam load

Advanced edge focused brightness control ensures a perfect contrast at the strip edges independent of the centre temperature. Based on that both edges operator side and drive side are isolated by improved edge filtering algorithm.

Due to the process, it cannot be avoided completely that measurement fails when isolated images are considered. To improve this the adapted edge filtering algorithm is also considering past images in combination with statistical methods for further improvement.

This development and the positive test results where the basis to proceed with the next step: the automatic integration of the device to a control unit called Strip Steering Expert in order to improve strip threading and -guidance.

**Results from this technology:**

Compared with standard edge filtering algorithm the implemented significantly improve the reliability and accuracy of edge identification.

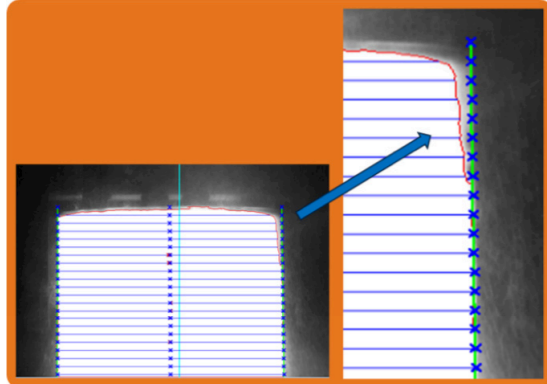


Figure 4: Improved edge filtering (blue) - standard (red)

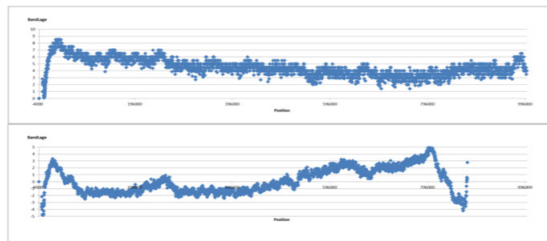


Figure 5: Measurement variance: classical (top) and new method (bottom)

In combination with the Strip Steering Expert tests showed a significant reduction of the cobble rate caused by head end camber as well as a reduction in wedge change.

**2. EdgeMon for improved side trimming quality and reduced maintenance effort**

Strip thickness in processing lines starts from 0.3 mm or even thinner. Therefore, inspecting the strip edge surface is a challenge. The inspection software of Primetals Technologies strip edge inspection device EdgeMon was now improved in order to be able to reliably inspect this product spectrum, too.

Best practice examples from existing EdgeMon installations will explain how to achieve process improvement in short time.

Strip Edge Inspection is already established in Pickling Line section where the strip thickness is typically between 1.5 and 6.5 mm. Automatic inspection algorithm ensure that operators can concentrate on the added value processes. The inspection device automatically flags up in case of quality issues.

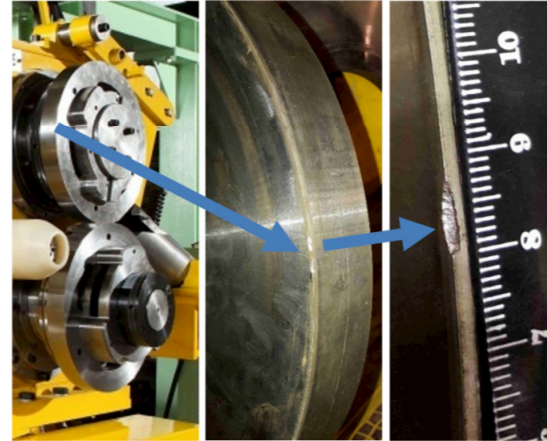


Figure 6: Knife chip

The device provides a **4-steps evaluation:**

1. The recorded image of the strip edge surface:

Due to sophisticated trigger technology the image length is always exactly one circumference of the knife. This is unavoidable as periodic quality issues related to the knife only can be seen clearly with this technology. Additionally, the software automatically eliminates the consequence of strip vibrations during recording.

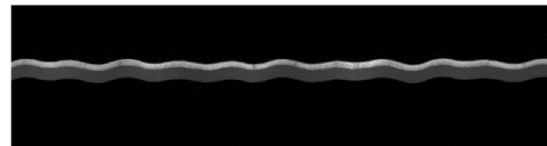


Figure 7: Original image



Figure 8: Compensation of strip vibrations

The compensated image according to Figure 2 is displayed to the operator.

2. The image is checked against irregularities:

This first check is already an important and informative information to the operator in order to get a general impression about side trimming process. Depending on the settings according to the needs (more or less sensitive thresholds) EdgeMon already provides a warning. This means that the operator does not have to have a look at

the screen all the time because he will get an information in case of a quality issue.

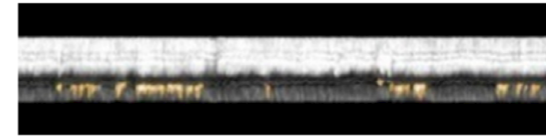


Figure 9: Irregularities in the breaking zone (yellow)

This evaluation for example provides characteristic images related to specific defects e.g. saw-tooth. So, these can be identified and troubles in cold rolling process avoided easily.

3. 2nd level evaluation:

Based on the quality issues mentioned under 2. All defects are analysed based on their shape on the one hand and based on the position in the image related to the previous image. Due to the synchronization to the knife circumference periodic defects (seen as marks in the image) always appear on nearly the same position in every displayed image during production.

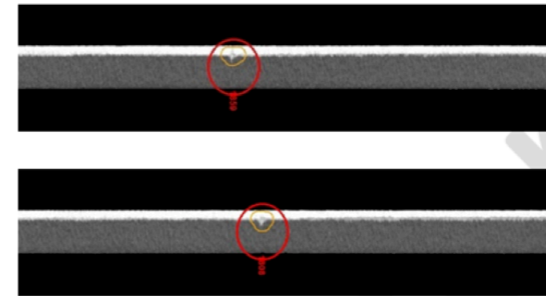


Figure 10: Automatic knife chip detection

A specially developed analysis algorithm prepares these marks related to geometrical properties and checks them against periodicity. If the same defect can be found periodically it can be assumed that this is a chip on the trimmers knife and a knife breakout alarm is provided.

4. Global coil evaluation:

As it can happen that defects are mixed up or frequent irregularities described in 2. are detected as a breakout when they are checked only locally at the currently produced strip position an additional evaluation step was implemented:

The identified defect information is collected in a so-called color-coded line which collects them over one complete coil length.

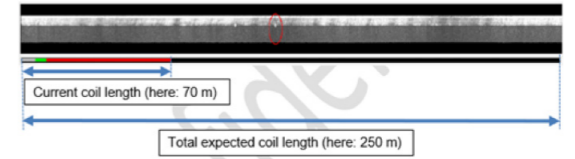


Figure 11: Colour-coded line

The information displayed is most possible simplified: good / warning / alarm. This makes it easy for the operator to derive decisions on how to proceed with this product and the side trimmer.

Additionally, the percentage along the strip length telling how likely an identified defect occurred is displayed.

Edge Quality ok	Edge Quality check	Knife ok	Knife Breakout
100% / 0%	56% / 44%	100% / 0%	11% / 89%

Figure 12: Defect percentage

**Results from this technology**

1. Identification of knife breakouts (knife chips):

Due to the color-coded line in combination with the resulting value of the percentage a simple classification could be implemented:

- If green percentage is between 70% and 100% no breakout is very likely
- If green percentage is between 60% and 70% no breakout is likely (watch the red circle for some evaluations is recommended)
- If the red to green percentage is 50% +/- 10% (40-60) it is unsure and a check of the images itself (watch the red circle for next 10 evaluations) is needed to give clarification.
- If red percentage is between 60% and 70% a breakout is likely (watch the red circle for some evaluations is recommended)
- If red is between 70% and 100% a breakout is very likely

The result of a performance test shows the reliability of this approach:

No breakout (70%-100%):	101,5
No breakout (60%-70%):	0
Uncertain (40-60%):	1,5
Breakout (60%-70%):	1
Breakout (70%-100%):	4

Comparison with the coil on stock showed that the 1st and the last group (70-100% for both – breakout and no breakout) was always correct.



Group 2 and 4 failed one time. For the evaluation resulted in group 3 EdgeMon could not find a clear decision (which typically is caused by an extremely poor general edge quality).

So, in this test 97,7% of the inspection results were correct.

2. Identification of knife saw-tooth:

An important defect type is the so-called saw-tooth. It causes troubles in the rolled edge, burr can lead to surface defects.

By evaluation of the stored EdgeMon data in coordination with the quality feedback from operators and quality engineers a relationship between image appearance and saw-tooth could be identified.

By providing a defect catalogue to the operator he can compare the present image with saw-tooth images and so it is easy for him to identify them and start the corrective measures.

Saw-tooth is characterized by a mixture of significantly increased cutting zone and massive local white spots in the break zone.

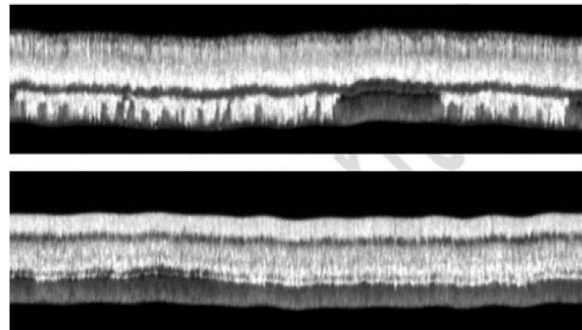


Figure 13: Typical saw-tooth image

3. **PropertyMon for material characterization with focus on mechanical and electrical properties**

The measurement is based on a sensor pair measuring from the bottom and the top.

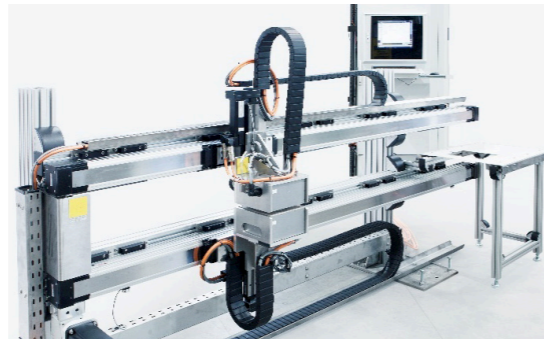


Figure 14: Sensor arrangement with traversing unit

The measurement is based on a coil system that primary magnetically excites the material to be measured and on the same time measures the reaction of the material on the magnetic field.

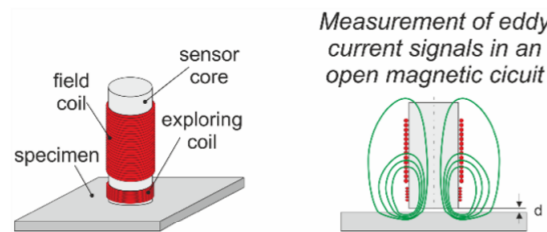


Figure 15: Measurement principle

The design of the coils allows a direction related measurement. For certain steel grades it is essential to distinguish between longitudinal and transversal behaviour.

The signal from the field coil is a hysteresis-loop equivalent. This signal is split to its characteristic frequencies and phases. With that a unique fingerprint of the material is already available. In order to be able to compare these fingerprints with process and product parameters known in literature it is necessary to transform these data to the well-known measurement values like polarization, remanence inductivity, tensile strength, yield point, hardness.

This is done by a calibration procedure. The raw data representing the fingerprint of the material are transformed to the interesting parameters.

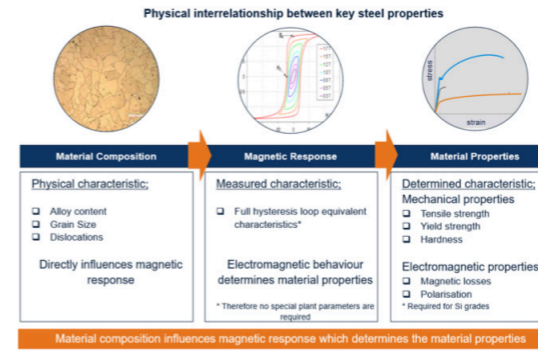


Figure 16: physical correlation between mechanical and electrical properties

Results from this technology

The following results focusses on Si-steel test series. The mechanical properties are well studied and published.

Several studies were carried out which in the meantime are confirmed by sensors in operation for more than two year.

The results of the comparison between the PropertyMon sensor results and the laboratory testing show an excellent correlation.

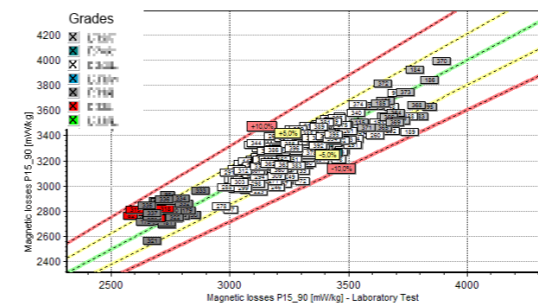


Figure 17: Correlation between online measurement and laboratory results

One of the conclusions is the direction related sensitivity of the sensor. This enables an important field of material and process examination.

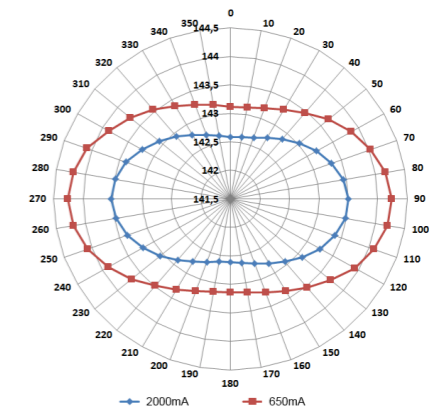


Figure 18: phase shift of the first harmonics related to the magnetization angle

Summary, conclusion and outlook

ShapeMon in combination with the Mill Steering Expert leads to a significant improvement of cobble and wedge situation. It is technically possible to operate optical measurement devices between finishing mill stands. Limitations cannot be avoided so they were considered in the design of the measurement algorithm as well as in the design of the controller.

This technology can also be implemented to the roughing mill section. This leads to a better transfer bar as a perfect precondition for finishing mill rolling.

Further development of this product family allows additional features and applications:

The technology can also be used to measure the speed of the strip and derived from that the length. This application is then also suitable for billet, bloom and strand casters. Regarding the billets and blooms section errors like rhombicity can also be measured. So, the torch cutting process can be optimized with respect to length and weight.

EdgeMon is available for hot band as well as for cold band with the same inspection quality.

This development now allows to inspect very thin products reliably. Further interesting aspects are edge cracks in Si-steel and stainless-steel lines to be detected automatically.

In order to meet different space situations in existing plants the device can be either provided as a so-called "standalone" variant that can be integrated to the plant a few meters after the side-trimmer or it can be directly attached to the side-trimmer itself – the so-called "integrated" variant. So, an instant feedback to the

operator is ensured and therefore side-trimmer parameters can be optimized immediately on the fly.

PropertyMon is the logical enhancement of present state-of-the-art measurement technologies. By use of least possible sensors and sensor technologies a wide range of material characteristics can be measured at once: mechanical parameters like tensile strength, yield strength and hardness as well as electrical parameters for Si-steel production like magnetic losses and polarization.

It can be used for several different needs:

1. End-product check after the last process step influencing the properties (e.g. skin pass mill)
2. Check of process steps (e.g. installation before and after annealing furnace)
3. Quality control of previous process steps (e.g. entry section of pickling line for hot band verification)

So, this is a typical example of an indispensable tool for operators and production for immediate feedback on present production on the one hand and process and quality engineers for process stabilisation and product development and optimization.

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3. H. Hlobil, W. Hackl, J. Traxler: An Appropriate Approach to Facilitate Decisions for Quality Improvements at Side Trimmers by use of Optical Inspection, 10th International Rolling Conference Graz Austria, Proceedings 2016

## High Carbon High Speed Steel Rolls

Yüksek Karbonlu Yüksek Hız Çeliği Merdaneler

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## Abstract

High carbon high speed steel rolls have excellent high-temperature abrasion resistance and thermal fatigue resistance. It has been broadly used in the hot rolling steel. In this paper, manufacture process, microstructure properties and performance of high carbon high speed steel rolls are introduced.

## 1. Introduction

With the development of the new species, technique and new rolling mills, the rolls are facing greater challenges in wear resistance, toughness and thermal fatigue performance. Roll material from Hi Cr Steel, Hi Cr Iron, ICDP and others develop to HSS and HC-HSS. Compared with traditional material, wear resistance, red hard ability and anti-fire crack ability of HC-HSS being improved significantly result in an excellent performance on roll profile retention, surface quality of strips and greatly improve the rolling efficiency<sup>[1-2]</sup>.

## 2. Chemical composition of HC-HSS

The proper design of alloy & microelements realized the densities of compound carbides and liquid phase at same level in the structure, so decreased carbides segregation. Adopt special manufacture technology to control the content of floating graphite in working layer within 0.2%.

**Table 1.** Chemical composition of HC-HSS (wt.%)

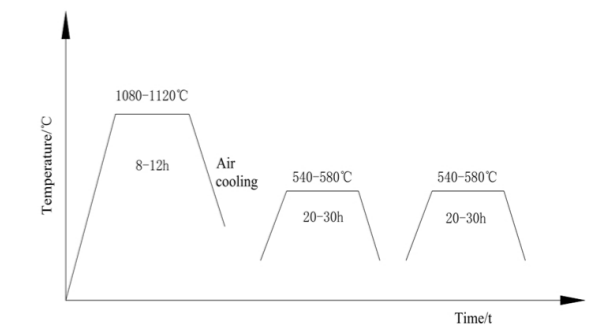
C	Si	Mn	Cr	Ni	Mo	W	V
2.0-3.5	0.4-0.8	0.5-1.0	1.0-2.5	4.5-5.5	2.0-2.6	1.5-3.5	1.0-3.0

## 3. Manufacturing process

### 3.1 The casting process

High-carbon HSS is melted in a frequency furnace. After being deoxidized with aluminium at 1550-1580 °C, the liquid steel is poured off and then modified in ladle with RE-Mg-Ti compound inoculant. On the horizontal centrifuge casting molding, the liquid metal was poured into the centrifugal casting mold at a rotation speed of 550 rad/min. Stop the centrifugal machine when the inner surface temperature dropped 10 °C below the crystallization temperature. and placed in the casting mold on the vertical pit, pouring core iron liquid, and demolding after cooling down a certain temperature, get high carbon high speed steel roll blank.

### 3.2 Heat treatment process



**Figure 1.** The curve of treatment process

Quenching process of HSS is (1080-1120) °C × (8-12)h, air cooling, temper process is (520-580) °C × (20-30)h, air cooling ( twice ) .



4. Microstructure properties

4.1 Microstructure of HC-HSS

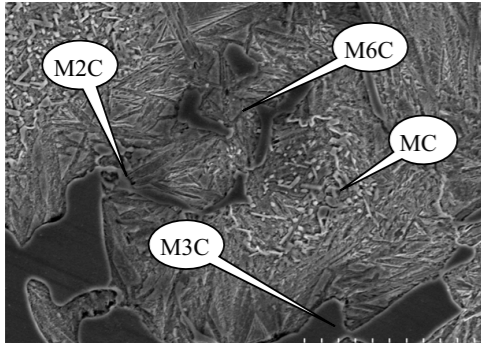


Figure 2. Complex carbides of HC-HSS

The microstructure of HC-HSS by centrifugal casting is shown in figure 2. It can be seen from figure 2 that except MC type carbides, the HC-HSS roll also contains massive of M2C type, and M6C type compound carbides with high micro hardness which only existing in HSS material.

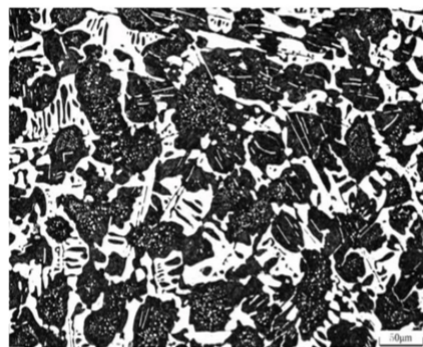


Figure 3. Metallographic image of HC-HSS

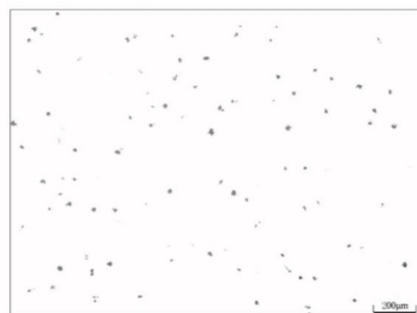


Figure 4. Graphite particles of HC-HSS

Meanwhile, compared with Enhanced-ICDP, the graphite particles of HC-HSS are more fine and disperse, it can be seen in figure 4. During rolling process, graphite particles fall off which played a role of lubrication between the roll and strip, that effectively improve surface quality. Due to matrix of HC-HSS contains tempered martensite that is of high strength, finer grains, that we can see from figure 3, the HC-HSS work rolls have good capacity to anti-crack forming.

4.2 The hardness of working layer

Due to increase alloy content, especially W, Mo element, the hardness uniformity in the working layer of HC-HSS roll is improved significantly. The figure 5 is the curve of the hardness of work layer test data of E-ICDP and HC-HSS work rolls. Hardness drop in HC-HSS working layer can be controlled within 1.5HS and ICDP roll hardness drop in work layer is 3.5HSD.

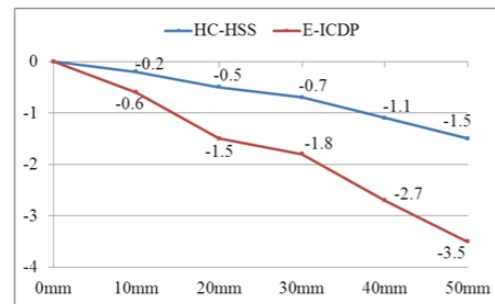


Figure 5. Hardness drop in working layer

4.3 Wear resistance of working layer

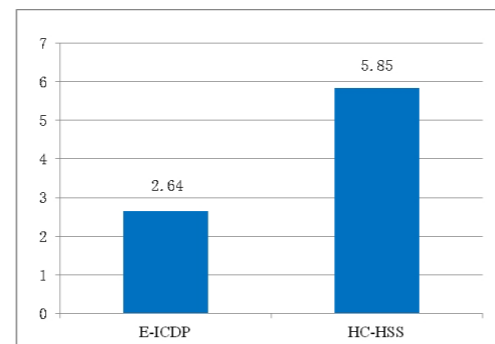


Figure 6. Relative wear resistance

The wear test is done on a high temperature wear test machine. The size of specimen is 6×25mm. Due to diffusive MC granular carbides, the matrix have high hardness and strength, at the same time, M2C type and M6C type compound carbides with high micro hardness, Relative wearing resistance of HC-HSS roll is 2.2 times of Enhanced-ICDP roll.

5. Application and performance

5.1 Rolling tonnage per mm

HC-HSS work roll is used on the late finishing stands F4-6(7) of conventional HSM or Steckel mill finishing stands. Below is the performance of HC-HSS work roll in one of our customer. According to the statistics, till roll normal scrapped, the comprehensive rolling tonnage on rolling line 2050 is 5195 t/mm; on rolling line 1880 is 4724t/mm. Compared with Enhanced ICDP roll on these two lines, the average rolling tonnage per mm was respectively improved 40% and 51%.

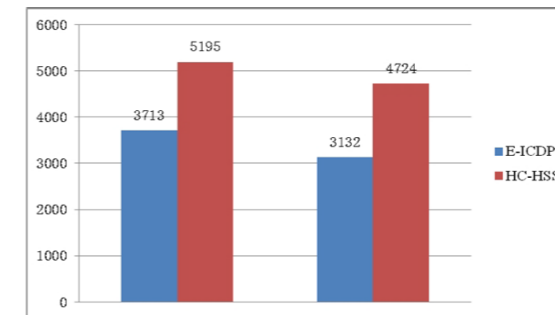


Figure 7. Rolling tonnage (t/mm)

5.2 Excellent of crack resistance and accident resistance

The thermal fatigue test is done on a self-straining thermal fatigue tester. Heating in a high frequency induction heater and cooling by running water. The circulating temperature is between 550°C and 40°C. After 1500 cycles, stopping test and measuring the depth of crack. The Hot-impact test is done on a thermal shock tester. The specimen size is 60mm × 40mm × 50mm, hot impact for 15s with 150N pressure, stopping

test and measuring the depth of crack. It can be seen in figure 8, compare with E-ICDP, the HC-HSS cold-hot fatigue crack depth is less than 30%, hot impact crack depth is less than 55%.

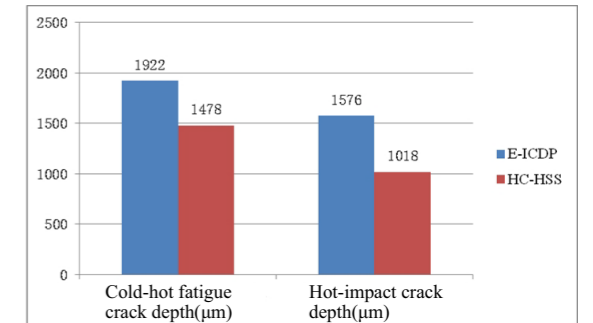
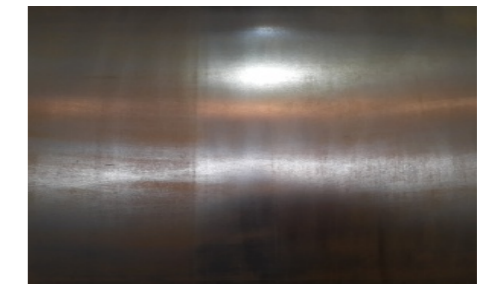


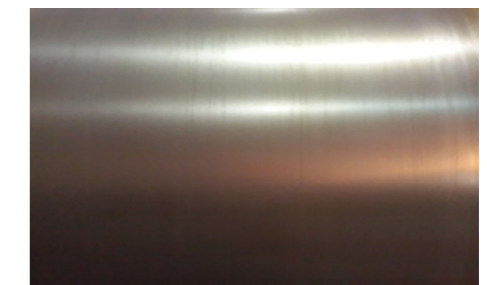
Figure 8. crack resistance and accident resistance

5.3 Excellent of surface quality and roll profile retention

Martensite matrix of HC-HSS work roll has higher strength than Bainite, can wrap carbides particles better. So reduced the carbides particles fell off and increased wear resistance. Surface quality after service of HC-HSS roll is obviously better than that of Enhanced ICDP roll.



E-ICDP



HC-HSS

Figure 9. The surface quality after service

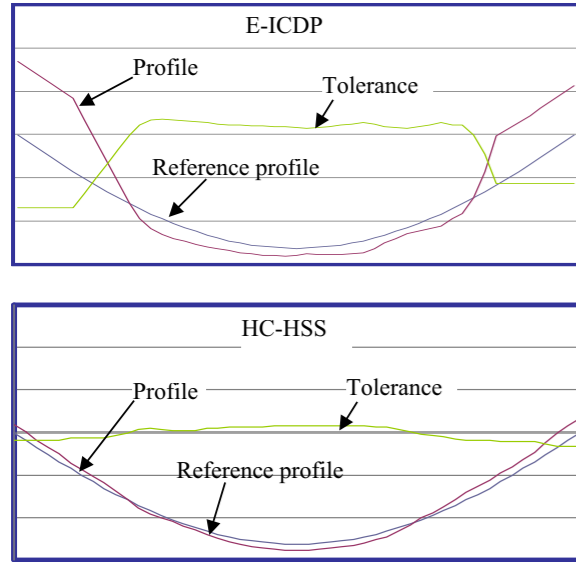


Figure 10. Roll profile retention ability

In the figure 10, is the roll profile retention ability of E-ICDP and HC-HSS work rolls. Due to the matrix have high hardness and strength and contains M2C type and M6C type compound carbides with high micro hardness, HC-HSS work rolls on-line wear out reduced significantly. The wear resistance and roll profile retention ability improved obviously, satisfy to roll super auto sheet and white plate.

The performance per mm is improved greatly. If the rolling campaign prolonged and grinding amount reduced, compare with E-ICDP work rolls, the performance of HC-HSS work rolls would be increased by 1 time.

## 6. Culouision

1. The microstructure of HC-HSS is mainly composed of martensite, austenite, and the secondary carbides precipitated from austenite and/or eutectic ledeburite. The carbides are of MC, M2C, M3C, M6C type.

2. Due to containing massive of M2C type, and M6C type compound carbides with high micro hardness as well as the matrix having high hardness and strength result in the

diffusive MC granular carbides, HC-HSS wear resistance improve significantly.

3. HC-HSS work roll has much better capability on wearing resistance, surface quality and accident resistance than the Enhanced-ICDP roll, and the rolls can be directly used on rolling mill without any adjustment, so it can fully substitute Enhanced-ICDP roll.

## Reference

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- [2] Hanguang Fu, Research status and prospect of high speed steel roll [J]. Steel, 2000, 35(5): 67-73.

## İstatistiksel Veri Analiz Teknikleri Kullanarak Sıcak Haddehane Proses Parametrelerinin Optimizasyonu Uygulaması

The Application of Hot Rolling Mill Plant Process Parameters Optimization Using Statistical Data Analysis Techiquies

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İSKENDERUN DEMİR VE ÇELİK • Türkiye

## Abstract

İskenderun Iron and Steel Co. (İSDEMİR) is the only integrated plant producing flat and long products in Turkey with its 3,5 million tons/year capacity hot rolling mill. İsdemir has a production capacity of approximately 5,3 million tons of crude steel, 3,5 million tons of flat products, 0,6 million tons of wire rod and 2,5 million tons of billets of finished products annually. İsdemir produces billets, slabs, pig, wire rod, hot rolled products in international quality standards and provides inputs to many sectors such as cold rolling mills, service centers, general manufacturing, machinery and equipment, construction, shipbuilding industry, general construction, pipes and profiles, road and rail vehicles, pressure vessels and boilers. Improvement activities are carried out in all departments with the participation of all employees, using lean manufacturing techniques (suggestions, kaizen, 5S, visual factory, etc.) in order to produce sustainable production without harming people and the environment. In addition, Operational Excellence Projects (OPEX Projects) are carried out in order to increase productivity, minimize process variability to solve problems that occur frequently, use operational resources effectively and increase customer satisfaction. In this paper, İsdemir's Opex project approach is explained and the application example conducted with using advanced statistical data analysis techniques in the Hot Rolling Mill Plant. Ferro alloy savings and cost advantages have been achieved by providing process optimization for the structural steels quality, which constitute more than 50% of the flat product production in İsdemir, by providing the mechanical strength required by the EN 10025-2: 2019 standard. The data of the process were analyzed with the Minitab® program and the results were evaluated.

## Özet

Ülkemizin kuruluş tarihi itibari ile üçüncü, uzun ürün üretim kapasitesine göre en büyük entegre demir ve çelik fabrikası

olan İskenderun Demir ve Çelik A.Ş. (İsdemir), 2008 yılında devreye aldığı 3,5 milyon ton/yıl sıcak haddeleme kapasitesi ile Türkiye'nin uzun ve yassı ürün üreten tek entegre tesisidir. Uluslararası kalite standartlarında kütük, kangal, pik, slab ve sac üretimi yapan İsdemir, haddecilik, genel imalat, makine ve alet, inşaat, gemi sanayi, genel konstrüksiyon, boru ve profil, iş makineleri, karayolu ve demiryolu araçları, basınçlı kaplar ve kazanlar, soğuk haddehaneler ve servis merkezleri gibi pek çok sektöre girdi sağlamaktadır. İsdemir'de; insana ve çevreye zarar vermeden sürdürülebilir üretim yapmak amacıyla yalın üretim tekniklerini (öneri, kaizen, 5S, görsel fabrika vs.) kullanarak tüm çalışanların katılımı ile tüm departmanlarda iyileştirme faaliyetleri yürütülmektedir. Bunun yanında, verimliliği arttırmak, proses değişkenliklerini en aza indirmek, işletme kaynaklarının etkin kullanmak, kanıksanmış problemleri çözmek ve müşteri memnuniyetinin arttırmak için Operasyonel Mükemmellik Projeleri (Opex Projeleri) yürütülmektedir. Bu çalışmada, İsdemir Opex proje yaklaşımı anlatılarak, Sıcak Haddehane'de ileri istatistiksel veri analizi teknikleriyle yürütülen bir uygulama örneğine yer verilmiştir. İsdemir'de yassı ürün üretiminin %50'sinden fazlasını oluşturan yapı çelikleri kalitelerinde EN 10025-2:2019 standardının gerektirdiği mekanik mukavemetleri sağlamak koşuluyla proses optimizasyonu yaparak ferro alayım tasarrufu ve maliyet avantajı sağlanmıştır. Prosesle ait veriler MiniTab® programı ile analiz edilerek sonuçları değerlendirilmiştir.

## 1. Giriş

İsdemir'de; insana ve çevreye zarar vermeden sürdürülebilir üretim yapmak amacıyla yalın üretim tekniklerini (öneri, kaizen, 5S, görsel fabrika, vs.) kullanarak tüm çalışanların katılımı ile tüm departmanlarda 2004'den beri iyileştirme faaliyetleri yürütülmektedir. Sürdürülebilir, yenilikçi, rekabetçi, hızlı ve çevik, müşteri taleplerine anında cevap verebilen bir şirket olma yolunda, süreçlerimizi yalın ve etkin hale getirerek stratejik hedeflerimize ulaşmamızı

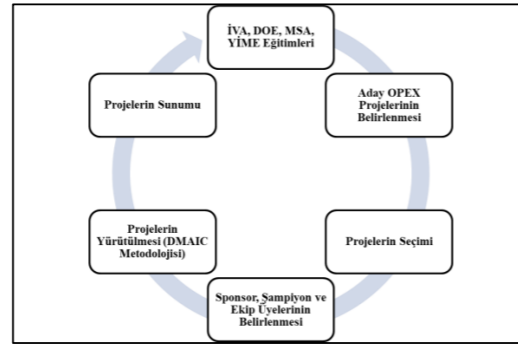


sağlamak, değer yaratmayan faaliyetlerin azaltılması ile işletme kaynaklarının etkin olarak yönetilmesini sağlayacak yöntem ve araçların hayata geçirilmesi, çalışan katılımıyla sürekli iyileştirmeyi kurum kültürü haline dönüştürmek amacıyla 2014 yılında Oyak Maden Metalürji Grubu (OMMG) bünyesinde Operasyonel Mükemmellik Direktörlüğü departmanı ve bu departmana bağlı Operasyonel Mükemmellik Müdürlüğü kurulmuştur. İsdemir'de; verimliliği arttırmak, proses değişkenliklerini en aza indirmek, işletme kaynaklarını etkin kullanmak, kanıksanmış problemleri çözmek ve müşteri memnuniyetini arttırmak için Operasyonel Mükemmellik Projeleri (Opex Projeleri) yürütülmektedir. Opex Projeleri, süreç sahipleri ve proje ekipleri ile yürütülen iyileştirme projeleridir. Opex Projeleri geliştirme sürecinin ilk adımı Opex eğitimlerinin gerçekleştirilmesidir. Her yıl Opex Direktörlüğü ve süreç sahipleri tarafından belirlenen kişilere farklı dönemlerde Opex Direktörlüğü tarafından MiniTab® destekli İstatistiksel Veri Analizi Eğitimi (İVA), Deney Tasarımı Eğitimi (Design of Experiment - DoE), Ölçüm Sistemleri Analizi Eğitimi (Measurement System Analysis - MSA), Yöneticiler İçin İstatistiksel Modelleme Eğitimi (YİME) verilir. Her yılın son çeyreğinde bir sonraki yıl üzerinde çalışılacak yeni dalga proje konularının belirlenmesine yönelik hazırlık çalışmaları yapılır. Bu kapsamda; geçmiş dönemde Opex eğitimlerine katılmış tüm çalışanlara ve tüm müdür ve direktörlere proje seçim sürecinin başladığı bilgisi verilerek proje teklifleri talep edilir. Önerilen Opex Proje teklifleri Operasyonel Mükemmellik Müdürlüğü tarafından ön değerlendirmeye tabi tutulur. Bu kapsamda projeyi teklif edenler ile görüşülür, konu direktörlük seviyesinde incelenir. İlgili direktörlükte projeyi teklif eden kişilerin de bulunduğu bir toplantı organize edilir. Bu toplantıda projeler değerlendirilerek önceliklendirme yapılır. Şu kriterler dikkate alınarak projeler önceliklendirme sıralamasına tabi tutulur:

- Maliyet azaltma, kalite, verimlilik, tasarruf, duruş azaltma vb. proses optimizasyonu
- Kısa dönemde değişmeyecek ve üzerinde çalışma yapılabilecek süreçler
- Veri toplama imkanı olan süreçler
- Anlamlı finansal sonuçları olabilecek çalışma konuları
- Sınırları ve kapsamıyla üzerinde çalışma ve değişiklik yapılabilecek süreçler

Direktörlükler seviyesinde belirlenen çalışma konuları, başkanlığını İsdemir İşletmeler Genel Müdür Yardımcısı'nın yaptığı, Genel Müdür'ün davet edildiği ve ilgili tüm direktörlerin ve müdürlüklerin bulunduğu toplantıda görüşülür. Yapılan değerlendirmeler neticesinde bir sonraki yıl üzerinde çalışılacak yeni Opex Projeleri belirlenmiş olur. Opex Projeleri'nin yönetimin onayı ile belirlenmesi sonrasında proje ekipleri oluşturulur. Proje ekipleri "çekirdek ekip" ve "gözlemci ekip" olmak üzere iki ayrı ekipten oluşmaktadır.

Çekirdek ekip; en fazla 7 kişiden oluşur. Projenin hayata geçmesinde direkt katkısı olan ve zamanını proje için kullanan kişilerdir. Ödüllendirmeye tabi ektir. Gözlemci ekip; sayı sınırı yoktur. Projenin yapılışını görmek, eğitimlerde öğrendiklerinin uygulanmasına tanık olmak amacıyla toplantılara katılırlar. Ödüllendirmeye tabi değildir.

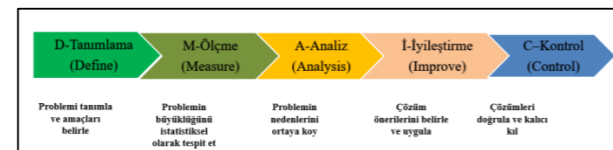


Şekil 1. Opex Projeleri döngüsü

Proje kapsamında ihtiyaç duyulan kaynakların sağlanması, proje ekibinin oluşturulması, ekibin çalışmalarını izleyerek ortaya çıkan sorunların çözülmesinde teknik ve yönetsel destek sağlanması amacıyla "Proje Sponsoru" ve Proje Şampiyonu" belirlenir. Proje Şampiyonu; genel olarak projenin yapıldığı birimin müdürüdür. Ekibin çalışmasını izler, önlerine çıkan sorunları çözmede teknik ve yönetsel destek olur. Projeler Sponsoru; projenin yapıldığı birimin bağlı olduğu direktördür. Kendisinde bir ya da daha fazla proje bulunur. Direktörlüğündeki projelerin gidişatını izleyip üst yönetimle paylaşır.

Opex proje ekiplerinin kurulması sonrasında Operasyonel Mükemmellik Müdürlüğü tarafından proje toplantıları organize edilir. Toplantılara, Proje Sponsoru, Proje Şampiyonu ve ekip üyeleri davet edilir. Gerekliğinde toplantıya başka ilgili kişiler de davet edilebilir. Proje toplantılarında Operasyonel Mükemmellik Direktörlüğü çalışanları danışmanlık yapar. Projelerin yürütülmesinde DMAIC Modeli uygulanır. Toplantılarda, projenin amacı, proses çıktıları, proses parametreleri, ölçüm sistemlerinin varlığı ve ölçüm sistemi analizi ihtiyaçları, geçmiş veri analizleri, hedeflenen çıktıya ulaşmak için izlenecek yol, projenin içeriğine göre analizler ve deneme çalışmaları yapılır.

DMAIC döngüsü tanımlama, ölçme, analiz, iyileştirme ve kontrol adımlarından oluşmaktadır.



Şekil 2. DMAIC döngüsü

Tanımlama adımının sonrasında; projenin gösterge, hedef ve sınırlarının herkes tarafından anlaşılabilir bir şekilde tanımlanması, müşteriye olan etkisinin belirlenmesi beklenmektedir.

Ölçme adımının sonrasında; projenin çıktılarının ve girdilerinin doğru bir şekilde ölçüldüğünden emin olunması, mevcut durumun belirlenmesi, grafiksel analizlerin yapılması beklenmektedir.

Analiz adımının sonrasında; sürecin değişkenliğini yaratan önemli girdilerin belirlenmesi, düzeylerinin araştırılması, zaman tuzaklarının belirlenmesi beklenmektedir.

İyileştirme adımının sonrasında; sürecin değişkenliğini yaratan önemli girdilerin hangi düzeylerde ayarlanacağını belirlenmesi ve doğrulanması beklenmektedir.

Kontrol adımının sonrasında ise sürecin iyileştirilmiş seviyede devam etmesi için kontrol planlarının oluşturulması ve kontrollerin belirlenmesi beklenmektedir.

DMAIC döngüsünün her bir adımında farklı teknikler kullanılabilir. Tanımlama adımında süreç akış şeması, sebep sonuç matrisi yaygın kullanılan yöntemlerdendir. Ölçme adımında; veri seti hazırlığı, grafiksel analizler, ölçüm sistemleri analizi, süreç yeterliliği analizi kullanılabilir. Analiz adımında; detaylı proses analizi yapılmakta, korelasyon, çoklu doğrusal regresyon analizi, ikili lojistik regresyon analizi, hipotez testleri gibi yöntemler sıklıkla tercih edilmektedir. İyileştirme adımında; tam faktöriyel deney tasarımı, kesirli faktöriyel deney tasarımı, anova deneyleri, çoklu çıktı optimizasyonu yöntemleri kullanılabilir. Döngünün son adımı olan kontrol adımında ise önce-sonra analizi, istatistiksel proses kontrol, standartlaştırma ve dökümantasyon faaliyetleri gerçekleştirilir.

Bu çalışmada İsdemir Sıcak Haddehanesi'nde gerçekleştirilen ve başarı ile tamamlanan bir Opex projesine ait uygulama adımlarına yer verilmiştir.

## 2. Deneysel Çalışmalar

İsdemir Sıcak Haddehanesi'nde 2019 yılında "Yapı Çeliklerinde Sıcak Haddehane Parametrelerinin İncelenerek Mekanik Mukavemetin Modellenmesi" konulu bir Opex projesi gerçekleştirilmiş ve başarı ile tamamlanmıştır.

Yüksek fırınlardan gelen sıvı ham demir, konverterde çelik olarak üretimi sonrası daha önce kalite bazında belirlenen alaşımlama ve diğer faaliyetler için pota fırınlarında işlem görür ve slab döküm tesisinde döküm emrine uygun ebatlarda dökülerek yarı mamul haline getirilir. Daha sonra sıcak haddehanede müşterinin talep ettiği ebatlarda haddelenerek nihai ürün olarak üretimi gerçekleştirilir.

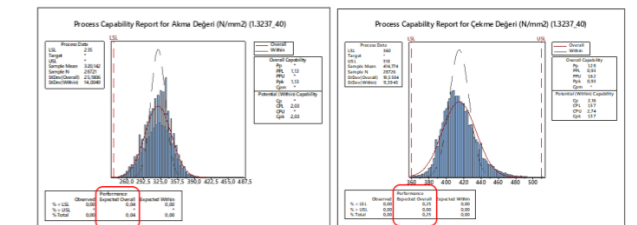
Yapı çelikleri, çekme dayanımı ve akma dayanımı ile tanımlanan alaşımsız veya az alaşımlı çeliklerdir. Yapı çelikleri kaliteleri EN 10025-2:2019 standardına dahil olup

genel olarak S235, S275 ve S355 kalitelerinde JR, J0, J2, K2 uzantıları ile belirtilmekte ve +AR, +N, +M teslim şartları ile üretilmektedir. Bu kalitelerin tamamı C-Mn çelikleri olup düşük mikro alaşım elementleri ile kalınlık bazında mukavemet artırılmış ve haddelemesi konvansiyonel haddeleme ile yapılan ferritik-perritik mikro yapıya sahip çeliklerdir. Mekanik özellikler, karbon ve mangan miktarı ile birlikte üst kalitelerde ilave edilen alaşım miktarına bağlıdır. Şekillendirilme ve form verilme özelliklerinden daha çok, yüksek dayanım gerektiren uygulamalar için kullanılır. Örneğin; çelik konstrüksiyon, iş makinaları, oto korkuluk sistemleri, aydınlatma direkleri, makine imalatı, vinç üretimi, kara ve demir yolu araçları imalatı, inşaat makineleri imalatı gibi. Bu kalitelerde temel olarak akma mukavemeti, çekme mukavemeti, % uzama ve bazı kalitelerde de darbe dayanımı ve katlama testleri mekanik özellikler olarak ön plana çıkmaktadır. En düşük kalite grubu minimum 235 MPa akma mukavemeti ve minimum 360 MPa çekme mukavemeti değerine sahip olup, en üst derecede ise minimum 355 MPa akma mukavemeti ve minimum 510 MPa çekme değerine sahiptir. Darbe sıcaklıkları ve diğer detaylar ise kalite uzantısına göre değişmektedir.

Üretimimizin büyük bölümünü oluşturulan bu kalitelerde, standardın gerektirdiği mekanik mukavemetleri sağlamak koşuluyla ferro alaşım tasarrufu yapılması ve kazanç elde edilmesi amacıyla çalışma yapılmıştır.

### 2.1. Mevcut Durum

Mevcut durum tespiti çalışmaları kapsamında yapı çelikleri grubunun temel kaliteleri için akma mukavemeti ve çekme mukavemeti değerleri üzerinden süreç yeterliliği analizleri yapılmıştır. Mevcut durumdaki hatalı oranları tespit edilmiştir. Kalite ekstrasında yer alan alaşım elementleri ve aralıkları bilindiği için potansiyel müdahale imkanları değerlendirilmiştir.

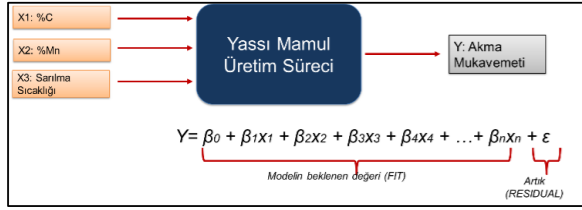


Şekil 3. S235JR kodundaki 3237 kalitenin proje öncesi süreç yeterliliği analizi

### 2.2. İyileştirme

Projenin iyileştirme adımında mekanik mukavemeti tahminleyen en iyi modeli bulmak amacıyla çoklu doğrusal regresyon analizi yapılmıştır. Yapı çelikleri kalitelerinden Grup1 kaliteleri için ayrı, Grup2-Grup3 kaliteler için ayrı çalışma yürütülmüştür. Girdi faktörleri olarak, sarılma

sıcaklığı, ikmal sıcaklığı, kaba hadde çıkış kalınlığı, şerit hadde giriş sıcaklığı gibi haddeleme proses parametreleri ile %C, %Mn, %Si gibi kimyasal analizler dikkate alınmıştır. Çıktı faktörü olarak ise akma mukavemeti belirlenmiştir.



Şekil 4. Çoklu doğrusal regresyon analizi yöntemi şematik gösterimi

Grup1 kaliteler için akma mukavemetini en iyi açıklayan modeli bulmak amacıyla best-subset regresyon analizi yapılmış, bu analiz sonucunda oluşturulan faktör kombinasyonlarından en uygunu seçilerek çoklu doğrusal regresyon analizi yapılmıştır. Akma mukavemetini açıklama gücü R-sq(adj) değeri %73,68 ve standart sapması 1,57 olan "Grup1 Kaliteler Akma Mukavemeti İstatistik Modeli" elde edilmiştir.

Model Summary				
S	R-sq	R-sq(adj)	R-sq(pred)	
1,57462	73,75%	73,68%	73,53%	

Coefficients					
Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	4.12	1.88	2.20	0.028	
RM_CIKIS_KAL	0.0434	0.0142	3.05	0.002	4.28
FM_GIRIS_SIC	0.003002	0.000608	4.93	0.000	1.72
DUSLU_MASA_SOGUMA_HIZ	0.09476	0.00343	27.61	0.000	2.29
C	12.17	1.57	7.77	0.000	1.84
SI	10.62	1.33	8.00	0.000	1.19
MN	6.320	0.583	10.83	0.000	1.35
AVGTEMP13	-0.00029	0.00180	-0.16	0.873	2.39
AVGCOILERTEMP13	-0.005101	0.000718	-7.10	0.000	1.41
MFSFM2	0.01571	0.00169	9.30	0.000	2.04
MFSFM3	0.00238	0.00189	1.26	0.210	3.37
MFSFM4	0.02732	0.00263	10.37	0.000	6.22
MFSFM5	0.02625	0.00164	15.96	0.000	3.57
MFSFM6	0.01766	0.00132	13.40	0.000	7.36

Regression Equation	
NUMUNEAKMADEGERI	= 4.12 + 0.0434 RM_CIKIS_KAL + 0.003002 FM_GIRIS_SIC + 0.09476 DUSLU_MASA_SOGUMA_HIZ + 12.17 C + 10.62 SI + 6.320 MN - 0.00029 AVGTEMP13 - 0.005101 AVGCOILERTEMP13 + 0.01571 MFSFM2 + 0.00238 MFSFM3 + 0.02732 MFSFM4 + 0.02625 MFSFM5 + 0.01766 MFSFM6

Şekil 5. Grup1 kaliteler akma mukavemeti istatistik modeli

Model Summary				
S	R-sq	R-sq(adj)	R-sq(pred)	
2,04060	81,71%	81,65%	81,57%	

Coefficients					
Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	38.35	1.50	25.59	0.000	
FM_GIRIS_SIC	-0.001664	0.000892	-1.87	0.062	1.86
SARILMA_SIC	-0.03797	0.00107	-35.59	0.000	1.70
BOBIN_KALINLIK	-0.4856	0.0392	-12.38	0.000	4.37
DUSLU_MASA_SOGUMA_HIZ	0.02337	0.00440	5.31	0.000	2.18
C	17.27	2.34	7.38	0.000	2.65
SI	14.386	0.502	28.64	0.000	1.96
MN	6.097	0.197	30.93	0.000	3.39
CR	22.23	4.76	4.67	0.000	1.06
MFSFM2	0.01112	0.00283	3.93	0.000	2.13
MFSFM3	0.01188	0.00254	4.68	0.000	1.60
MFSFM4	0.02186	0.00275	7.96	0.000	2.87
MFSFM5	0.01755	0.00202	8.68	0.000	2.11
TI	84.41	5.25	16.07	0.000	1.36
NB	405.53	8.56	47.39	0.000	1.99

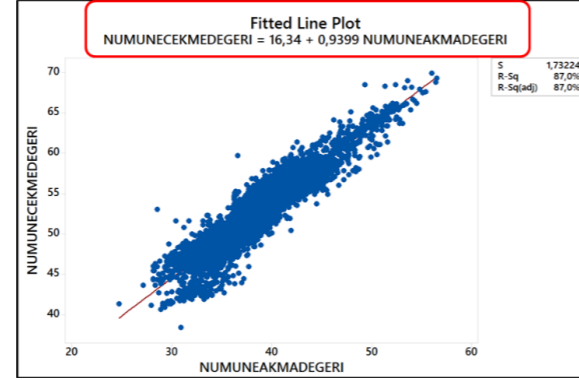
  

Regression Equation	
NUMUNEAKMADEGERI	= 38.35 - 0.001664 FM_GIRIS_SIC - 0.03797 SARILMA_SIC - 0.4856 BOBIN_KALINLIK + 0.02337 DUSLU_MASA_SOGUMA_HIZ + 17.27 C + 14.386 SI + 6.097 MN + 22.23 CR + 0.01112 MFSFM2 + 0.01188 MFSFM3 + 0.02186 MFSFM4 + 0.01755 MFSFM5 + 84.41 TI + 405.53 NB

Şekil 6. Grup2-3 kaliteler akma mukavemeti istatistik modeli

Benzer analizler Grup2-3 kaliteler için de yapılmış olup, akma mukavemetini açıklama gücü R-sq(adj) değeri %81,65 ve standart sapması 2,04 olan "Grup2-3 Kaliteler Akma Mukavemeti İstatistik Modeli" elde edilmiştir.

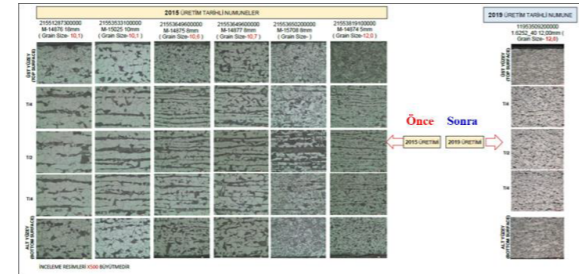
Grup2-3 kalitelerin çekme mukavemeti akma mukavemeti üzerinden basit doğrusal regresyon analizi ile modellenmiştir.



Şekil 7. Grup2-3 kaliteler çekme mukavemeti istatistik modeli

### 3. Sonuçlar ve Tartışma

Elde edilen regresyon modelleri doğrultusunda belirlenen sipariş çelik kaliteleri için kalınlık bazlı olarak kimyasal analizler ve haddeleme proses parametreleri revize edilmiştir. Grup2-3 kalitelerin birçok kalınlık değerlerinde %C ve %Mn düşürüldüğü için mikroyapı daha uygun hale gelmiş, bantlaşma durumu oluşmamış, daha homojen tane yapısı elde edilmiş ve ASTM E45 standardına göre tane büyüklüğü artırılarak darbe değeri daha yüksek ürün elde edilmiştir.



Şekil 8. Grup2-3 kaliteler proje öncesi-sonrası mikroyapı karşılaştırması (x500)

Proje kapsamında yapılan tüm değişiklikler kalite kartlarına işlenmiştir. Seviye-3'te yer alan kalite-proses raporuna proje kapsamında elde edilen regresyon modelleri kalite grubu bazında eklenerek üretilen her bir bobin için tahmini akma mukavemeti ve çekme mukavemeti değerlerinin hesaplanması, gerçekleşen değerlerle aradaki farkın raporlanması sağlanmıştır.

### 4. Sonuç

Geçmiş veri üzerinden yapılan istatistiksel analiz çalışması sonucunda elde edilen regresyon analizleri ile deneme üretim yapmadan mukavemet değerleri tahminlenebilir hale gelmiştir. Alaşım elementleri ve kimyasal analizlerde değişiklik yapılarak müşterinin ve standardın istediği mukavemet değerleri daha düşük üretim maliyeti ile elde edilmiştir. Yapılan çalışma sonrasında, çelik tasarımında deneme sayısının azalması sağlanmış, çelik tasarımı kolaylaştırılmış, daha düşük %C ve %Mn ile üretim yapıldığı için merdane ömrü olumlu yönde etkilenmiş, sıcak şarj oranının artmasına katkı sağlanmış ve müşteri memnuniyetinin artması sağlanmıştır.

### Referanslar

[1] İsdemir A.Ş. Kaynakları, Opex Proje Arşivi, (2019)



## Bor Alaşımlı Orta Karbonlu Çeliklerde Göçüklük

Coil Slumping in Boron Alloy Medium Carbon Steels

Koray Aray, Serdar Günbay

İSKENDERUN DEMİR VE ÇELİK • Türkiye

### Abstract

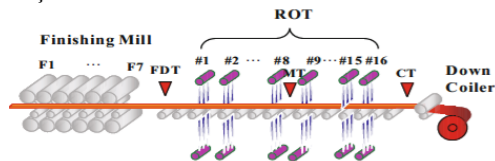
Steel strip is usually stored as a coil, which will slump to some degree after the removal of mandrel. Coil slumping/collapse is a visual quality problem in Hot Strip Mills. Slumping is determined after coiling by quality operators. Boron alloy medium carbon steels are tend to collapse because of the additions of the alloys. Changing process parameters and cooling strategy can be effect the coil collapse. In this study the effect of change of the process parameters and cooling strategy on the slumping has been investigated.

### Özet

Çelik şerit mandrelden çıktıktan sonra çeşitli derecelerde göçüklük olabilir. Göçüklük problemi Sıcak haddehanede yaşanan görsel bir kalite problemidir. Bobin sarıldıktan sonra göçüklük tespiti kalite operatörleri tarafından yapılmaktadır. Bor alaşımli orta karbonlu çelikler alaşım ilavelerinden ötürü göçük olmaya meyillidir bu göçüklük kusuru duşlu masa soğutma rejimi deęiştirilerek, proses parametreleri deęiştirilerek önlenabilir. Bu çalışmada proses parametreleri ve soğutma rejimlerinin göçüklük üzerindeki etkileri araştırılacaktır.

### 1. Giriş

Sürekli dökümlerden gelen slablar yüksek ısıda tavlanaarak ısıtılmaktadır. Slablar sırasıyla kaba hadde, şerit hadde, dışlu masa ve sarıcı sıralamasını takip ederek bobin halini almaktadır. Haddelemeye ait şematik görsel şekil 1 de verilmiştir.



Şekil 1. Haddeleme Şematik Gösterimi

Göçüklük problemi 2 farklı şekilde olabilmektedir. İlki sarıcıdan çıkar çıkmaz yaşanan göçüklük, diğeri ise bobin stok sahasında yaşanan göçüklüktür. Bobinler stoklanırken tek sıra halinde alt sıralar tamamlandıktan sonra üst sıralara

geçilerek ve sistemsel olarak adreslenerek stoklanmaktadır. (Şekil 2)



Şekil 2. Bobin stoklama

İsdemir'de iç çap ölçüm değerleri 762 mm (+/- %7) olarak hedeflenmektedir. 762 mm'in %7 toleransı dışında kalan bobinler göçük olarak nitelendirilmektedir. (Şekil 3) Göçük olan bu bobinler Bobin hazırlama hattının alabileceği iç çap ölçüsünde ise yeniden sarılma için recoil hattına yönlendirilmekte, iç çap ölçüsü uygun olmayanlar ise hurda olarak değerlendirilmektedir.



Şekil 3. Örnek göçük fotoğrafları

Göçüklük problemi hem üretim çıkışında problem yaratmakta hem de yeniden sarılma hattını meşgul etmektedir. Yeniden sarılmayan bobinler için ise hurda kararı alındığından dolayı yüksek bir kalitesizlik maliyeti yaratmaktadır. Bu nedenle göçüklük potansiyeli olan/göçüklük yaşanan Erdemir kalitesi 56xx seri çeliklerde göçüklük çalışmaları yapılmıştır.

### 2. Deneysel Çalışmalar

Göçüklük potansiyeli olan ve tespit edilen 56xx kalitelere denemeler yapılmasına karar verilmiştir. Sarılma ve ikmal sıcaklıkları deęiştirilerek denemeler yapılmıştır. Sarılma sıcaklığı 530-730 C aralığında kademeli olarak artırılarak denemeler yapılmış ve göçüklük durumları kontrol edilmiştir. Düşük sarılma sıcaklıklarında malzemenin

mukavemet değerleri yükselmesine rağmen sahada alınan ölçüm sonuçlarına göre göçüklük probleminin devam ettiği tespit edilmiştir. Kaliteye ait analiz tablo 1 de verilmiştir.

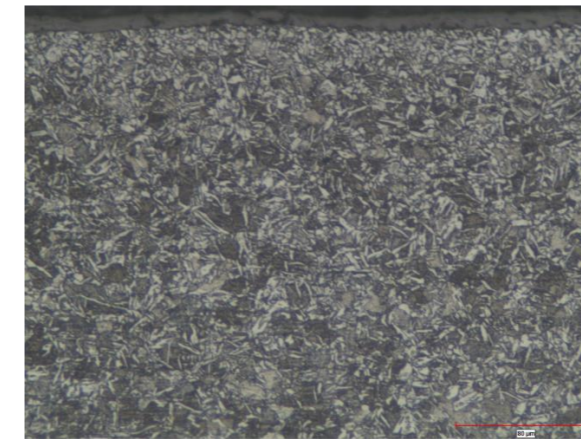
KALİTE	C		Mn		B	
	Min	Max	Min	Max	Min	Max
6.5630_50	0,25	0,32	1,00	1,50	0,0020	0,0050

Tablo 1. Kimyasal analiz

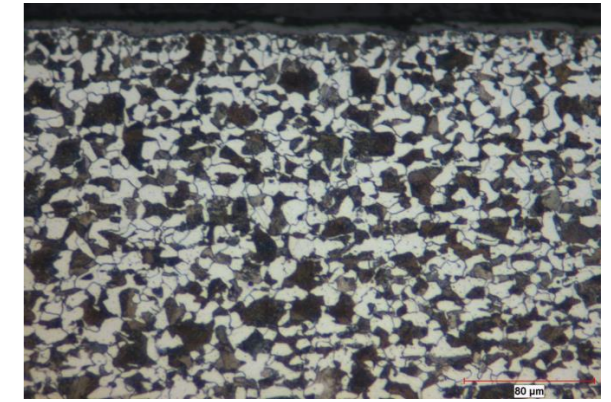
Denemesi yapılan bobinler stok sahasında tek sıra halinde dizilmiştir. Bobinlerin soğuması sonrası iç çap ölçümleri alınmıştır. alınan ölçümler toleransa göre değerlendirilmiştir. Ölçüm sonuçları kontrol edildiğinde düşük sarılma sıcaklığına sahip bobinlerin göçtüğü yüksek sarılma sıcaklığı ile üretilen malzemelerin göçmediği tespit edilmiştir.

### 3. Sonuçlar ve Tartışma

530 C ile sarılan ve göçüklük tespit edilen bobin ile 730 C ile sarılan ve göçüklük tespit edilmeyen bobinlerden numuneler alınarak mikroyapı analizi yapılmıştır. Göçüklük tespit edilmeyen numune kontrol edildiğinde ferrit perlit yapısının homojen olarak dağıldığı görülmektedir. (Şekil 4) göçüklük tespit edilen malzemenin mikroyapısı incelendiğinde ise düşük sarılma sıcaklığının da etkisi olarak accicular ferrit yapılarının görüldüğü ve tanelerin homojen olmadığı tespit edilmiştir. (Şekil 5)



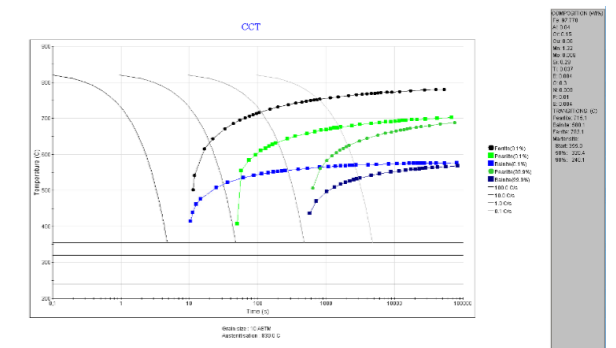
Şekil 4. Göçüklük tespit edilen bobine ait X-200 mikroyapı görüntüsü



Şekil 5. Göçüklük yaşanmayan bobine ait X-200 mikroyapı görüntüsü

Düşük sarılma ile üretilen malzemenin göçmesinin sebebi malzemenin sarıcı sonrası latent heat yaşaması olarak düşünülmektedir. Malzemenin iç kısmından yüzeye yönelen ve malzeme yapısının deęişmesine neden olan bu ısı sayesinde bobinin göçtüğü düşünülmektedir. Yüksek sarılma ile üretilen malzemede ise yüzey ve iç kısım arasında ısı farklılıklarının daha az olduğu bu sebepten dolayı latent heat durumuna maruz kalmadığı düşünülmektedir.

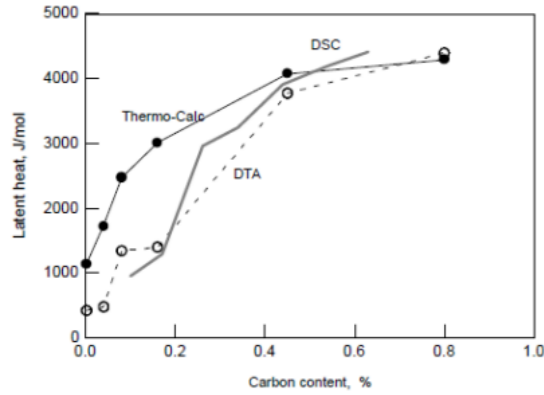
Mevcut analiz, sarılma-ikmal sıcaklıkları JMAT Pro programında kontrol edilerek CCT ve TTT diyagramları çıkartılmıştır. CCT diyagramına göre beynit dönüşüm sıcaklığının 580 C olduğu, perlit dönüşüm sıcaklığının ise 715 C olduğu tespit edilmiştir (Şekil 6).



Şekil 6. CCT diyagramı

Göçüklüğü gidermek adına sarılma sıcaklığını beynit dönüşüm sıcaklığı olan 580 C nin altında yada perlit dönüşüm sıcaklığı olan 715 C nin üzerinde seçilmelidir. 580 C nin altında seçilen sarılma sıcaklığı ile göçüklük tam olarak engellenememektedir ve aynı zamanda mukavemet çok yüksek seviyelere gelmektedir. Sarılma sıcaklığı perlit dönüşüm sıcaklığının üzerinde seçildiğinde ise dönüşümün tamamı sarıcıdan çıktıktan sonra olmaktadır. Dönüşümün soğuma hızı çok yavaş olmaktadır ve göçüklük sorunu

yaşanmamaktadır. Şekil 7 de karbon oranı ile latent heat arasında doğrusal ilişki bulunmaktadır.



Şekil 7. Karbon ile latent heat ilişkisi

#### 4. Sonuç

56xx kalitede yaşanan göçüklük problemi sarılma sıcaklığı yükseltilecek bobin iç ve yüzey arasındaki ısı farklılıklarını minimize edilmesiyle engellenmiştir. Bu kalite sorununun çözülmesiyle yeniden sarma hattına bobin yönlendirme işlemlerinin önüne geçilmiştir. Aynı zamanda aşırı derece bozukluk olan malzemelerin hurda olması engellenmiştir.

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## Bobinlerde Baş Bölgelerde Sarılma Sıcaklığı Tutmayan Metrajın Kısaltılması

Improvement of Coiling Temperature Deviation at The Coil Head

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İSKENDERUN DEMİR VE ÇELİK • Türkiye

#### Abstract

İskenderun Iron and Steel Co. (ISDEMİR) Hot Rolling Mill produces hot rolled flat coils in various thickness, width and grades. For conventional production coiling temperature along with the chemical composition has a great importance on strength of the material. In production, Level-2 system calculates the cooling speed and Level-1 automation system implement the calculated values for each material. However for the first 50 meters of the material the deviation of target cooling temperature is seen to be high and this situation could not be managed just with Level-1 and Level-2 systems. In this study the mathematical model was developed to achieve the target coiling temperature trend all along the material.

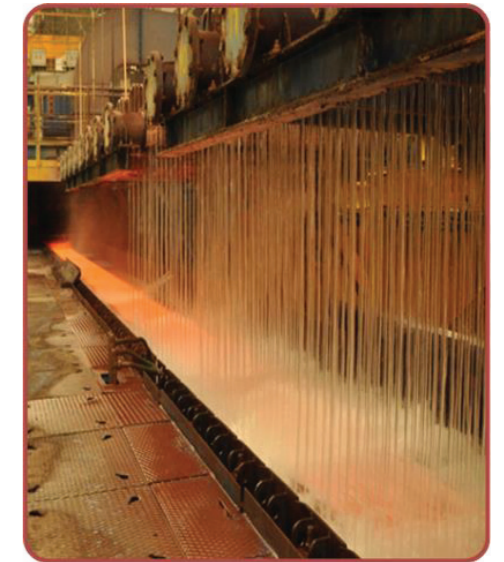
#### Özet

İskenderun Demir ve Çelik A. Ş. (İsdemir) Sıcak Haddehane tesisinde farklı kalınlık, genişlik ve kalitelerde yassı bobin üretimi gerçekleştirilmektedir. Konvansiyonel haddeleme yöntemi ile üretimde kimyasal kompozisyonun yanı sıra sarılma sıcaklığı parametresinin de malzemenin mukavemeti üzerinde büyük etkisi bulunmaktadır. Bobinlerin üretiminde Seviye-2 sisteminin soğutma hızını hesaplaması üzerine Seviye-1 sistemi hesaplanan değerleri her malzeme için sahada uygulamaktadır. Fakat malzemelerin ilk 50 metrelik bölümünde hedef sarılma sıcaklığından sapma değerinin salınımı yüksek gerçekleşmektedir ve salınım değeri Seviye-1 ve Seviye-2 sistemleriyle yönetilememektedir. Bu çalışmada malzemelerin baş bölgesinde de sarılma sıcaklığı hedefinin tutturulabilmesi üzerine matematiksel model geliştirilmiştir.

#### 1. Giriş

Sıcak haddelenmiş rulolarda mukavemet değerlerinin sarılma sıcaklığına ve duşlu masa bölgesindeki soğutma hızına göre değişkenlik gösterdiği bilinmektedir. Sıcak haddeleme prosesinde sırasıyla slab fırınlarında tavlanan slablar, kaba hadde ve şerit hadde bölgelerinde haddeleme işlemleri gerçekleştirilmektedir. Sonrasında bobin sarıcıya gelmeden önce mekanik özelliklerin belirlenmesi amacıyla

duşlu masada soğutma rejimi uygulanmaktadır. Duşlu masa bölgesinde uygulanan soğutma rejimi çelik kalitesi, kalınlık, genişlik, malzeme hızı gibi değişkenlere bağlı olarak uygulanmaktadır. Duşlu masa bölgesinde alt ve üst bölgede soğutmayı gerçekleştiren doğrusal header sistemleri bulunmaktadır. Şekil 1'de duşlu masa bölgesinde malzemeye uygulanan soğutma çalışması görülmektedir.

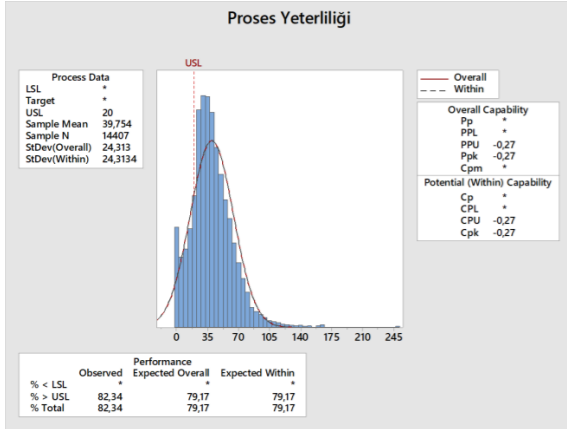


Şekil 1. Duşlu masa bölgesinde soğuyan malzeme örneği

Her malzemede değişkenlik gösteren sayılarda header açılarak soğutma işlemi gerçekleştirilmektedir. Uygulanan soğutma rejimi sonrası sarıcılar önünde pirometre vasıtası ile sıcaklık ölçümü yapılarak görseldeki şekilde malzeme boyunca trend takip edilmektedir. Üretilen bobinlerde sarılma sıcaklığı grafiklerinin malzemenin baş kısmında ilk 50 metrelik bölgede sarılma sıcaklığının hedef değerinde gerçekleşme durumu görülmekteydi. Sarılma sıcaklığının yükselmesi sonucu bu bölgelerde istenilen mukavemet değerinin tutturulamaması durumu oluşmaktaydı. Normal üretim koşullarında şerit hadde ile bobin sarma arasında bulunan duşlu masa soğutma bölgesi Seviye-2 otomasyon sisteminin hesaplamaları ile



yönetilmektedir. Seviye-2 sistemi malzemenin kalınlık, genişlik, kimyasal kompozisyon gibi verilerini kullanarak duşlu masa bölgesinde kullanılacak soğutma rejimini yönetmektedir. Fakat malzemelerin baş bölgelerinde yaşanan hedef değerler üzerinde gerçekleşme durumları Seviye-2 sistemine rağmen oluşmaktaydı. Bu problemin çözülebilmesi üzerine girdi ve çıktılar belirlenerek malzemenin baş bölgesinde harici olarak kaç soğutma hederi açılması gerektiğini öngörebilecek bir matematiksel model oluşturulma çalışması yürütülmüştür.



Şekil 2. 20 metre üzerinde tolerans değerleri dışında kalan bobinlerin tespiti amacıyla gerçekleştirilen proses yeterliliği analizi (Çalışma Öncesi)

Problemin mevcut durumunun görülebilmesi adına toplamda 14.407 bobin üzerinden proses yeterliliği analizi gerçekleştirilmiştir. Analiz sonucunda Şekil 2'de görüldüğü üzere tolerans değerleri dışında üretilen metrajın 20 metreyi aşması durumu oranı %79,17 olarak gerçekleşmiştir.

## 2. Deneysel Çalışmalar

Duşlu masa bölgesinde uygulanan soğutma hesaplamaları Seviye-2 sistemi tarafından yönetilmektedir. Seviye-2 sistemi tarafından gerçekleştirilen hesaplamaların üzerine Seviye-1 otomasyon sistemi tarafından yalnızca malzemenin baş bölgesinde açacak ve sonrasında tracking ile birlikte kapatılacak şekilde header açma işlemi uygulanması kararlaştırılmıştır. Malzemenin baş bölgesinde açılacak header sayısını tahminleyen en iyi modeli bulmak amacıyla çoklu doğrusal regresyon analizi kullanılmıştır. Analizde girdiler olarak malzemenin hedef kalınlık değeri, hedef genişlik değeri, şerit hadde çıkış sıcaklığı hedef değeri ve sarılma sıcaklığı hedef değeri kullanılmıştır. Çıktı olarak açılması gereken header adedinin tespiti hedeflenmiştir.

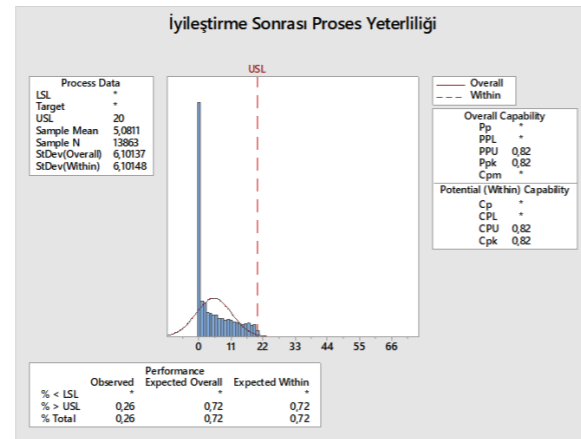
$$H_d = 115,7 + (0,6311 * h) - (0,007987 * w) - (0,0472 * t_{ex}) - (0,07217 * t_c) \quad (1)$$

$H_d$ : Açılması gereken header adedi  
 $h$ : Malzeme hedef kalınlık değeri (mm)  
 $w$ : Malzeme hedef genişlik değeri (mm)  
 $t_{ex}$ : Şerit Hadde çıkış sıcaklığı (°C)  
 $t_c$ : Sarılma Sıcaklığı (°C)

Oluşturulan matematiksel model 2,5mm-10mm aralığında sipariş kalınlığına sahip malzemelerde başarılı sonuç vermiştir. Matematiksel modelin belirlenen kalınlık aralığında otomatik olarak tüm malzemelere müdahale edebilmesi amacıyla Seviye-1 hat otomasyon sistemi içerisinde entegrasyonu sağlanmıştır.

## 3. Sonuçlar ve Tartışma

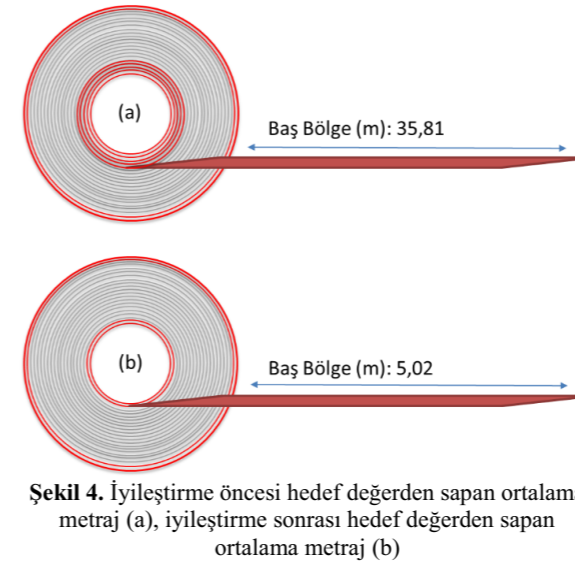
Çalışmanın devreye alınması sonrasında 13.863 bobin üzerinde aktif olarak kullanılarak tekrar proses yeterliliği analizi gerçekleştirilmiştir.



Şekil 3. 20 metre üzerinde tolerans değerleri dışında kalan bobinlerin tespiti amacıyla gerçekleştirilen proses yeterliliği analizi (Çalışma Sonrası)

Uygulanan proses yeterliliği analizi sonrasında sonuçlar Şekil 3 proses yeterliliği analizinde görülmektedir. Tolerans değerleri dışında üretilen metrajın 20 metreyi aşması durumu oranı %0,72 olarak gerçekleşmiştir.

İyileştirme öncesi hedef değerden sapan ortalama metraj değeri 35,81 metre olarak gerçekleşirken çalışmanın uygulanmasının ardından malzemenin baş bölgesinde hedef değerden sapan ortalama metraj değeri 5,02 metre olarak gerçekleştiği Şekil 4'de gösterilmektedir.



Şekil 4. İyileştirme öncesi hedef değerden sapan ortalama metraj (a), iyileştirme sonrası hedef değerden sapan ortalama metraj (b)

## 4. Sonuç

Yapılan çalışma sonucunda Seviye-1 sistemi üzerinde entegrasyonu sağlanan ve uygulama olarak operatör ekranlarına eklenmesiyle birlikte her bir malzemede malzeme kalınlığı, genişliği, ikmal ve sarılma sıcaklığı hedef değerlerine göre malzemenin baş bölgesinde açılması gereken fazladan header sayısı hesaplanmakta ve uygulanmaktadır. Bu şekilde malzemenin baş bölgesinde oluşan ve hedef değerden sapma gösteren metrajda iyileştirme sağlanmıştır.

Elde edilen sayısal iyileşmenin yanında ikincil kazanımlar da olmuştur. Numune alınan bobinlerde mukavemet değerinin tutturulamaması üzerine tekrar numune kesme işlemi gerçekleştirilmektedir. Sarılma sıcaklığının tolerans değerleri içerisine çekilmesi ile birlikte numune alınan bölgenin bobini temsil etmesi sağlanmış ve söz konusu olasılık ortadan kaldırılmıştır.

Yapılan iyileştirme sayesinde özellikle API kalite malzemelerde elde edilen iyileştirmenin getirisi daha fazla önem kazanmaktadır. Söz konusu kalitelere hedef mukavemet değerleri daha sınırlı aralıklarla talep edilmekte olup, iyileştirme sayesinde malzemelerin üretilebilirliği sağlanmaktadır.

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## İsdemir Sıcak Haddehanede Seyyar Tezgâhlarla Yerinde İşleme Faaliyetleri

On-Site Machining Activities in Isdemir Hot Strip Mill

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İSKENDERUN DEMİR VE ÇELİK • Türkiye

### Abstract

Teamwork is being carried out effectively on, "On site enterprises", which is often heard of in recent years. "Revision of Cradle roll 1A-1B pivot chassis bearings" carried out by the Mechanical Workshop staff of the Iskenderun Iron and Steel Co. (ISDEMİR) Mechanical and Auxiliary Workshops Directorate and is considered as an important maintenance work. In this field mission; the purpose of the on-site application, the equipment used, the method of application, the difficulties encountered in the process and the solution methods will be explained using the question-answer technique.

### Özet

Son yıllarda adı sıkça telaffuz edilip duyulan « Yerinde işlemlerde» takım çalışması etkin bir şekilde uygulanmaktadır. İskenderun Demir Çelik A.Ş. (İsdemir) Mekanik ve Yardımcı Atölyeler Müdürlüğü Mekanik Atelye personelleri tarafından gerçekleştirilen "Cradle roll 1A-1B pivot şase yatakları revizyonu" önemli bir bakım çalışması olarak değerlendirilmektedir.

Yapılan bu çalışmada; yerinde işleme uygulamasının amacı, kullanılan ekipmanlar, uygulama biçimi, süreçte karşılaşılan zorluklar ve çözüm yöntemleri soru-cevap tekniği kullanılarak açıklanacaktır.

### 1. Giriş

Tarih boyunca talaşlı imalat metal malzemelerin üretimiyle yakın ilişkili olan bir faaliyet olmuştur. İlk çağlardan beri insanoğlu parçaların geometrik şeklini değiştirerek bunları amaçlarına uygun hale getirmiş, süs eşyaları ve avlanma araçları yapmışlardır. Sanayi inkihabıyla birlikte makineleşme hız kazanmış, makine parçalarının üretimi ve tamiri için büyük atölyeler kurulmuştur. Bu atölyelerde yapılan geleneksel tamir ve imalatlar her ne kadar olağan ve doğru yol olsa da zamanla yeterli gelmemeye başlamıştır. Savaşlar, büyük sanayi kuruluşlarının kurulması, teknolojik ilerlemeler; makine parçalarının imalatı ve özellikle tamirlerinin yerinde yapılması ihtiyacını doğurmuştur. Bu ihtiyacın giderilmesine yönelik "seyyar işleme tezgâhları"

geliştirilmiştir. Seyyar işleme tezgâhlarının yapılması ve gelişmesine paralel olarak seyyar ekipmanlarla yerinde işleme metodolojisi gelişerek devam etmektedir.

### 2. Uygulama

*Seyyar tezgâhlarla yerinde işleme nedir?*

Klasik anlamdaki iş makine parçalarının atölyeye gelip sabit tezgâhlarda işlenmesi ve tamir edilmesidir. Yerinde işleme işi ise makine parçalarının bulunduğu yerde seyyar taşınabilir işleme tezgâhlarıyla gerçekleştirilen işleme, tamir yöntemidir. Kısacası atölye tezgâhlarının seyyar olarak sahaya taşınarak sahada işleme & tamir yapılmasıdır.



Resim 1. II. Dünya savaşında uçak ve tank tamirinde seyyar işleme

*Yerinde işleme yöntemi neden kullanılır ve ne zaman tercih edilir?*

Üretim sahasında yerinde de montajı yapılarak atölyelere tamir için gönderilmesi mümkün olmayan bazı ekipmanlar vardır; bu ekipmanların bazıları hacim olarak çok büyük olması nedeni manipülasyonu/transferi mümkün olmamaktadır, bazıları yerinden söküldüğünde tekrar hassas olarak yerine montaj edilememektedir, bazıları ise taşıma maliyeti çok yüksek olduğundan nakliye tercih edilmemesi gibi sebeplerden dolayı yerinde işleme tercih edilir. Ayrıca denizin, çölün ortasındaki petrol kuyularında; dağın başındaki rüzgâr türbininde, yerleşim yerine çok uzak şantiyelerde özellikle yerinde işlemler tercih edilir.



Resim 2. Çeşitli sektörlerde yerinde işleme faaliyetleri

*Yerinde işlemlerde ne tür ekipmanlar kullanılır?*

Günümüzde atölye içerisinde sabit durumda bulunan birçok tezgâhın değişik ebatlarda işleme yapabilen ve seyyar şekilde kullanılabilen seyyar bohrwerk tezgâhları, seyyar tornalar, seyyar flanş yüzeyi işleme makineleri, seyyar frezeler, seyyar testereler gibi modelleri vardır. Fakat bu tezgâhlar tek başına seyyar işleme için yeterli olmamakta ek olarak istenilen işi yapabilmek için bu tezgâhlarla uyumlu birçok aparat yapmak gerektiği gibi var olan tezgâhları yapılan modifikasyonlarla yapılacak işe uygun hale getirmekte gerekebilmektedir.



Resim 3. Seyyar işleme ekipmanları

*Yerinde işleme prosesi nasıldır? Her iş yerinde işlenebilir mi / buna uygun mudur?*

Her işin yerinde işlenmesi uygun değildir. Yerinde işleme sadece seyyar ekipmanların yeterli geldiği standart bir talaşlı işleme yöntemi değildir. İşleme süresi çok uzun olmayabilir fakat ön hazırlık zaman alan ve detaylı analiz gerektiren çok önemli bir süreçtir.(Şekil 1.) Bakım birimlerinin, boyutsal ölçüm ekiplerinin ve atölye ekiplerinin tamamının ortak çaba harcadıkları takım çalışmasında başta tecrübe olmak üzere inanç ve çaba sarfı gerektirmektedir. Süreçte ünitesi tarafından yerinde işlenmesi / tamir edilmesi gereken ekipmanlar bildirildikten sonra öncelikle projeler detaylı olarak incelenerek işin bulunduğu yerde etüt çalışmaları tamamlanır. Sonraki aşamada iş parçası için en uygun işleme & tamir yöntemi belirlenerek seyyar ekipman seçimi yapılır. Tezgah ve aparatları üzerinde gerekli görülen modifikasyonlar yapılır uygun seyyar ekipman yoksa sıfırdan imal edilir. Çalışılacak ortam ve şartlara uygun simülasyonlar hazırlanarak, deneme çalışmaları reele yakın şartlarda atölyelerde yapılır. Duruşlarda plan dâhilinde işin gerçekleşmesinde sürprizlere açık alan bırakılmaması hedefli olarak yapılan bu simülasyon çalışmalarında tespit edilen eksiklikler giderilir.



Şekil 1. Yerinde işleme aşamaları

*İSDEMİR'de yapılan yerinde işlemler hakkında bilgi verir misiniz?*

İSDEMİR kurulduğundan günden bugüne yerinde işleme çalışmaları yapılmıştır. Bunlar çok hassas ve spesifik olmayan işlerdir. Sıcak haddehanenin devreye girmesiyle birlikte hassasiyet seviyesi yüksek olarak işlem gerektiren makine parçalarının yerinde işlemeye yönelik 2011 yılında ilk seyyar freze tezgâhi alınarak kapsamlı yerinde işleme işlerine başlanılmıştır. Yeni tesislerin kurulumu ve eskiyen tesislerin modernizasyonunda "yerinde işleme" ihtiyacı artarak devam etmektedir. 2011 yılı sonrasında yapılan birkaç örnek yerinde işlemeden bahsedebiliriz.



Şekil 2. Yerinde işleme faaliyeti

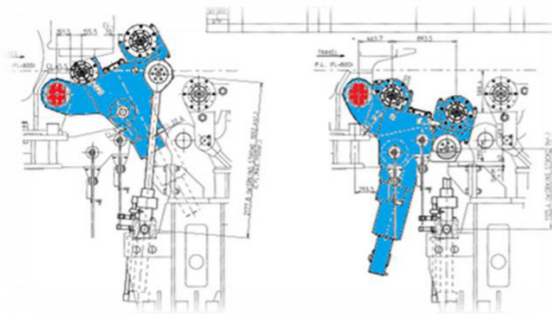
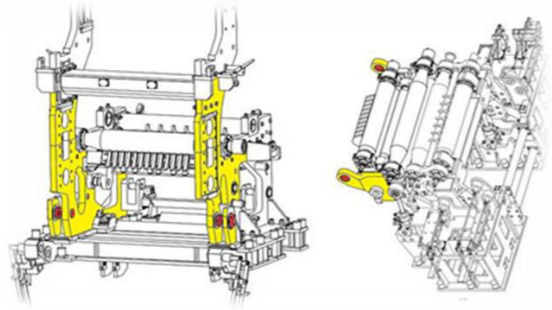
Sıcak Haddehane Cradle Roll şasilerinin yerinde işlenmesi:

Cradle roll 2A-2B pivot şasi ve Cradle roll 1A-1B pivot şasi (Resim 1. ) yuvalarında 30mm'yi bulan aşınmalar nedeniyle sistem çok aşırı vuruntulu çalışmakta ve şaftlara aşırı yük gelmekte olduğu gözlemlenmişti. Mevcut pernelara gelen dengesiz yük, uzun vadede perneların kırılmasına ve sıcak haddehane hattında beklenmedik uzun süreli duruşlara sebep olabilecekti. Sıcak haddehane bakım ekipleriyle birlikte durum görüşülerek aksiyon planı oluşturuldu. Mekanik atelyeler bünyesinde 3 aylık süre içinde ihtiyaca uygun ekipmanlar hazırlandı, atölyede deneme çalışmaları simüle edildi, tespit edilen eksiklikler giderildi ve planlanan duruş günü çalışmalar başlatılarak yerinde işleme faaliyeti gerçekleştirildi. (Resim 3.) Bu çalışmada delik çapı büyütülen Cradle roll pivot şasi yuvalarına ısıl işlem görmüş özel burçlar montajları yapılarak deliklerin proje ölçülerine getirilmesi sağlandı. Erdemir Mühendislik ölçüm ekipleri tarafından sürekli hassas ölçümler alınmış ve alınan ölçümler anlık değerlendirilerek süreç yönetilmiştir. (Resim 2.)

Bu çalışmayla birlikte;



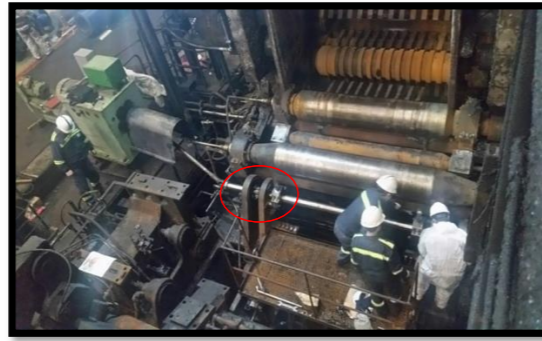
- I. Şasi çok ciddi bir hasarlanma sonucu üretimi etkilenmeyecek duruma geldi,  
 II. Şasi üzerinde dönen roll yataklarındaki gevşemelerin önüne geçildi,  
 III. Yakın zamanda istavrozlarındaki boşluklar nedeniyle hasarlanan 2 adet kardan şaft muadili durumda etkilenmeyecek duruma geldi,  
 IV. Sarım kalitesi arttı.



Resim 4. Cradle roll pivot şasi



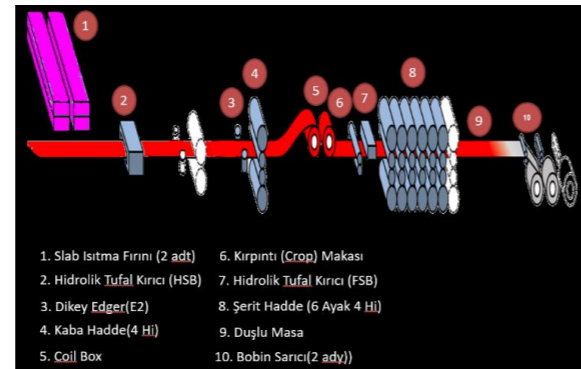
Resim 5. Cradle roll pivot şasi işleme öncesi referans alma



Resim 6. Cradle roll pivot şasi işleme

### Sıcak hadde Crop Makas milinde yerinde işleme ve kaplin tadilatı:

Crop (kırpıntı) makası sıcak haddehane coil box ile hidrolik tufal kırıcı (FSB) arasında yer almaktadır. (Şekil 2.) Crop makas malzemenin baş ve kuyruk kısmında oluşan ve haddeleme & kalite açısından uygun olmayan parçaları kesmek için kullanılır. (Resim 4.)



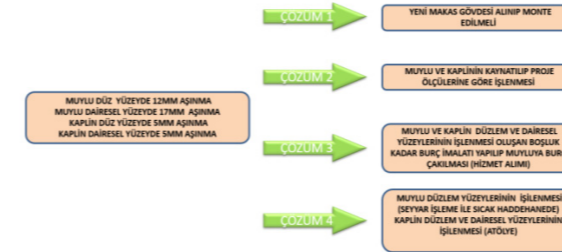
Şekil 3. Sıcak haddehane şeması



Resim 7. Crop makas

Çalışma esnasında yüksek darbelerle maruz kalan crop makas muylu ve kaplini, zamanla aşınarak sistemde

vuruntulu çalışmaya başlamaktadır. Bu durum bıçağın kesme kalınlığı değerlerini aşağıya çekmekte, düzgün kesim yapmamasına sebep olmaktadır. Kesim hataları nedeniyle sistemde duruşların artması ile Crop makas kaynaklı duruşları azaltacak en uygun ve kısa zamanlı çözüm araştırmaları başlatılmıştır.



Tablo 1. Çözüm önerileri

**Çözüm1:** Yeni makas gövdesi alınıp monte edilmelidir.

**Kısıtlar:** Makas Gövdesi hazır malzeme olmayıp temin süresi yaklaşık 1,5-2 yıldır. Yeni makas gövdesi siparişi verilmiştir fakat bu çözüm mevcut durum için acil uygulamaya konulabilecek bir çözüm değildir.

**Çözüm 2:** Muylu ve Kaplin kaynatılıp proje ölçülerine tekrar işlenmelidir.

**Kısıtlar:**

- \*Parçanın büyüklüğü, demontaj / montaj zorlukları,
- \*Kaynak işleminin süresi ve kaynak verim güvensizliği,
- \*Kaynatılan parçaların atölyede istenilen hassasiyette işlenememesi.

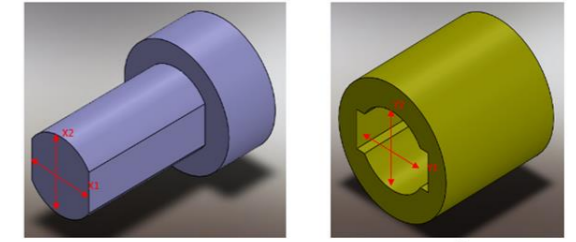
Süreç yönetimi sorunları ve belirsizliklerin fazlalığı nedeniyle Çözüm 2 uygulanmamıştır.

**Çözüm 3:** Muylu ve Kaplin düzlem ve dairesel yüzeylerinin işlenmesi, oluşan boşluk kadar burç imalatı yapılarak muyluya burç çakılmalıdır.

**Kısıtlar:** Muyluyu işleyecek seyyar tezgâhın olmaması ve muylu mukavemet değerlerinin çok düşmesi nedeniyle Çözüm 3 uygulanmamıştır.

**Çözüm4:** Muylu düzlem yüzeylerinin seyyar tezgâhlarla işlenmesi. Kaplin düzlem ve dairesel yüzeylerinin atölyede işlenmelidir.

Yapılan mukavemet hesaplamaları ve işleme sürelerinin kısıtlılığı nedeniyle tercih edilmiş ve Çözüm 4 uygulanmıştır.

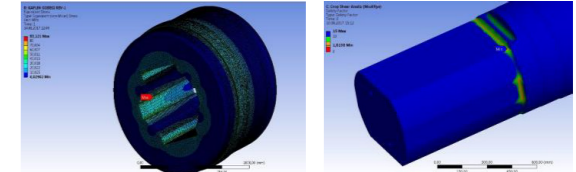


MUYLU KAPLIN

MUYLU			
	Proje Ölçüsü (mm)	Mevcut Ölçü (mm)	Fark(mm)
X1	520	495	25
X2	Ø650	Ø633	17
KAPLIN			
	Proje Ölçüsü (mm)	Mevcut Ölçü (mm)	Fark(mm)
Y1	507,5	512,5	5
Y2	Ø651	Ø656	5

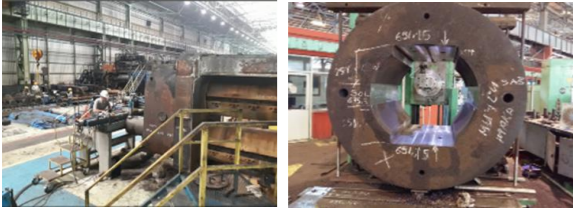
ÇALIŞMA BOŞLUKLARI	
Z1	Düzlem yüzeyler arası boşluk: 512,5-495= <b>17,5</b>
Z2	Dairesel yüzeydeki boşluk: 656-633= <b>23</b>

Tablo 2. İşleme öncesi Crop makas muylu-kaplin ölçüleri



Resim 8. Muylu Kaplin ANSYS mukavemet hesabı

Makas kaplini göbeğine açılacak ek kama yuvasının kaplin mukavemetine olan etkisi incelenmiştir. (Resim 5.) Orjinal kaplinde oluşan maksimum gerilme 132 Mpa iken ek kama yuvalarının açılması durumunda maksimum gerilme 83 Mpa değerine düşmektedir. Dişli kaplin göbeğine açılan ek kama yuvaları kaplin mukavemetini daha da artırmaktadır. Makas muylusunun mevcut durumu (düz yüzey ölçüsü: 495mm) ANSYS Programı ile yapılan yük analizlerinde yorulma emniyet faktörü 2,04 olarak hesaplanmıştır. Düz yüzeydeki ölçünün 486mm'ye düşmesi halinde ve radiuslu yüzeylere 150mm genişliğinde lineer basma yüzeyinin işlenmesi ile revize edilen yeni ölçülere göre program tekrar çalıştırılarak yorulma emniyet faktörü 1,81 olarak hesaplanmıştır. (Tablo 1.) Yapılacak olan işlemin güvenilir olduğuna karar verilmiş olup uygulama yapılacaktır.



Resim 9. İş parçalarının Yerinde ve atölyede işlenmesi

Makas muylu ve kaplin işleme aşamasında eşzamanlı olarak Erdemir Mühendislik ölçüm ekipleri tarafından sürekli hassas ölçümler alınmış ve alınan ölçüler anlık değerlendirilerek süreç yönetilmiştir. 0.02mm hassaslıkta işlenen işler proje ölçüsündeki 0.5mm geçme boşluğuna göre yapılarak teslim edilmiştir. ( 23mm boşluklu çalışan aşınmış muylu kaplin arası 4 noktada 0,5mm boşlukla birbirine basar nihai haline getirilmiştir. (Resim 6.)

### 3. Sonuçlar ve Tartışma

Madencilik sektörü tesisleri, Demir Çelik tesisleri, Rüzgâr enerji türbinleri, Petro Kimya tesisleri, Nükleer enerji tesisleri, Petrol/gaz arama platformları, Denizcilik sektörü, Havacılık sanayi, Elektrik üretim tesisleri gibi birçok alanda daha büyük kapasiteli ve kompleks yapılar çoğalmaktadırlar. Bu yapıların kurulması sonrasında gereken bakımlarının yapılmasında “seyyar ekipmanlarla yerinde işleme” zaruri hale gelmekte iken buna karşın tesislerin uzun ömürlü olmasını sağlayan, verimliliğini artıran, kesintisiz çalışma isteğini yerine getiren, nakliye / lojistik / işçilik ve zamandan büyük tasarruflar elde etmeyi sağlayan “yerinde işleme faaliyetleri” gelişerek devam etmektedir. Dünyada hızla gelişerek önemli bir sektör haline gelen seyyar tezgâhlarla yerinde işleme faaliyetleri ve seyyar tezgâhların üretilmesine Türkiye’de daha fazla önem verilmeli ve desteklenmelidir.

### Referanslar

- [1] [www.climaxportable.com](http://www.climaxportable.com)  
 [2] [www.miragemachines.com](http://www.miragemachines.com)

## Backup Roll Chamfer Design for İsdemir HSM

İsdemir Haddehanesi İçin Destek Merdanelerinde PAH Dizaynı, Profili ve Sürdürülebilirliği

M. Umut Kaya, Tolga Okuyucu, İskender Gök

İSKENDERUN DEMİR VE ÇELİK • Türkiye

### Abstract

Changes in roll geometries and rolling programs to meet demands of strip quality may lead to tougher rolling conditions and more severe loading of rolls. The design and maintenance of backup roll chamfers and profile has a significant influence upon the stress distribution and concentration within the rolls during rolling, along with the wear conditions of both backup and work rolls. Optimization is available for backup roll chamfers and profile for specific rolling conditions.

### 1. Introduction

Stress condition at the contact between work and backup rolls is one of the critical causes for in service damage of both rolls. Such stresses can be to some extent controlled by appropriate design of the backup roll chamfers and profile.

Chamfer and profile practices of backup rolls vary a lot from mill to mill. The evolution of rolling practice and technology to meet higher productivity and strip quality may result in tougher rolling conditions. For example, the length of the campaigns have been increased in hot mill roughing stands, the number of passes increased in reversing roughers. So that rolls are used with large amount of wear and high rolling forces. In hot mill finishing stands and cold mills, the use of profiled barrels together with shifting has modified the contact geometry between work and backup rolls [1].

This paper aims to describe what kind of damage might be induced by stresses at the contact between work and backup rolls and how a sound backup roll chamfer design and practice can help to increase mill productivity and strip quality.

### 2. Experimental Procedure

İsdemir HSM have 4-hi stands, pair cross and shifting systems. In 4-hi stands, transmission of the rolling force is through the contact between work and backup rolls. The location where the contact area is small exposes the rolls to the highest contact forces. Moreover, the distribution of the contact force along the contact line between work and backup rolls is not homogeneous. Because of bending and surface deflection in the contact zone, edge effect induces a peak of the contact force at the ends of the barrels (Figure 1).

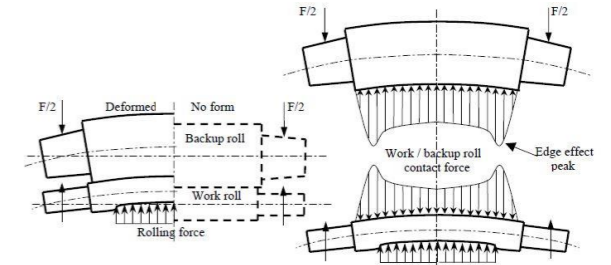


Figure 1. Sketch of the contact force distribution between work and backup rolls.

In reaching the material strength, such stresses might induce damage. The following shows the damages that occurred after such cases in the Iskenderun Iron and Steel Co. (ISDEMİR) HSM (Figure 2 and Figure 3).



Figure 2. Backup roll spalling



Figure 3. Backup roll spalling



## 2.1. Backup Roll Chamfer And Design And Practices

The way to minimize the highest contact loads between work and backup rolls is to machine adapted profile, chamfer and edge relief on the backup roll. The profile is the change in diameter along the major part of the barrel. The chamfer is a decrease in diameter of the roll machined at the ends of the barrel in order to limit edge effects of the contact between work and backup rolls. A machined edge relief at the very end of the chamfer causes the contact force to vanish at that point [2].

Figure 4 gives some typical practices for chamfer and edge relief geometries.

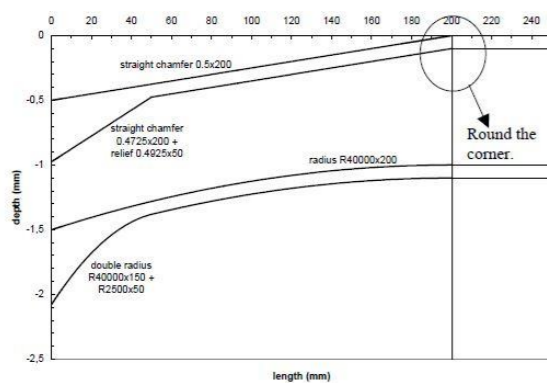


Figure 4. Different types of chamfer and edge relief.

The chamfer enables to reduce the specific force peak as compared with no chamfer. When increasing the length of the chamfer, the value of the peak decreases. However, a longer chamfer affects less the height of the peak so that it might not be useful to increase too much at least in the case of low wear of the work roll. Recommended is a chamfer length of 8 to 10% of the barrel length to take care of the edge effect.

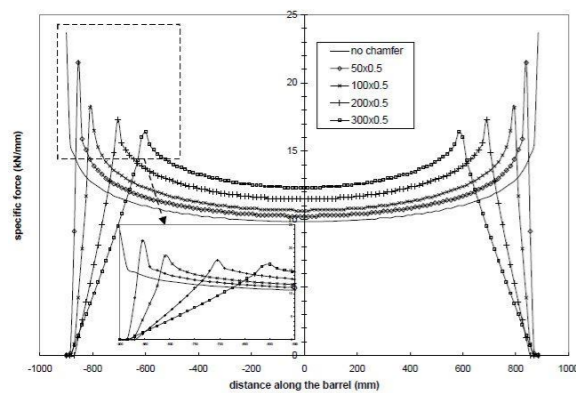


Figure 5. Specific force distribution along rolls barrel for straight chamfers of 0.5mm depth and different length. Figure 6 shows a comparison between straight and radius chamfer of same length and depth. In all cases, the radius chamfer practice gives lower peak values and thus is preferred. A rounded corner in the case of straight chamfers is required.

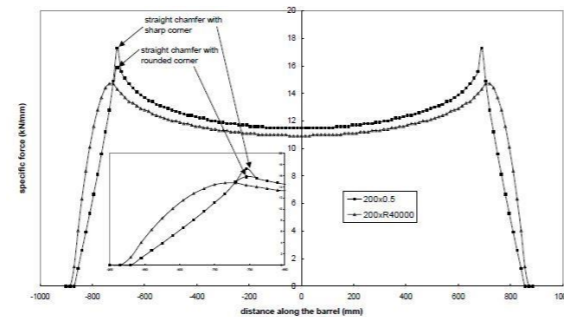


Figure 6. Comparison of the specific force distribution for a straight chamfer 200x0.5mm and a radius chamfer 200xR40000mm (0.5mm depth).

In the same idea, any step at the junction between the chamfer and the barrel profile of the backup roll that results from nonadapted machining practices will significantly increase the local contact force (Figure 7). Two cases experienced include lathing of the chamfer as in steps, and grinding of the body without ensuring that the grinding pass does not traverse beyond the start of the chamfer.

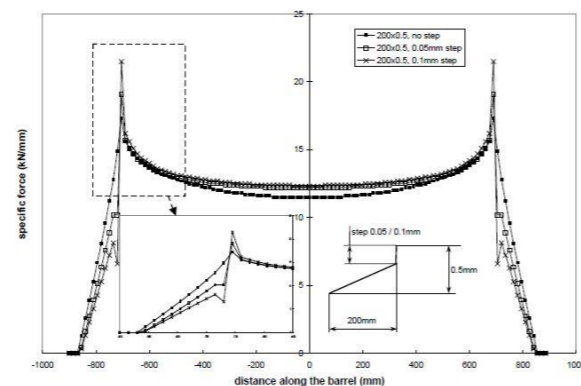


Figure 7. Effect of a step at the transition between chamfer and roll body will result in a high localized contact force..

## 3. Results and Discussion

The chamfer design, which is shown in figure 8, had been used between 2007-2018 in ISDEMIR HSM. As a result of using that chamfer design, 14 backup rolls were become scrapped.

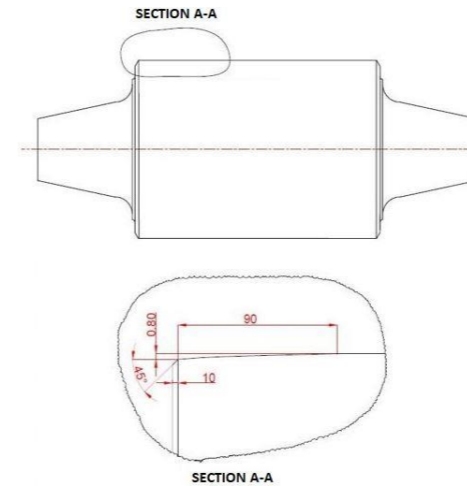


Figure 8. The chamfer design, which had been used between 2007-2018 in ISDEMIR HSM.

After some literature reviews, it was decided to use the new design, which is shown in figure 9.

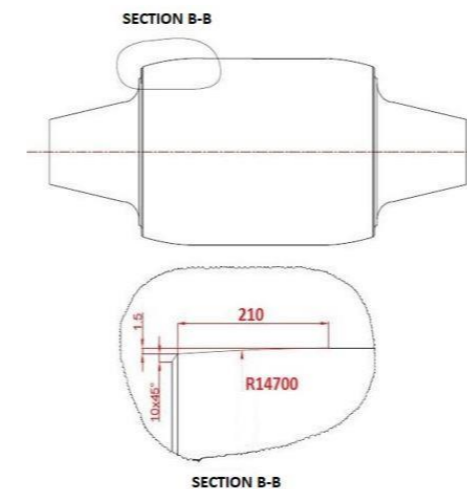


Figure 9. The new chamfer design, which is being used in ISDEMIR HSM.

No damage was encountered after the use of the new chamfer design in ISDEMIR HSM.

The following summarizes typical standard sound practices:

- Typical chamfer length may vary between 8 to 10% of the barrel length to take care of the edge effect.
- The total depth of the chamfer, including edge relief, should be chosen high enough so that the specific contact force vanishes at the ends of the

barrel but low enough so that the chamfer area takes a part of the specific force. It must be deeper when rolling force increases and deep enough to take care of the fact it might wear. Typical depth varies between 0.5 to 1mm for non-profiled rolls and applications without shifting.

- In the case of straight chamfers, round the corners and eliminate all steps.
- Radius chamfer is preferred.
- Edge relief might be useful for high loaded stands.

## 4. Conclusion

The stress conditions at the contact line between work and backup rolls are of importance regarding roll damage. Backup roll chamfer and profile practice is the way to handle the question. Reasoning for such standard sound practices exists. After establishing an adapted chamfer design, it is necessary to maintain the practice. Machining practices must consider the capabilities and equipments available.

## References

1. W.H. Tait, "The Nature and Causes of In Service Roll Defects." Rolls for the Metalworking Industries, ISS, 1990, 135-149
- [2] B. Berger, "Die elastische Verformung des Walzen von Quarto – Walzgerüsten und die Beeinflussung des Walzspalt durch Walzenbiegeeinrichtungen", (Dissertation zur Erlangung des Grades eines Doktor – Ingenieurs, Technischen Universität Clausthal, 1975)

## Roll Grinding Optimization

Merdane Taşlama Optimizasyonu

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### Abstract

Iron and steel rolls are ground to production quality requirements with a grinding wheel that requires minimal wheel wear compensation, profile error compensation or taper error compensation during the grinding process. Researchers through different processes have attempted improvement in surface finish, one of the important parameters in surface integrity. Grinding has been widely used for final machining of components requiring smooth surfaces coupled with precise tolerances. Experiments were performed on surface grinding and cylindrical grinding for optimization of grinding process parameters for improved surface finish. Grinding wheel speed, depth of cut, table feed, grinding wheel material and table travel speed for surface grinding operation, and work speed for cylindrical grinding operation were taken as the input parameters

### 1. Introduction

In steel the industry, the roll grinding machine has become important for maintenance. The rolls always have surface or shape errors after plastically deforming steel slabs to the steel plate. This error causes unexpected quality issues of the steel plate manufacturing process. There are many parameters for the manufacture of roll grinding machine, such as speed of roll, Speed of grinding wheel and speed of moving horizontally, etc. The objective of this work is to reduce the surface error of the roll. One important problem is the uncorrelated speed between the roll (S2) and the Z axis; the lower roll speed and fast Z axis movement will result in a roll curve error. To reduce this error a helical path will be used. The roll grinding machine as shown in Figure 1.

This paper considers the relationship between roll speed (S2) and the Z axis. The helical path will be used to reduce this error. The helical path is used for C axis (C axis convert from Spindle axis as shown in Figure 1.

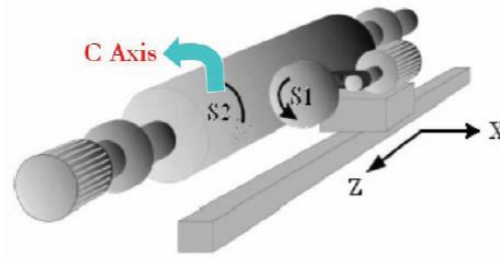


Figure 1. The problem of the uncorrelated S2 and Z-axis and Spindleaxis (S2) to the C Axis

### 2. Surface Revolution

The rotation of a planar curve overangle  $\nu$  about an axis of rotation creates a circle (if  $\nu = 360$ ) for each point on the curve whose center lies on the axis of rotation and whose radius  $rZ(u)$  is variable, as shown in Figure 2. The planar curve and the axis of rotation form the plane of zero angle, that is,  $\nu = 0$ . To derive the parametric equation of a surface of rotation, consider a point  $G(u) = P(u, 0)$  on the profile that rotates at an angle  $\nu$  about ZL when the profile is rotated through the same angle. Considering the shaded triangle which is perpendicular to the ZL axis, the parametric equation of the surface of revolution can be written as [2]

$$P(u, \nu) = rZ(u) \cos \nu \hat{n}^1 + rZ(u) \sin \nu \hat{n}^2 + ZL(u) \hat{n}^3, \quad 0 \leq u \leq 1, \quad 0 \leq \nu \leq 2\pi \quad (1)$$

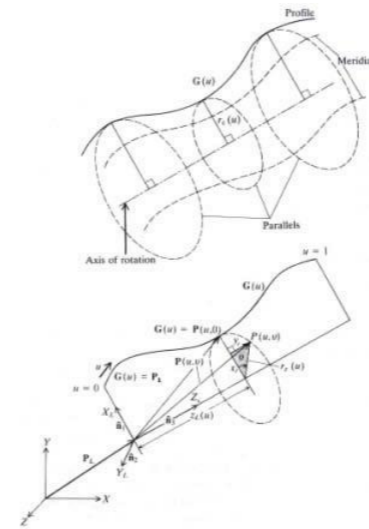


Figure 2. Parametric representation of a surface of revolution

### 3. Helix Equation

A helix, sometimes also called a coil, is a curve for which the tangent makes a constant angle with a fixed line. The shortest path between two points on a cylinder is a fractional turn of a helix, as can be seen by cutting the cylinder along one of its sides, flattening it out, and noting that a straight line connecting the points becomes helical upon re-wrapping. It is for this reason that squirrels chasing one another up and around tree trunks follow helical paths.

The parametric equation of the helix [3] shown in Figure 3 with a radius  $a$  and a pitch  $b$  is given by

$$P(u) = [a \cos 2\pi u \quad a \sin 2\pi u \quad 2b u]^T, \quad 0 \leq u \leq 1 \quad (2)$$

The nonparametric equation of the helix

$$x = a \cos 2\pi u \quad (3)$$

$$y = a \sin 2\pi u \quad (4)$$

$$z = b 2\pi u \quad (5)$$

or

$$u = \frac{z}{b 2\pi} \quad (6)$$

These can be substituted into Equations. (3) and (4) to give:

$$x = a \cos \left( \frac{z}{b} \right) \quad (7)$$

$$y = a \sin \left( \frac{z}{b} \right) \quad (8)$$

Therefore

$$P = \left[ a \cos \left( \frac{z}{b} \right) \quad a \sin \left( \frac{z}{b} \right) \quad z \right]^T \quad (9)$$

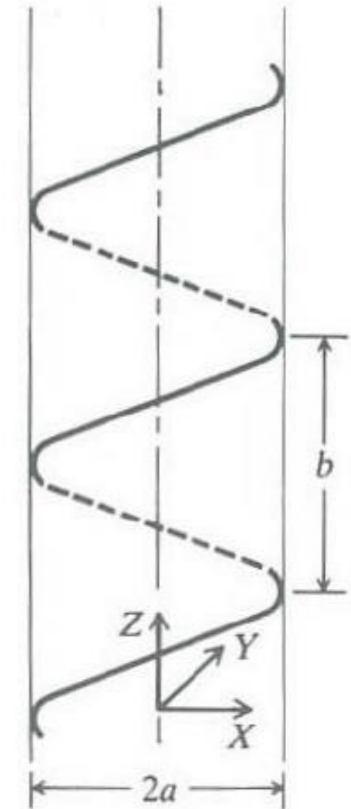


Figure 3. A helix curve



4. Grinding Equation

In the steel industry, equations are used for grinding processes such as crown, chamfer, taper equation, etc. This study has selected the crown equation for the experiments. The crown equation [4] in Eq.(3).

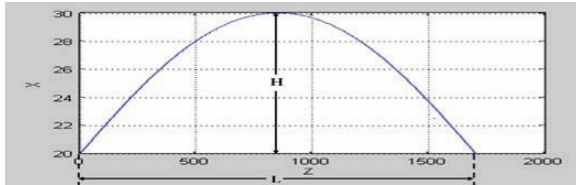


Figure 4. A crown curve

5. Grinding Helix Equation

The grinding helix equation used to generate helical path, as shown in Figure 5. From equation (9) replace

$$a = \left( 3.2 \times H \left[ \frac{z}{L} - 2 \times \left( \frac{z}{L} \right)^3 + \left( \frac{z}{L} \right)^4 \right] \right)$$

$$P(z) = \begin{bmatrix} \left( 3.2 \times H \left[ \frac{z}{L} - 2 \times \left( \frac{z}{L} \right)^3 + \left( \frac{z}{L} \right)^4 \right] \right) \cos\left(\frac{z}{b}\right) \\ \left( 3.2 \times H \left[ \frac{z}{L} - 2 \times \left( \frac{z}{L} \right)^3 + \left( \frac{z}{L} \right)^4 \right] \right) \sin\left(\frac{z}{b}\right) \\ z \end{bmatrix}, 0 \leq z \leq L \quad (11)$$

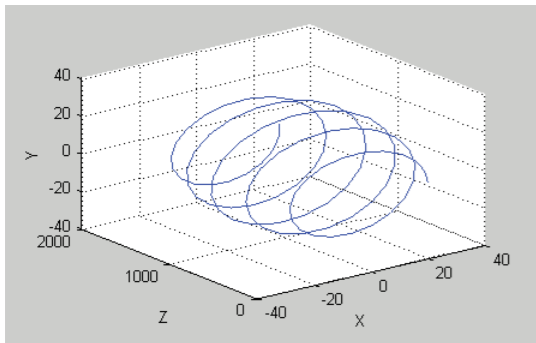


Figure 5. A grinding helical path

6. Experimental Design and Analysis

The grinding processes have many parameters, Therefore the experiment followed three steps: 1. Select the best parameter for the crown equation method. These parameters will affect the roll surface. In this step the speed of S1 is kept constant at 10 m/s. The other axes X, Y, S2 are show in Table 1.

Factors	Level	
	Low (-)	High (+)
Feed X-axis (X) - mm	0.2	0.5
Feed Z-axis (Z) - mm	100	200
Speed S2-axis (S2) - rpm	5	15

Table 1. Experimental Factors for Crown Equation Method

From Table 1, all parameters are the minimum and maximum values for the grinding machine. The computational experiment was carried out by adopting three factors and two levels in a full factorial 23 design [5] with two replications. The Minitab program was used for design and analysis. Analysis of variance (ANOVA) results for on the value of this method that give the best results are shown in Table 2. In general, the ANOVA table contains a source of variation, sum of squares (SS), degree of freedom (DF), mean squares (MS), F and p values [5]. Table 2 summarizes the estimations of the crown equation method grinding parameters considered as main factors corresponding to the function value. It can be seen that all main factors which are the Feed X-Axis (X), Feed Z-Axis (Z) and Speed S2-axis (S2) are statistically significant with a 95% confident interval for the p value less than or equal to 0.05. The best setting that produced the optimal solutions (See Fig 6) was the Feed X-Axis at 0.5, the Feed Z-Axis at 200 and Speed S2-axis 15.

Source	DF	SS	MS	F	P
X	1	18.039	18.039	42.68	0.000
Z	1	44.734	44.734	105.82	0.000
S2	1	13.094	13.094	30.98	0.001
X*Z	1	0.683	0.683	1.62	0.239
X*S2	1	4.661	4.661	11.03	0.011
Z*S2	1	7.973	7.973	18.86	0.002
X*Z*S2	1	9.615	9.615	22.75	0.001
Error	8	3.382	0.423		
Total	15	102.180			

Table 2. Variance for Crown Equation Method

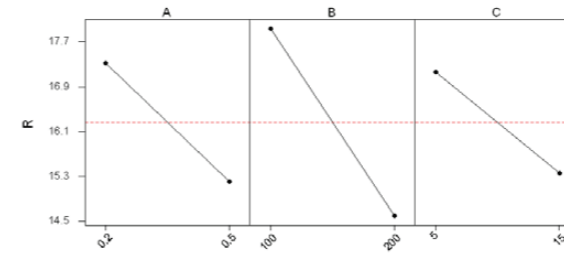


Figure 6. Main effect plot of the function value for the crown equation method (A= X, B= Z, C=S2 and R = Plot value normalization)

2. Select the best parameter for the helical path method This step considers three axes (X-axis, Z-axis and S1-axis) but this study sets the S1-axis as being constant at 10 m/s (maximum value for a grinding machine). The angles of the C-Axis (in the crown equation method S2- Axis) are calculated from the helical path method. The experimental factors and the values considered are given in Table 3 and used the same crown equation method.

Factors	Level	
	Low (-)	High (+)
Feed X-axis (X) - mm	0.2	0.5
Feed Z-axis (Z) - mm	100	200

Table 3. Experimental Factors for Helical Path Method

Table 4 summarizes the estimates of the crown equation method grinding parameters considered as main factors which correspond to the function value. It can be seen that the main factors which are the Feed X-Axis (X) and the Feed Z-Axis (Z) are statistically significant with a 95% confident interval for the p value less than or equal to 0.05. The best setting that produced the optimal solutions (See Fig 7) was the Feed X-Axis at 0.5 and te Feed Z-Axis at 200.

Source	DF	SS	MS	F	P
X	1	4.4239	4.4239	88.30	0.001
Z	1	22.0889	22.0889	440.90	0.000
X*Z	1	0.0076	0.0076	0.15	0.717
Error	4	0.2004	0.0501		
Total	7	26.7208			

Table 4. Variance for The Helical Path Method

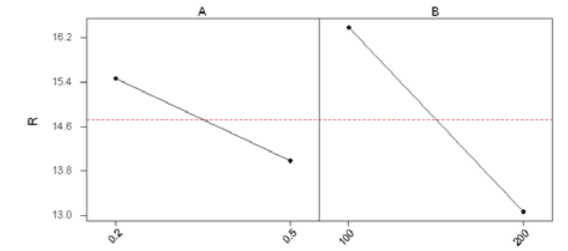


Figure 7. Main effect plot of the function value for the helical path

3. Compare results between step 1 and step 2 This step selects the best parameters from experimental step 1 and step 2 to compare both methods.

No.	Step 1	Step 2
1	17.90928	17.14192
2	19.25974	17.05967
3	19.46064	17.99874
Average	18.87655	17.40011

Table 5. Comparison Result Between Step1-Step2

Table 5 the error average for of step 1 is 18.87 % and step 2 is 17.40 %. Therefore the helical path method reduces the error by 7.82 %.

6. Conclusion

The general roll grinding machine has four main axes X-Axis, Z-Axis, S1-Axis (grinding wheel speed) and S2-Axis (roll speed). An important problem with the roll grinding machine is the uncorrelated roll speed (Spindle axis) and Z axis speed. This study converts the S2-Axis to a C-Axis and uses a helical path method to compare the crown equation method. The computational experiment was carried out by adopting a full fractional factorial design. Experimental results obtained were analyzed using a general linear form of analysis of variance and main effect plots. It was found that the best parameters of the crown equation method were the Feed X-Axis at 0.5 mm/min, the Feed Z-Axis at 200 mm/min and the Speed S2-axis 15 rpm. The best parameters for helical path method were Feed X-Axis at 0.5 mm/min and Feed Z-Axis at 200 mm/min. After selecting the best parameters from the crown equation method and the helical path method was tested again. The result of the experiment show that the helical path method reduces the error 7.8 %

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## Selection and Maintenance of Cold Roll

Soğuk Hadde Merdaneleri Seçim ve Bakımı

Shifeng Liu

QINGDAO YELONG • China

### Abstract

As professional mill rolls supplier, Qingdao Yelong has been committed to supply high quality mill rolls and service to customers, as well as offer solutions to eliminate occurrence of rolling problem ; Assist customers to improve roll performance and product surface quality, lower production cost, as well as ensure customer continuous and efficient operation . In this paper , with the statement of three aspects on cold rolls material selection and manufacturing , roll grinding and maintenance , provide customers with reference either on reduce roll consumption or improve quality of steel strip .

### 1.Introduction

QINGDAO YELONG , besides strictly control roll manufacture process , also focus work on providing service at pre-sales, sales and after-sales ; Get well known customers' rolling conditions and requirements; Being able to provide customized product services to customers either from roll material, hardness or other aspects, offer solutions to solve problems on customers' site. Thanks to supplying high quality products and service, Qingdao Yelong has established long-term and stable cooperative relationship with steel enterprises in Turkey, Saudi Arabia, Egypt, India and other countries.

### 2.Manufacture process and quality control

#### 2.1 Manufacture process of cold roll

In order to ensure product quality, the mill rolls provided by Yelong are all from the beginning of the ingredients,

through smelting, LF/VD, ingot casting, electroslag remelting, forging, post-forging heat treatment, rough machining, preparatory heat treatment, semi-finishing, induction quenching, sub-zero treatment, tempering, finish machining, packaging and other processes.

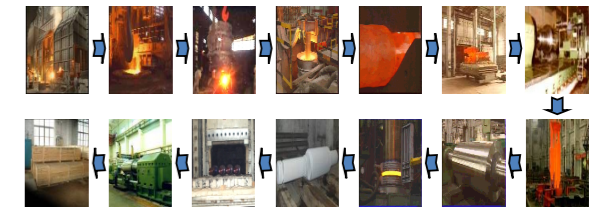


Figure1. Manufacture process of cold roll

#### 2.2 Control of production process

Technicians of Yelong will monitor the production process and strictly implement testing rules , including: Chemical composition, mechanical properties, metallographic inspection, retained austenite and stress testing, hardness testing, nondestructive detection, etc. Evaluate test data to ensure roll performance properties. Among them , after rough machining and conditioning treatment , Roll blank will be tested to obtain its mechanical property value so as to ensure the matrix strength of the roll neck and barrel during roll service. After quenching, metallographic inspection is tested on roll barrel. The grain size is controlled at grade 9.5-11 and martensite grade  $\leq 2$  to ensure the wear resistance and anti-accident performance of the roll. The residual stress of the same batch of rolls is tested to ensure the fatigue resistance and the stability of the hardness and dimension tolerances. Three times Ultrasonic detection will be carried out during production process to ensure the quality of roll inside and surface.



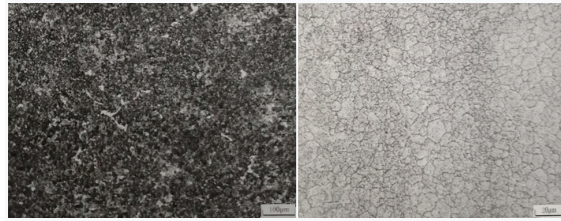


Figure 2. Metallographic image of Cr5

### 3. Roll selection

#### 3.1 Select rolls according to hardness layer

When work roll hardness layer <15mm, Cr2 series material are suitable for adoption; When between 15-28mm suitable for use Cr3 series; While >28mm suitable for use Cr5 series. Compared with Cr2、Cr3, carbide type of Cr5 material have changed from M3C to M7C3 which have higher micro hardness. The distribution of carbides become finer and more uniform, so make work rolls have higher wear resistance.

Table 1. Carbide type of material

Material	Carbide type			
	M3C	M7C3	M2C	MC
Cr2	●			
Cr3	●			
Cr5	●	●		●
S-HSS	●	●	●	●

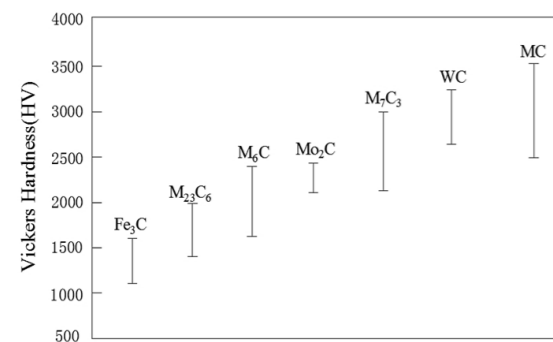


Figure 3. The hardness of carbide<sup>[1]</sup>

#### 3.2 Select rolls according to the stage of mill put into production

At the beginning stage of rolling mill put into production, due to mill commissioning, rolling accidents occur frequently. Therefore, it is suitable for use low hardness (90±2HSD) and shallow hardened layer rolls, so as to minimize rolls consumption due to rolling accident. After normal production, select rolls with more alloys and higher hardness so as to improve wear resistance, elongate rolling campaign as well as improve surface quality of stripes.

#### 3.3 Select roll material according to using stand

Tandem cold rolling work rolls section usually comply with principles as: For front stands, due to thick steel strip work rolls need to endure big rolling force, so it is suitable to choose rolls with lower hardness; However for rear stands, thanks to small rolling force and strict requirement of surface quality, work rolls with high grade material and high hardness are good.

Intermediate rolls, due to on line campaign longer than work rolls, have to endure long time and large contact stress from backup roll and work roll. So Cr5 or Semi-HSS material are recommended so as to ensure intermediate rolls possessing higher contact fatigue strength. Especially the development of Semi-HSS

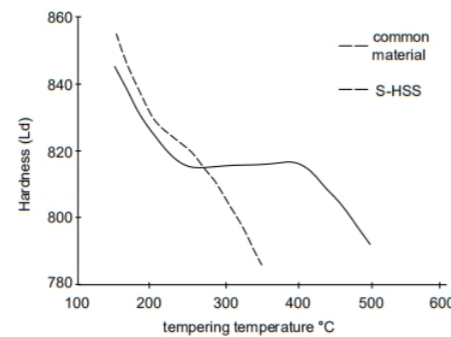


Figure 4. Tempering curve

significantly increase the tempering temperature of

intermediate rolls, improve the property of wear resistance and anti-accident; Its online service time has reached up to 1.5-2 times than traditional material. Its excellent performance has been more and more recognized and accepted by customers.

Skin pass mill work rolls are recommended to use Cr5 material with the barrel hardness above 95 Shore D, to fulfill the technical requirement of high wearing resistance and good profile retention so as to guarantee high surface quality of steel strip.

To sum up, the selection of work rolls ought to fully consider elements such as type of mill, rolling conditions, product specifications, quality requirements, roll maintenance etc. Conduct scientific and reasonable choice.

### 4. Maintenance and grinding of cold rolls

#### 4.1 Make a record of roll history

Make a record of roll history. Content includes: roll diameter before and after mill service; time of in and off the mill; amount of product for each campaign (tonnage or kilometers); stock remove for each grinding; the inspection results after grinding; reason of roll change; measures and results of disposal in case of roll accidents; etc.

#### 4.2 Reasonable grinding specifications

Roll grinding should be done after roll surface temperature cooling down to ambient temperature; And after grinding, rolls need to be placed for certain period to eliminate grinding stress. These factors require steel mills to set up reasonable campaign period and quantity of standby rolls.

The campaign length will need to be balanced with the grinding practice to ensure optimum performance.

Including grinding wheel selection, feed amount, grinding amount and coolant control, to prevent grinding burn.

#### 4.3 disposal measures of accident rolls

When accidents or abnormalities in the rolling process occur, such as strip welding, cobbles, slip, strip broken, overload and so on, the damaged layer must be removed from the roll barrel and confirmed by eddy current and ultrasonic detection. Then test hardness of the damaged area, if the hardness is almost the same with the normal condition, the roll is acceptable for mill service; Otherwise, should grind more stock off and retest.

Table 2. Roll damage in accident<sup>[2]</sup>

Strip welding	Color change	Fuse	Min. depth of crack (mm)	Min. of stock removing (mm)
Nothing	Nothing	Nothing	0.05	0.15
Slight	Nothing	Nothing	0.10	0.25
Slight	Nothing	A little	0.40	0.70
Much	Pale	Have	0.50	0.90
Much	Dark	Have	1.20	0.90
Severe	Blue or	Severely	2.0	Determined

Remark: Above is the empirical data. The specific sizes of damaged layer shall be determined by nondestructive detection and grinding.

#### 4.4 Hardness test of backup roll

Test the hardness across the length of the backup roll barrel after grinding. If the average hardness exceeds 3 HSc (15 HLe) points above the predicted hardness, then grind more stock off of the barrel and retest. If the average hardness is within 3 HSc (15 HLe) points of the predicted hardness, then the roll is acceptable for mill service.

The purpose for grinding the roll until the surface hardness is less than 3 HSc above the predicted hardness

is to ensure that the majority of work hardening that was induced during mill service is removed. Ensure that all repairs to back-up rolls result in complete removal of all cracking and spalling. All repairs should be performed using the criteria given above in the Repair Procedure section.

#### 4.5 Reasonable edge chamfering of roll

When rolls are ground and loaded into the mill the stress distribution at the point of contact between the back-up roll and work roll is uniform. However as the campaign progresses the barrel profile of back-up rolls change as a result of wear quickly at the barrel centre positions. This change in profile results in an increase in contact stress at the barrel edges. Ensure adequate edge relief/chamfering is applied to back up rolls to alleviate localized contact stress, to prevent backup roll shoulder break / spalling and work roll spalling at the contact area of the barrel edge .

#### 5. Conclusion

1. Strict process control and inspection are very important during mill rolls' production, which can effectively guarantee the integrated performance of rolls.
2. Select suitable roll material and hardness according to rolling conditions that can greatly decrease rolling cost in addition to ensure the product quality.
3. Reasonable roll maintenance not merely ensure rolls to be recovery from fatigue caused by long time service , but also can significantly reduce roll consumption.

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## Morphology and Surface Chemistry based Defects in Steel Cold Rolling

Soğuk Çelik Haddedelemde Morfoloji ve Yüzey Kimyası Temelli Kusurlar

Rob Smits, Bas Smeulders

QUAKER CHEMICAL • Holland

#### Abstract

*In steel cold rolling, both morphology defects and surface chemistry based defects can occur. Morphology defects, such as mottling and 'white marks', are usually lubrication-related, displaying a deviating distribution of microscopic areas with mild plough marks and so-called transverse fissures. Studying this distribution provides qualitative information on the local lubrication regime that led to the formation of the defect. Surface chemistry based defects feature a wide range of shapes and colours, often involving a characteristic chemistry that can easily be identified by means of SEM/EDS analysis. The root cause of the defect can often be deduced and remedies suggested to the customer by combining SEM/EDS or surface morphology data with process data from the field. Several field cases are discussed.*

*Keywords: steel cold rolling, morphology defects, surface chemistry defects*

#### 1. Introduction

During the production of flat steel products, the steel undergoes a series of processes to achieve the required metallurgy, thickness, surface roughness and texture. Due to this large number of production steps, the critical conditions that need to be maintained in each of these steps, the numerous steel alloys being produced and the fact that the steel surface is exposed to different process fluids, surface defects can occasionally occur. These are undesirable and may cause rejection or downgrading of the affected coil.

Some of the defects are purely topographical and only due to (subtle) local differences in surface roughness or texture over the surface<sup>1</sup>. Such defects are sometimes caused by lubrication issues and in that sense can be indirectly linked to the chemical nature of the lubricant, but the defect itself is not characterized by local differences in chemistry. In contrast, other defects are clearly characterized by a deviating surface chemistry, due to reactions of the steel surface with process fluid, exposure of the steel surface to the open atmosphere, contamination of the steel surface with alien matter or due to migration of certain alloy elements to the surface<sup>2</sup>.

Analysis of nearly five hundred defect cases originating from more than 90 steel mills showed that about two-thirds (330 defects) was chemical in nature and one-third (170 defects) purely topographical. Most often, in 48% of all cases, it concerned defects of the cold rolled strip surface. Defects after annealing, galvanizing/tinning, wet tempering and oiling each contributed to approximately 13% of all surface defects.

Below, it is demonstrated that SEM/EDS and/or surface profilometry measurements are very useful techniques to characterize surface defects and to aid in finding the root cause of the defect. Surface morphology analyses were carried out with a surface profiler (Wyko NT 1100 interference microscope) whereas surface chemistry analyses were carried out with a Jeol 6480 Scanning Electron Microscope, equipped with an EDS system for surface elemental analysis (Energy-Dispersive X-ray Spectroscopy by EDAX).

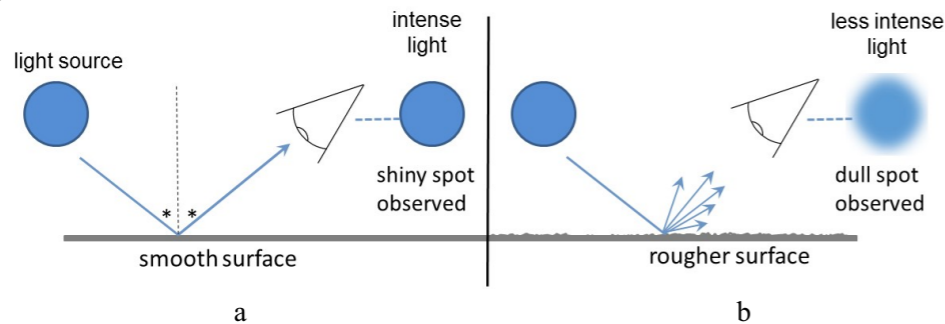


## 2. The interaction of light with surfaces

In the field, surface defects are mostly noticed by automated in-line CCD camera equipment with fast image processing software, involving bright and/or dark field illumination to detect defects most effectively<sup>3</sup>. However, as the software is generally not suitable to classify defects properly, additional visual inspection is often necessary.

When surfaces contain defects (spots, lines, stains, etc.) it means that there are differences in the manner in which incoming light reflects off the surface, and/or the color of this light. These differences are perceived by the observer as an undesirable surface deviation. In order to fully understand such surface defects it is therefore helpful to consider the physical background behind the interaction between incoming light and a surface, and how the nature of the surface influences the nature of the reflected light. Four aspects should be distinguished: a) reflection off (metallic) surfaces, b) refraction in (semi) transparent media, c) absorption of certain wavelengths in (semi) transparent media, d) interference (leading to disappearance of certain wavelengths). These aspects are discussed briefly below. See also textbooks<sup>4</sup>.

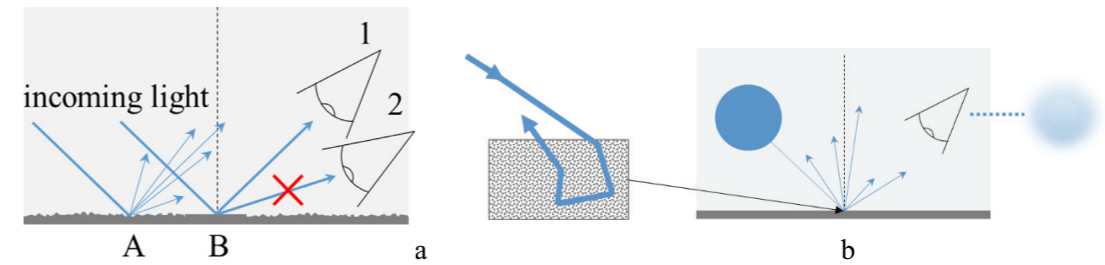
a) Completely flat, polished surfaces reflect light according to Snell's law which states that the angle of reflection equals the angle of incidence. This is sometimes referred to as specular reflection (figure 1a). Light reflected off such surfaces gives rise to perfect mirror images. In case the surface is not completely smooth (i.e. it has a certain roughness) incoming light is reflected in many directions. This is called diffuse reflection. Objects reflected off this kind of surface appear (slightly) more blurred, with indistinct boundaries (figure 1b). The surfaces themselves, when illuminated, also appear differently, and the surface in figure 1a has a more bright appearance, whereas the surface in figure 1b has a (slightly) more matt, or dull appearance.



**Fig. 1** Illustration of specular (a) and diffuse (b) reflection, depending on surface roughness.

On surfaces with local variations of light reflection, e.g. due to the presence of areas of lower roughness, smoother areas usually appear darker than the general surface, but when viewed at another angle with respect to the incident light, they may seem lighter. This is due to the fact that at most angles of incident light the light reflected off the spot misses the eye whereas when observing the spot area roughly at the angle of reflection the eye will receive much more light (figure 2a).

b) The manner in which light reflects off the surface also depends on the nature of the material. For instance a completely smooth surface may be unable to display specular reflection due to interaction of the light with internal microstructures (grains, air bubbles et cetera). As a result, severe light scattering takes place (figure 2b), which may be the reason for the white appearance of some materials, i.e. having the color of the scattered (white) light.



**Fig. 2** a: Illustration of the brightness with which a smooth spot B (at the center) on an otherwise rough surface A is perceived. b: Illustration of severe light scattering occurring on some materials, which can be conceived as an extreme form of diffuse reflection.

This mechanism is also often the reason that oxides (rust) can appear white whereas others appear dark, even though they are composed of similar chemistry. In case oxides have a porous structure they often strongly scatter light (similar to figure 2b), and appear white. In contrast, when oxides have a dense structure they may reflect light more specularly and thus appear darker.

c) A further aspect that needs to be considered is the surface color. Color is a result of the absorption of certain wavelengths of the incident light depending on the molecular composition of the surface material. For instance the red pigments in a red paint absorb all wavelengths except red, so that the reflected light contains only the 'red' wavelengths.

d) A surface may also appear colored due to an interference phenomenon which cancels out certain wavelengths of the incident light. This interference phenomenon is found when a thin (semi) transparent layer is present on top of a reflective surface, such as a thin oxide layer on metal. The incoming light will reflect off the oxide surface, as well as off the underlying surface. When the waves recombine at the surface they may cancel out or reinforce one another. Depending on the oxide thickness and the wavelength of any one of the light waves that constitute the incoming light, certain specific frequencies will be cancelled out, leading to the loss of certain wavelengths in the reflected light. Mostly incoming light is white, so this loss of certain wavelengths means that the light reflected off the surface will have a color, i.e. the surface is perceived as colored. This is often the explanation for the color of (mild) oxidative staining on steel surfaces.

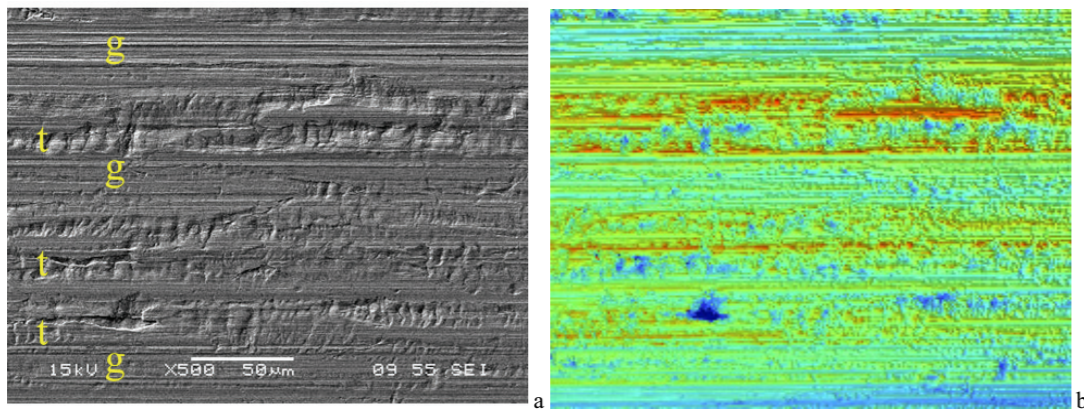
In some cases, visual inspection may lead to misidentification of the defect because appearance is not always indicative for the chemical nature of the defect. This requires additional surface morphology and SEM/EDS analysis to correctly identify the defect.

## 3. Surface morphology defects

The cold rolling process generally occurs in the mixed lubrication (ML) regime. This can be inferred from the typical values of the coefficient of friction (CoF) during cold rolling, ranging from 0.04 to 0.08. The exact value depends on factors such as process speed, roll roughness, and of course lubricant chemistry. The physical background to the characteristic values of the CoF in the ML regime is that due to the roughness of both work roll and strip, microscopic areas of close contact coexist with areas of larger separation, as described in the 3-D Stribeck curve<sup>5,6</sup>. In the areas of close contact boundary lubrication (BL) conditions exist, where the local CoF is governed by adsorption of lubricant components<sup>5</sup>. In the areas of larger separation elasto-hydrodynamic lubrication (EHL) conditions exist, where the local CoF is governed by high-pressure and high-shear rate lubricant rheology<sup>5</sup>. This explains the characteristic values of the CoF in cold rolling as they correspond to a weighted average of the CoF in the boundary regime (order 0.1) and the CoF in the EHL regime (order 0.01).

These two distinct lubrication regimes also leave distinct surface features on the strip. In areas of close contact, the work roll is in sliding contact with the strip, which normally only leads to mild grooving caused by ploughing. In areas of larger separation, a lubricant cushion separates the two surfaces, leading to the survival of roughness valleys. The distribution of the areas of mild grooving and the areas where roughness valleys survive is therefore a direct reflection of the distribution of the two lubrication regimes BL and EHL and hence of the CoF in the cold rolling process. A qualitative impression about the lubrication regime can thus be obtained from a strip surface morphology analysis. In the current paper, the ratio between grooving and roughness valleys is assumed to be directly related to the entrained film thickness (which influences the ratio between BL and EHL).

In figure 3a can be seen a SEM image of the characteristic features on cold rolled strip. Roughness values can be seen, as well as areas of mild grooving, caused by local ploughing of work roll asperities that slide over the strip surface. Cutting angles in cold rolling are relatively small, and due to molecular adsorption the interfacial shear stress is low, leading to sliding along the interface rather than within the metal matrix. In figure 3b a surface profile is shown of the same area.



**Fig. 3** SEM image (a) and surface profile (b) of the same area of a characteristic cold rolled surface. The right image has a height scale of  $-2\mu\text{m}$  (blue) to  $+2\mu\text{m}$  (red). Note the areas of mild grooving and areas with transverse fissures (in yellow: 'g' and 't' respectively).

In the areas with roughness valleys, so-called transverse fissures can also be readily identified (figure 3a). These characteristic features occur in cases of plastic deformation where (locally) a pressurized lubricant cushion separates the two surfaces. This leads to deformation of and within the metal grains, leading to morphological structures perpendicular to the rolling direction<sup>7</sup>. These features were investigated experimentally and theoretically by a number of researchers, resulting in the assumption that transverse fissures originate either from local surface fracture, due to reduced ductility<sup>(8)</sup>, or from differential deformation of individual metal grains<sup>(9,10)</sup>.

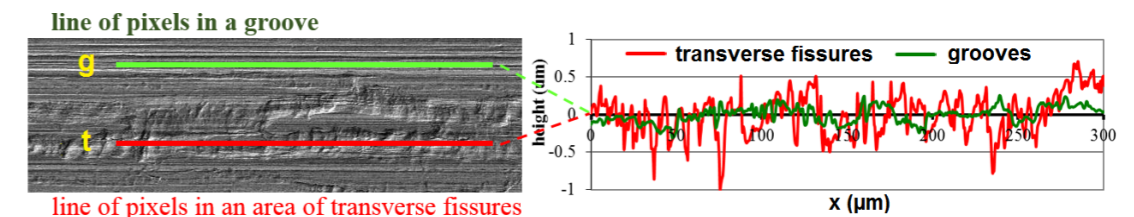
As mentioned before, measurement of the relative amount of the areas of mild ploughing and of areas where roughness valleys survived (areas with transverse fissures) provides a qualitative measure of the lubrication regime. In the current paper an alternative approach is presented for quantifying the relative proportion of transverse fissures and mild grooving, based on surface roughness measurement.

Traditionally, surface roughness is measured with a perthometer ('stylus' measurement), which physically slides a narrow probe for a certain length along a surface,

registering the deflection. The center-line average is usually referred to as Ra value. Modern techniques, such as interference microscopy, are mostly contact-less and use e.g. a light source with which a two-dimensional area can be probed. This results in a 3-D height map of the surface, such as shown in figure 3b. The 'center-plane' average is usually referred to as Sa value. This height map can be analyzed with appropriate software. For instance, the center line averages parallel and perpendicular to the process direction can be calculated, which can be significantly different when the roughness has an orientation (lay), e.g. in ground surfaces.

The alternative method for quantifying the relative proportion of transverse fissures and mild grooving, relies on the fact that the center-line average in the rolling direction along a single line of pixels in a groove is lower than in a region of transverse fissures. In this paper this method is referred to as the 'stylus-x' method, with the rolling direction in the x-direction. See figure 4 for an illustration. With the defect example we will see that this method can be quite useful to quantify even small deviations of surface morphology. Note that not all morphological deviations require this method; in some cases measuring Sa values is sufficient.

The appearance of cold rolled strip in terms of the relative proportion of areas of mild grooving and transverse fissures is important for aesthetic reasons, but often also for functional reasons (e.g. for coating demands). In this respect qualifications such as 'dull' and 'bright' apply, corresponding to a predominance of transverse fissures and grooving, respectively. Small variations in surface brightness of cold rolled strip from batch to batch are often acceptable, e.g. due to variations in work roll roughness, mill operation and the condition of the emulsion. However, when such variations occur on the same strip, in proximity to each other, these variations may be no longer acceptable. An example of such an unacceptable variation in surface brightness is given in the next paragraph.



**Fig. 4** Illustration of the stylus-x method for quantification of the relative proportion of grooves and transverse fissures. The center-line average of the heights along a single line of pixels in a groove is lower than in an area of transverse fissures.

### 3.1. Example of a surface morphology defect: white streak

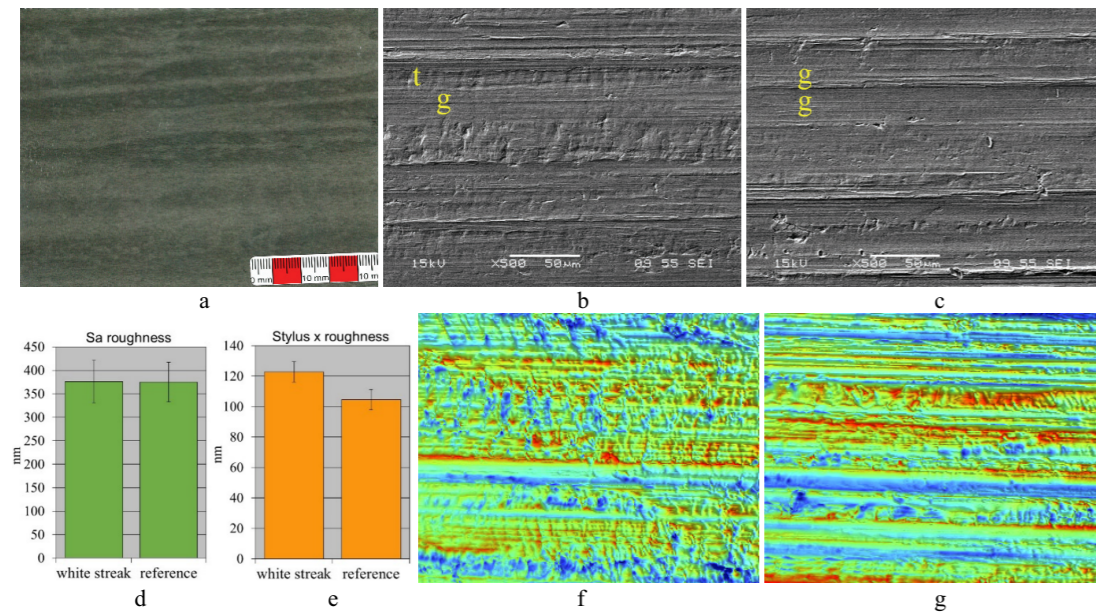
White streaks have a characteristic appearance such as illustrated in figure 5a. They consist of irregular, 'white' areas roughly in the rolling direction, but often oriented at a small angle. Their width may vary considerably and they often have a 'splash-like' appearance. A 'splash' of streaks may cover quite a large area, e.g. 20-50 cm, but some sections of the strip may be defect-free. White streaks may occur after cold rolling with relatively smooth work rolls, but may also occur after cold rolling where a texture is imprinted in the last-stand, at low reductions. In this paper a defect in the first category is discussed.

When investigating this defect with a SEM, one always observes a (slight) dominance of transverse fissures in the whiter areas and of mild grooving in the darker, reference areas, as is illustrated in figure 5b,c and 5f,g. In other words, the whiter areas correspond to a 'duller' surface aspect, whereas the remainder of the surface correspond to a slightly 'brighter' surface aspect. This would suggest that the white streaks defect is the result of small local



variations in oil film thickness. It can be seen in figure 5d that the Sa value (the 'centre-plane' average of the height map created in the interference microscope) is not able to distinguish the white streak from the reference. The reason for this is that the Sa roughness is dominated by the imprint of the roll grinding marks (the 'blue' and 'yellow' bands in the rolling direction, as shown in figure 5g). However, as mentioned above, these defects can be quantified with a stylus-x calculation from a 3-D height map. In figure 5e can be seen that the white streak ('dull') areas correspond to a significantly higher stylus-x value than the reference surface.

Using SEM and surface profiler it was shown that the white streak defect is purely topographical. This was also confirmed with EDS analysis which showed that there is no compositional difference between the defect and reference areas.



**Fig. 5** Illustrations of a white streaks defect. Photograph of the defect (a), SEM images of streak (b) and reference (c) with indicated bands of transverse fissures ('t') and grooves ('g'), Sa roughness of the white streak and reference areas (d), Stylus-x roughness of the white streak and reference areas (e), Surface profile of streak (f) and reference (g); dimension: 150 x 110 $\mu$ m, height scale -1.5 to +1.5 $\mu$ m.

The white streak defect is caused by local variations in 'plate out' of the oil on the strip<sup>3</sup> or by variations in film thickness during rolling. This in turn can be caused by inhomogeneities in the emulsion, or variations in emulsion application. Note also that the white streak defect has a striking macroscopic fluid flow, splatter or splash-like appearance, which corroborates the sketched scenario. Usually this defect is reduced by improving the lubrication consistency across the width of the strip, either by adjusting the emulsion properties or the application of the emulsion.

Similar defects, also caused by a locally increased separation between work roll and strip (lubricant cushion) include mottling, mostly observed after tinplate rolling and white spots. The latter are mostly due to the presence of inhomogeneities or contaminations in the emulsion.

#### 4. Surface chemistry based defects

All cold rolling process steps occasionally suffer from the occurrence of surface chemistry based defects. The number of different surface defects is substantial. Based on 330 SEM/EDS analyses, carried out over a 10-year period, the following overview can be given.

After cold rolling, the full hard strip surface can be oxidized due to coiled-in emulsion or incorrect coil storage, sometimes accelerated by salt remains originating from the rolling emulsion make up water, or a too high strip exit temperature. Also contamination of the strip surface with rolled-in alien matter occurs, involving compounds such as calcium and iron soaps, scale remains, metal fines, grease etc. Note that in many cases where alien matter was rolled in, the deviating surface chemistry of the defect is accompanied by morphology changes of the underlying steel surface as well. This means that after cleaning defect spots with a solvent, a roughened surface often emerges, which may be due to the presence of transverse fissures<sup>1</sup> or etching holes ("pinholes"), formed by a mild, local corrosion process.

After annealing, carbonaceous residues may occur on the strip surface which may be a consequence of incomplete decomposition of organic compounds or due to methane decomposition near the strip edges ("snaky edge defect"). Other residues may also be found, such as remains of alien matter or salts from emulsion make-up water that were present on the full hard strip surface. Finally, the surface may also oxidize immediately after annealing due to a too early exposure of the hot strip surface to the open air.

Surface chemistry-based defects after tinning and galvanizing occur less frequently, involving mostly oxidation of the underlying steel surface due to incomplete coverage of the steel or due to the tin or zinc layer being too thin.

Surface chemistry-based defects after tempering and after subsequent oiling also mostly involve oxidation, resulting from coiled in temper fluid (insufficient blow-off), or a too long or a too short storage time between tempering and oiling, the latter likely resulting in insufficient passivation of the annealed surface. Furthermore, the amount of protective oil may be too small or its distribution over the surface inhomogeneous. More rarely, the presence of chlorine originating from airborne salt particles (coastal areas) or from HCl vapours from a nearby pickle line may result in strip surface oxidation.

Chemistry-related defects do not only cover a wide range of visual appearances, also their microscopic appearance, as observed for instance with a SEM, can vary significantly. Particularly where corrosion products are involved, there are some frequently occurring features. Corrosion products quite often have the appearance as shown in figure 6a: smooth, often globular structures with mostly a cracked morphology, likely formed during drying. These oxide structures are often characteristic for atmospheric corrosion.

Locally, quite severe corrosive conditions can occur, which is often accompanied by widespread etching. These are tiny holes of submicron dimensions that usually start off individually, but can grow to larger sizes and join to create significant cavities in the surface. See figure 6b. Often, the pattern of etching holes suggest that they have likely developed along grain boundaries. Etching holes are the result of a corrosion process in which the corrosion products were soluble, e.g. in a locally acidic environment. This leaves behind the etching holes where the metal has disappeared, while the corrosion products may have been deposited elsewhere. Local acidic conditions can occur in cases where anodic and cathodic regions are separated.

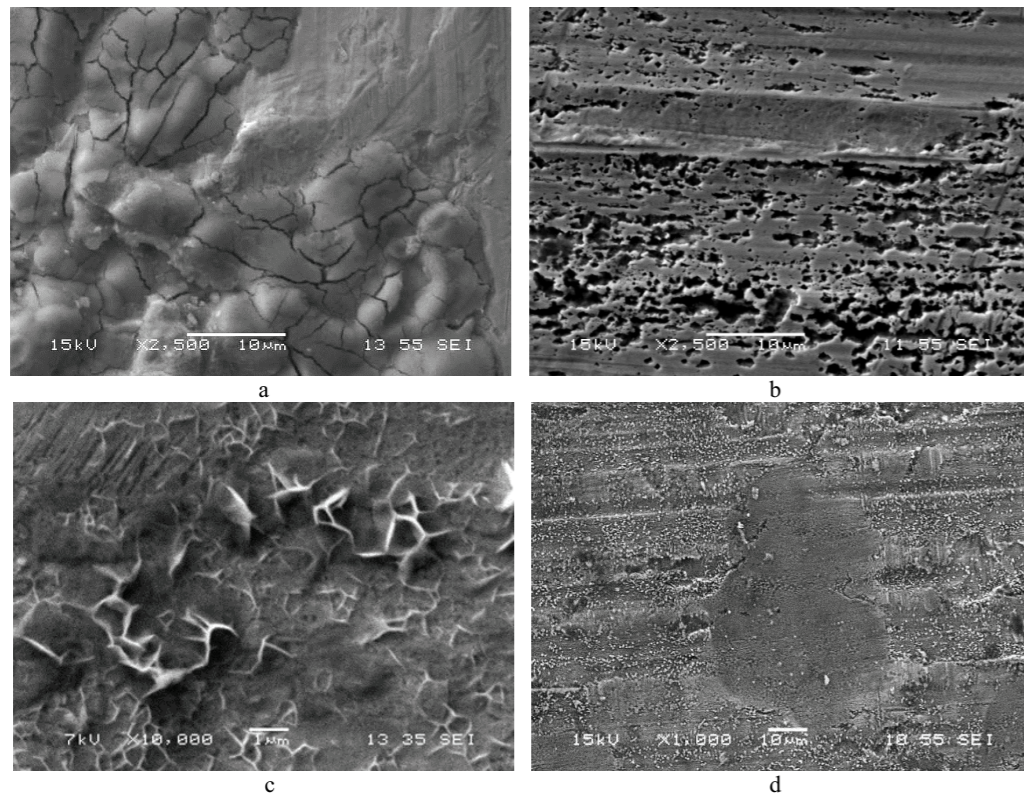
At high magnifications, sponge-like porous structures are sometimes seen, mainly after wet temper rolling, as shown in figure 6c. The exact nature and mechanism of formation of these structures is not known, but organic material is sometimes involved as well as oxides.



It is possible that some of these structures form in between windings in a coil and are ruptured when opening the coil. The porous nature of the material that had grown between the windings is then revealed.

Oxides, when present on the surface, e.g. after cold rolling, or even due to rolled-in scale may be chemically reduced by the environment present during annealing. This leads to the formation of metallic iron and the disappearance of bound oxygen but leaves the deviating morphology of the former oxides intact. Some of this deviating morphology may survive the next processing step, e.g. wet temper rolling, leading to surface defects attributable to oxidation/corrosion/scale, but without the oxygen levels normally found in oxides.

In figure 6d is shown an example of submicron particles on a cold rolled surface which were flattened into the general surface by the wet temper rolling process. This kind of evidence can be used to conclude that these features did not result from the wet temper rolling process, but were created upstream.



**Fig. 6** Examples of the morphology of some chemistry-related defects on steel.

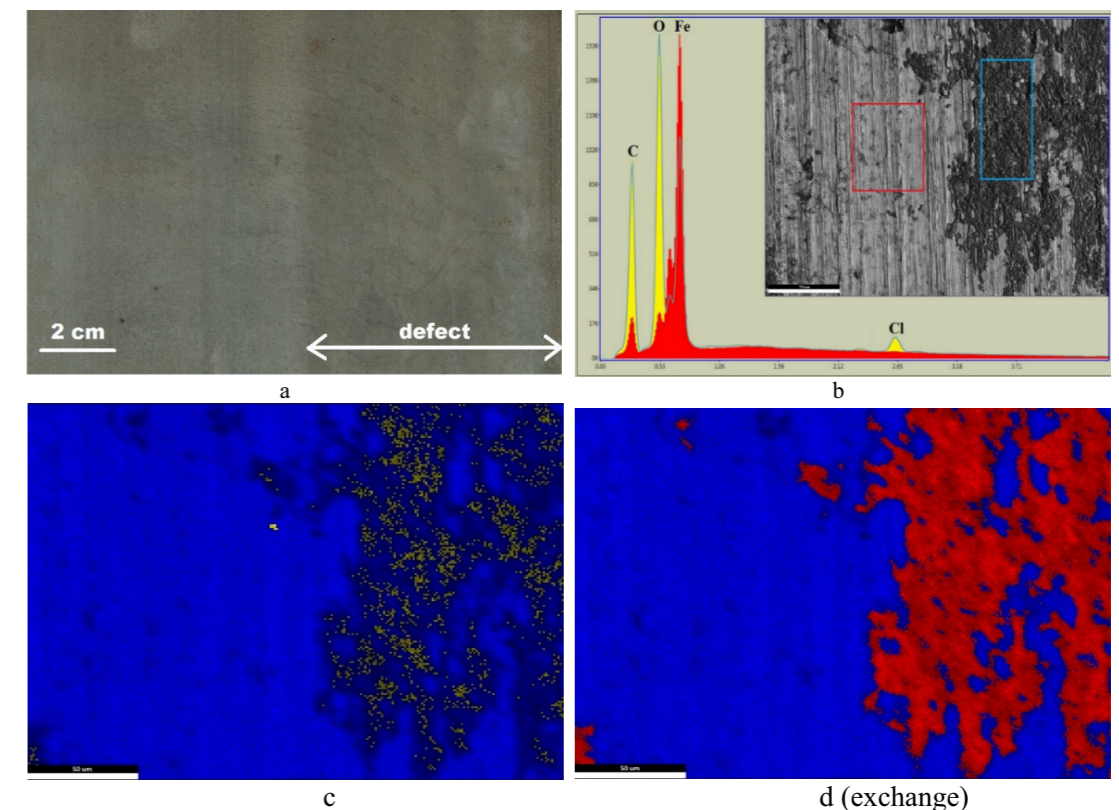
Oxidation-induced staining is sometimes so subtle that oxides can hardly be detected at the surface, despite the discoloration being clearly visible. This can be due to very low oxygen levels in the environment, low reaction rates, or only very short times available for this reaction.

There is often debate on whether a defect should be identified as ‘staining’ or ‘corrosion’. Both lead to defected surfaces (local variations in reflection and/or color). Staining can be defined as occurring through reactions of the steel surface with any reactant (oxygen, water, sulfur, phosphorus, etc.), but -crucially- leaving the substrate morphology intact. Corrosion can be defined as occurring through oxidative reactions (oxygen or water),

leading to significant deposition of oxides and/or strong substrate damage. As usual, ‘grey’ areas exist, e.g. when ‘staining’ leaves the macroscopic surface morphology intact, but leads to sub-micron etching holes, and some settling of oxides. In such cases, staining can be considered as ‘mild oxidation’.

#### 4.1. Example of a surface chemistry based defect: corrosion after cold rolling

Most surface chemistry-based defects that occur on full hard steel concern corrosion caused by coiled-in rolling emulsion left behind on the surface due to an insufficient blow-off or sub-optimally functioning wipers. Subsequent storage of the coils may then result in corrosion in the shape of oxide spots or bands of more or less severe staining. In some cases, the corrosion process was triggered by traces of chlorine originating from the pickling process (acid carry-over) or by salts originating from the water used to prepare the rolling emulsion. An example of full hard strip corrosion due to acid carry-over is presented in figure 7.



**Fig. 7** a) Visual appearance, b) EDS spectra of a staining spot (inserted SEM image) and of adjacent non-stained surface. c,d) Element maps for iron (blue) and oxygen (red) and chlorine (yellow), of the same surface. The area comprising chlorine closely matches that with elevated oxygen levels.

Here, a 6-7 cm wide band of greyish-brown staining was observed close to the strip edge. An EDS spectrum of a small oxide spot, observed under high magnification, reveals the presence of a high amount of oxygen and, due to the porous nature of the oxide, a high amount of carbon (representing rolling oil remains). Closely associated with the corrosion spot is the presence of a relatively high amount of chlorine, which may have accelerated the corrosion process.



## 5. Conclusions

Surface defects after steel cold rolling and the processes further downstream are found occasionally. Despite the wide range of sizes, shapes, colors and reflectivity of these defects, the actual chemistry and/or morphology underlying most defects is well-known. Surface chemistry based defects can often be easily identified by means of SEM/EDS analysis whereas for morphology defects the relative proportion of mild grooving and transverse fissures, assessed by means of surface profilometry can be used for identification.

Combining the information on where in the process the defect occurred, the conditions under which these were formed, and the microscopic morphology and chemical composition of the defect, the root cause of the defect can often be deduced, and remedies suggested to the customer.

## Acknowledgement

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## CERAN® - A Market Leading Grease Technology Reviewed

CERAN® - Pazar Lideri Gres Teknolojisi İncelemesi

Franck Bardin, Raphael Brueggemann, Peter Leus, Olaf Kurtz

1TOTAL MARKETING & SERVICES • France

## Abstract

The presentation will focus on morphological aspects as base to explain the performance characteristics of the CERAN® greases followed by a comparative study with other Calcium Sulfonate Complex products. Finally, the results of a cost saving calculation during production (continuous casting and rolling line) which has been prepared in cooperation with a steel industry customer shall be presented.

## 1. Introduction

The CERAN® product range belongs to the Calcium Sulfonate Complex (CaSC) greases and its high performance and its success are based on a patented production process [1]. This process ensures the specific three-dimensional morphology of the CERAN® greases which is key for the unique characteristics [2,3].

## 2. Grease Morphology

The core of this structure is the Calcium Carbonate (CaCO<sub>3</sub>), the shell is formed by the thickener calcium sulfonate. The structure is a so-called inverse micelle which is created by the interaction of colloids from surfactants in this case in a non-polar solvent [4,5]. The patented production process ensures the conversion of amorphous CaCO<sub>3</sub> into crystalline calcite which is forming the core of the nanosized inverse micelles. Calcite is besides the vaterite an anhydrous polymorphs/ crystal structure of CaCO<sub>3</sub> which has enormous advantages due to its structure compared to vaterite. In contrast to the vaterite, the calcite has a fish scale/wafer-like platelet form which is orientated parallel to the metal surface during the lubricant process [6-8]. The parallel orientation creates a sacrificial shear plane which prevents the damage and destruction of the micelles under extreme pressure and leads to an excellent anti-wear performance. In addition, the patterns cover the full surface of the lubricated metal surface and form a highly efficient water barrier to prevent corrosion.

## 2.1. Morphology and Grease Characteristics

Without any additive the CERAN® greases provide excellent extreme pressure, anti-wear and anti-corrosion properties based on this morphology. Furthermore, the formation of large inverted micelles enables the grease to

absorb up to 40 w% water without any change neither in consistency nor in performance. This exceptional characteristic makes the CERAN® greases the best choice in applications where water, also saltwater, is omnipresent such as in steel, paper, food or mining industries [9-11].

## 3. Benchmark Results

In several benchmark studies these advantages could be quantified by comparing the thermal and mechanical stabilities, the behavior in the presence of water, oil separation, anti-wear and EP properties as well the characteristics at low temperature. Results of one benchmark will be presented.

## 4. Technology that pays off

Worldwide references prove that the patented CERAN® technology brings technical and economic benefits to our customers, i.e. by reduction of bearing failures, by significant reduction of grease consumption as well as by a reduction of maintenance and downtime of the machinery. An exemplary TCO (Total Cost of Ownership) calculation based on customer data will be presented.

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## Improvement of Work Safety and Reduction of Environmental Issues with Fire Resistant Lubricants in Steel Plants

Demir & Çelik Tesislerinde Ateşe Dayanıklı Hidrolik Sıvılar ile İş Güvenliğinin İyileştirilmesi ve Çevresel Sorunların Azaltılması

Tim Mattern, Ronald Knecht

QUAKER HOUGHTON • Holland

### Abstract

Fire hazard in the steel industry is not a new topic and the steel industry is taking any possible efforts to lower the fire hazard in its production plants. Fire hazard is present in several different forms, but fires induced and intensified by mineral oil based lubricants are notorious and feared. For hydraulic fluids, gear oils and greases several alternatives are available. This paper explains typical examples in steel plants of successful conversions and the impact on safety and environment. In addition, the paper describes what change can be made to the choice of lubricants to get to a situation with significant reduced risk, enhanced work safety and a secured productivity in Casters, Rolling Mills and auxiliary equipment.

### 1. Introduction

The Steel producing industry is an industry where situations occur every day that can be classified as dangerous. Dangerous not only due to the plant's heavy machinery, or the operations involving liquid or red hot steel, but also because of the escalated fire risk based on the Lubricants & Greases being used.

In this paper we will focus on the potential risks associated with the use of mineral oil based hydraulic fluids and greases in steel plants, and what alternatives can be used without jeopardizing the performance or productivity of the production line.

### 2. The Fire Risks of mineral oil based lubricants

A fire is one of the events that, once experienced, leaves a huge impression on the people involved. In addition to the risk of personnel injuries, there is a likelihood of loss in both capital and production.

These losses not only include damage to the building and equipment, but also encompass interruptions in production that can idle lines for days or even months.

One cause of fire in a steel production plant is the ignition of mineral oil based hydraulic fluids or greases.

In Figure 1, all the areas in red represent an operation where the processed materials reach temperatures  $\pm 900^{\circ}\text{C}$  up to  $> 1500^{\circ}\text{C}$  ( $\pm 1652^{\circ}\text{F}$  up to  $> 2732^{\circ}\text{F}$ ). In most of these processes hydraulic units are used to operate the equipment, and in many cases a mineral oil based hydraulic fluid is chosen to fuel the hydraulic unit. While mineral oil has the definite advantage of a good cost-performance ratio, it is a distillate from crude oil, and not always the safest choice, due to its tendency to catch fire easily.

Fire resulting from the ignition of a mineral oil based lubricant can happen in many different ways. Two that occur most often are when mineral oil based lubricants leak onto a very hot surface; or when sparks or hot (liquid) metal land in a pool of mineral oil based lubricants.

The first instance becomes a larger issue when it happens with a liquid mineral oil based lubricants like a hydraulic fluid because the risk of larger spills or oil spray has a much wider reach. The second example is likely to happen with both liquid as well as greases like mineral oil based lubricants.

Fortunately, there are alternatives available to manage these risks and reduce the chance of an ignition.



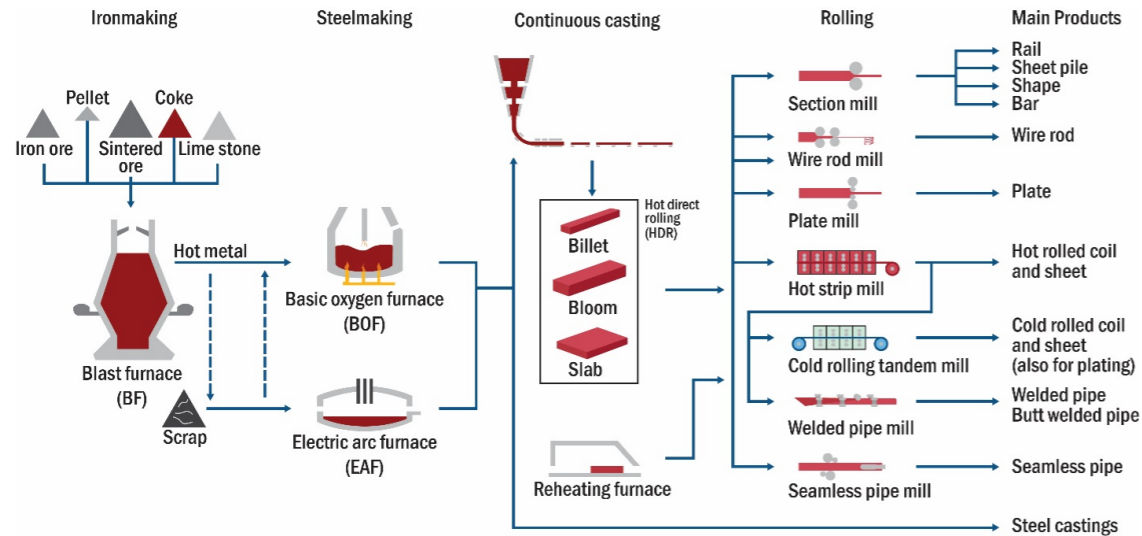


Figure 1. Rough schematic of the steel making process

3. Fire Resistant Hydraulic Fluid.

3.1 Types of Fire Resistant Hydraulic Fluids

The standard hydraulic fluids used in steel production are mineral oil based. But an alternative to mineral oil hydraulic fluids are fire resistant hydraulic fluids, as described below using the ISO 6743/4 classification.

Water-based Fluids	Water-free Fluids
<b>HFA-E:</b> Oil in water emulsions water content > 80% common use 1 to 5%	<b>HFD-R:</b> Phosphate ester based. These products are less used because of CMR reputation
<b>HFA-S:</b> Synthetic aqueous solutions water content > 90% common use 1 to 5%	<b>HFD-U:</b> Based on other compounds, but mainly synthetic polyol ester and natural esters (renewable resources)
<b>HFC:</b> Water glycol solutions water content >35%	

Figure 2. ISO 6743/4 classification

For each fluid type there are both pros and cons. Figure 3 shows a comparison of the performance properties for several hydraulic fluid types. The properties shown are considered important by both Maintenance Managers as well as Purchasers.

Property	Mineral Oil	Phosphate Ester (HFDR)	Water Glycol (HFC)	Synthetic Polyol Ester (HFDU)
Fire resistance	--	++	+++	+
Environmental performance	-	+ and -	+ and -	++
Thermal stability	++	++	-	+
Fluid maintenance	+	--	--	+
Component life/System reliability	+	+ and -	--	+
Price	++	--	++	+/-
Total Cost of Operation	-	-	--	+

Figure 3. Hydraulic fluid comparison when used in fire hazardous situation.

The comparison table shows that mineral oil has good hydraulic fluid performance attributes, at a reasonable price. However, because mineral oil is not biodegradable, it is not environmentally friendly, and the rating for Total Cost of Operation (TCO) is due to the aftermath experienced once a fire takes place.

Phosphate ester (HFDR) fluids are an older fluid technology, and are fire resistant by chemistry, but have a negative reputation. They are reported to be formulated with CMR (Carcinogenic, Mutagenic, Reprotoxic) materials, and the combustion fumes they produce are reported to be neurotoxic. HFDR fluids can be 10 to 15 times more expensive than mineral oil and need to be carefully maintained as these products become aggressive acids as they age. These fluids are mainly used nowadays in Power generation, although they are sometimes found in a steel plants as well.

HFC fluids, better known as water glycols, are widely used in steel plants as well as other industries, and represent about 50% of the total fire resistant hydraulic fluids market. Their high water content makes them very good for fire resistance, and while they have a comparable price to mineral oil, they do not measure up in performance attributes. Additionally, compared to water free hydraulic fluids, the hydraulic units for HFC are more expensive to purchase, the service components have a shorter lifetime, more fluid management is needed, and energy consumption is 10 to 20% higher compared to mineral oil or polyol ester based fire resistant hydraulic fluids.

Polyol ester based fluids (HFDu) are the best solution and alternative to mineral oil. Typically, no changes need to be made to the hydraulic unit when converting from a mineral oil or water glycol hydraulic fluid to a polyol ester fluid. They are more expensive than mineral oil (around 2 to 3 times more), but with the reduction in the risk of fire from the hydraulic fluid, the result is a lower Total Cost of Operation and a much safer work environment. Additionally, nothing is sacrificed in terms of the fluid's performance, and the polyol ester based (HFDu) fluids have reduced environmental impact.

When the user knows the types of Fire Resistant Hydraulic Fluid available, a comparison between possible solutions can be made, figure 4.

3.2 How is Fire Resistance perceived?

The term *fire resistant* is often mistakenly understood to be the same as *fire retardant*. It is not necessarily the same. Almost all fire resistant hydraulic fluids will burn under certain conditions.

- » HFC fluids will ignite if a certain amount of water evaporates
- » Most HFDu fluids will burn, but will not give the vaporized kind of explosion mineral oil generates

The ignition-like explosion caused by the mineral oil is what leads to an uncontrollable situation. The only hydraulic fluids that can truly be considered fire retardant are the high water content (HFA) fluids.

Fluids can be tested to determine their fire resistance. The most common and generally accepted tests are those used by Factory Mutual (FM Global), the testing and approval arm of a major industrial insurance underwriter ([www.fmglobal.com](http://www.fmglobal.com)). Using an FM global approved hydraulic fluid can reduce the premium a company needs to pay.

Additionally, beyond FM Global, many other organizations and companies have developed fire resistance tests, usually to simulate a certain type of real-world accident.

In Figure 5. video frame shots show the comparison between ignition of mineral oils and HFDu fluids.

FINANCIAL AND TECHNICAL EVALUATIONS OF POSSIBLE SOLUTIONS TO ENHANCE SAFETY		
Solution	Positive	Negative
Change design of the Unit to avoid mineral oil leakages close to the hot surface	» Company can keep the same oil technology	» Does not avoid using a straight hydraulic oil (HLP) coming close to the hot surface. Does not avoid formation of pools.
Installation of a fire extinguisher system	» Company can keep the same oil technology	» Very expensive and it does not catch the explosive ignition and fire balls
Change hydraulic fluid to a Water Glycol HFC type	» Offers a safe solution	» Reduction in lubrication performance » Expensive
Change hydraulic fluid with HFD-U type	» Hydraulic performance closest to Mineral oil based lubricants and general no investments needed on hydraulic systems	» Low risk of spreading fire (under control) but still possible on a 900°C (1,650°F) surface

Figure 4. Possible solutions to enhance safety

### 3.3 Comparison of Mineral Oil and HFDu Polyol Ester when poured on a 900°C Surface.

#### 20 ML OF MINERAL OIL (HLP-46) POURED ON A 900°C PANEL

Mineral oil forms vapours which results in explosive ignition



#### 20 ML OF QUINTOLUBRIC® 888-46 POURED ON A 900°C PANEL

QUINTOLUBRIC® 888-46 produces controlled ignition, no explosion, and ultimate control of the situation



**Figure 5.** Comparison of Mineral Oil and HFDu Polyol Ester

The complete movie can be found on Youtube under <http://www.youtube.com/watch?v=bEtlikCMRWM>

The still frames demonstrate the problem that typically occurs when a mineral oil based lubricant comes into contact with a hot surface. The mineral oil evaporates easily, and therefore, tends to build a vapour of oil droplets. Once ignition takes place, the oil droplets can catch fire and result in an explosion and/or fire ball. These two effects make the fire with a mineral oil dangerous and hard to control as the fire ball can go to the roof or to cables and can ignite that area. With the polyol ester based HFDu fluids this evaporation does not take place and thus no explosion or fire ball will be generated. The HFDu fluid might burn as well, but there is no vapour or explosion and it is limited to the place it comes in contact with, so the situation remains under control.

### 3.4 Comparison of a pool of Mineral Oil and HFDu Polyol Ester a hot subject drops into it.

To explain this phenomenon some physical parameters should be understood.

Property	Mineral oil	QUINTOLUBRIC® 888 HFDU
Auto Ignition Temperature	300°C	460°C
Specific Heat	1.7-1.8 J/g.K	2.06 J/g.K
Heat of Combustion	43 KJ/g	38 KJ/g

**Figure 6.** Physical Parameters

A driving force in this process is the relative low auto ignition temperature of mineral oil in combination with a relative low specific heat and high heat of combustion.

1. The auto ignition point of MO is much lower than that of QUINTOLUBRIC® 888
2. The Specific heat expresses the energy needed to heat 1 g MO 1°K => 10-15 % less energy to heat Mineral oil based lubricants .
3. The heat of combustion of a mineral oil based hydraulic fluid is typically about 43-44 kJ/g, whereas an HFDu, polyol ester fire-resistant hydraulic fluid has a heat of combustion of about 38 kJ/g. So chemically an HFDu fluid generates 10-15% less heat during combustion.

So purely on physical facts it can be stated that less energy is needed to heat Mineral oil based lubricants to reach the temperature needed to auto ignite ( which is already relatively low ). The relative high heat of combustion of Mineral oil based lubricants acts as a catalysis in the process and creates the situation of the explosive ignition and propagation of the flames.

### 4. Examples how Fire Resistant Grease improved work safety and reduced fire hazards in high risk areas

Because of the nature of steel production, steel plants have hazards in every operation. This requires a “safety first” approach from everyone, including visitors, to minimize the risks of negative outcomes. Within the large context of safety, fire hazards are substantial areas of risks within steel plants.

Fire hazards exist in many places within steel plants. This includes, but is not limited to areas such as the coke oven, blast furnace, melt shop, hot rolling mills, etc.

To extinguish the fire, the National Fire Protection Agency [1] describes the four main approaches. These are cooling the burning material, eliminating the oxygen, removing the fuel and breaking the chemical reaction. Typically, steel plants cool the burning material. This is usually done with water either from a system or from a steel worker manually extinguishing the fire.

#### Example #1 – Hot Rolling Mill Walking Beam Furnace Exit – Roller Table

In the hot rolling mill of a major North American steel producer, hot scale was falling off the 1,260°C temperature steel bars as they exited the walking beam furnaces, causing excess grease on the bearings to catch on fire. The steel producer thereupon instructed Quaker Chemical to develop a fire-resistant grease that could be used on the roller bearings to reduce the amount of fire hazards. Quaker Chemical proposed QUINTOPLEX™ LXS 1002-EP grease for use on the hot rolling mill. Before introducing QUINTOPLEX™ into operation, the steel producer challenged the fire-resistant properties of the grease with tests that exposed it to open flames and extremely hot metals. QUINTOPLEX™ passed all the tests performed, resulting in its introduction into the hot rolling mill lubrication system. Running their system with the fire resistant grease, the mill realized 90 percent less fire hazards. Furthermore, the continuous water supply the mill was using to control the fire hazards could be removed, which led to a reduction in corrosion on the roller bearings. Keeping operations running smoothly Mill operators should work with a grease supplier who has the expertise to offer technical advice to help evaluate situations, and who can offer realistic solutions to solve problems ranging from production efficiency to worker safety. At a minimum, grease manufacturers need to provide sustainable product solutions that require

less volume and reduce energy during use, in order to bring real value to the customer

#### Benefits of Fire-Resistant Greases in Hot Mills

In steel plants, the common approach to putting out the fire is done with variations of cooling the burning material. With a fire resistant grease, the approach is removal of the fuel. This is because a typical mineral oil based lubricating grease is a fuel source. A fire resistant grease is not a fuel source because the base oil and additive chemistry are selected based on their ability to resist combustion. Ultimately, the combustible hydrocarbons are removed from the formulation. This results in materials with lower volatility, which minimizes the generation of combustible vapors that are able to ignite and propagate the flame after ignition. Furthermore, some base oils, such as esters require substantially more energy to ignite and sustain fires.

#### Example #2 – Continuous Casting – Ladle Turret Bearing

Challenges: A major steel producer in China with an integrated steel plant for flat steel production faced 3-4 fire hazards annually at the ladle turret area The ladle turret main bearing is been centralized lubricated and used a common Mineral Oil based EP2 Multi Purpose Grease. Although the area of the ladle turret is usually not seen as a high risk area as usually there are not a lot of media installations like Oxygen, Nitrogen, Natural Gas or Argon Pipes and the amount of electrical cables and other installations is usually low. Due to the high amount of grease applied to the main bearing of this ladle turret the grease piles up at the floor. Both inside and outside the ladle turret. Combined with all kinds of dirt and dust from the casting process it creates a significant fire hazard. While starting casting liquid steel rinse from the Ladle though a shroud into the tundish. In this case it usually happens that hot steel particles and sparks flying on the casting platform and can reach the hazardous waste grease on the casting floor. In this case the grease will catch fire and set the whole grease that is in that area under fire and creates a lot of smoke. It will burn as long as mineral oil is present. Fires are a potential risk and needs to be distinguished asap. This required trained people and necessary equipment. To be on the safe side the production should be stopped controlled to allow operators and staff working in that area to get out of the risk area to a safe assembly point outside and away from any building.



## 5. Conclusions

Safety hazards are inherent within the steel industry. In particular, fire hazards present a sizeable risk for steel workers as the nature of steel production requires significant heat to produce the desired finished products. Minimizing and controlling the hazards is very challenging and this paper explains how fire resistant fluids and greases can reduce some of those risks.

According to Schrama [2], about 50% of all steel tonnage is processed at the hot strip mill. Within the hot strip mill, the furnace exceeds 1,260°C. As the furnace moves hot bars of steel to the rolling table, the process creates excess slag that falls on to the ground. Simultaneously, the bearings on the rolling table expel excess quantities of grease on to the floor.

Because fluids and greases are typically mineral oil based, this becomes the fuel for a fire event. The authors propose that using a synthetic ester oil based fluid and grease would reduce the likelihood of lubricants catching on fire. This ester technology is used in fire resistant hydraulic fluids for many years. This is further supported in that the ester technology requires a higher energy level to cause and sustain combustion. Additionally, the physical characteristics of this type of synthetic ester oil has a tendency to char and reduce the oxygen needed for fire.

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## Demir ve Çelik Sanayi için Kalsiyum Sülfonat Kompleks Greslerin Performans Ölçütleri

Calcium Sulfonate Complex Greases in Iron and Steel Industry

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## Abstract

The extreme heat conditions in iron and steel factories challenge lubrication at desired levels. Despite the presence of automatic lubrication equipment, they require constant monitorization, also the downtimes are very costly and malfunctions cause problems in both quality and work safety. Cooling water failures adversely affect the grease performance. For all these conditions, calcium sulfonate grease complexes have come to the forefront with their superior performance properties and took an important place in research.

## Özet

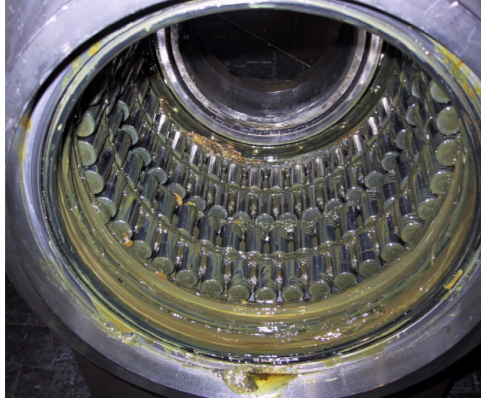
Demir ve çelik fabrikalarında ekstrem ısı şartları istenilen seviyede yağlama yapmayı güçleştirmektedir. Otomatik yağlama ekipmanlarının sürekli takip edilmesi gerekmekte ve duruşlar çok masraflı, arızalar ise hem kalite hem de iş güvenliği konusunda sıkıntılara sebep olmaktadır. Ayrıca soğutma suyu arızaları gres performansını olumsuz yönde etkilemektedir. Tüm bu şartların tamamında kalsiyum sülfonat kompleks gresler gösterdikleri üstün performans özellikleri ile ön plana çıkmış ve araştırma konusu haline gelmiştir.

## 1. Giriş

Demir ve Çelik fabrikaları, ekipmanlarının büyüklüğü ve uzun üretim hatları nedeniyle çok yüksek yatırım maliyetleri ile kurulan fabrikalardır. Bu yatırımların karşılığı mümkün olan en kısa sürede alınmalıdır.. Bunun başarılması için bazı önemli kriterler; düşük işletme-bakım maliyetleri ve planlanmayan arıza süresi olmadan güvenilir çalışma sağlanması gerekir. Planlanmamış her olay önemli gelir kayıplarına neden olabilir. Buna ek olarak, çelik üretim sürecinin her bileşeninin, kalite seviyesini korurken ve daha sıkı çevre standartlarını karşılarlarken, yıllık olarak daha yüksek miktarlarda çelik üretmesi gerekmektedir.

Çelik endüstrisinin hedeflerine ulaşmasına yardımcı olmak için, yağlama çok büyük önem kazanmaktadır. SKF verilerine göre rulman hasarlarının %36 gibi bir kısmının eksik, yanlış ve hatalı yağlamadan oluştuğu göz önüne alınırsa, endüstrinin aşırı gereksinimlerine göre tasarlanmış çok çeşitli yağlama çözümleri gerekmektedir. Demir ve Çelik üreticisinin yıl içinde koyduğu üretim hedeflerine ulaşması için yağlama; yüksek sıcaklıklara, yüksek yüklerle ve sürekli titreşime maruz kalan bileşenler ve su, buhar, asit

vb. ile kirlenmeye karşı doğru şekilde tasarlanmalıdır. Uzun ekipman ömrü veya artan çalışma süresi ile azaltılmış yağ tüketimi için, mutlaka karşılıklı olarak mühendislik çalışmaları yapılmalıdır.



Şekil 1: Çalışma sonrası sökülmiş rulman görseli

Demir ve Çelik endüstrisindeki çoğu uygulama yağlayıcıları sınırlarına kadar zorlansa da işlemin her adımında yağlayıcıdan farklı bir yağlayıcı özelliği beklenir.

Kalsiyum Sülfonat Kompleks gresler, çelik üretim sürecinin hangi aşaması olursa olsun, bu zorlukların neredeyse her birine cevap veren bir kimyasal yapıya sahiptir.

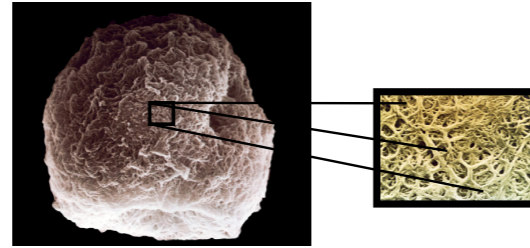
Kalsiyum sülfonat kompleks yapılı gresler, ısı, su, yüksek veya şok yüklerin olduğu gres uygulamaları için mükemmel bir teknolojiye sahiptir. Üstün derecede pas ve aşınma koruması, yüksek yük taşıma kapasitesi, yüksek damlama noktası ve su varlığında bile çok iyi derecede mekanik stabilite göstermektedir. Diğer gres tiplerinin aksine, bu performans özellikleri, ilave hiçbir hammadde kullanılmadan elde edilmektedir.

Kalsiyum sülfonat kompleks bazlı greslerin başta demir-çelik fabrikaları, denizcilik ve kâğıt fabrikaları, off-road, inşaat ve madencilik ekipmanları ve hatta gıda işleme endüstrilerinde başarı ile kullanılmaktadır.

## 2. Deneysel Çalışmalar

Aşırı bazlı kalsiyum sülfonatlar, sülfonat matrisinde dağılmış büyük miktarda amorf kalsiyum karbonat içerir. Kaynama noktası yüksek alkoller ve asitler gibi uygun kimyasalların mevcudiyetinde ve uygun sıcaklık aralığında jelleşme prosesinin ardından, amorf kalsiyum karbonatın kristalli kalsite dönüşümü gerçekleşir. Dağılmış kalsit

fazının partikül boyutu nano aralığında (4-5 nm) olduğundan, aşırı yüksek yüzey alanı ve gres benzeri bir tutarlılık sağlamak için yeterince güçlü olan stabil bir jel yapısını oluşturmaktadır.

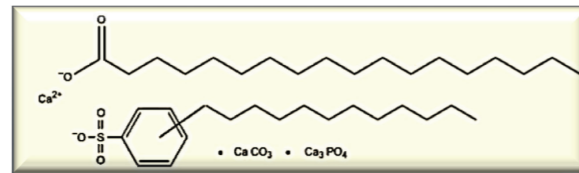


Şekil 2 : Gres sabun yapısı

Burada dikkat edilmesi gereken konu uygun reaktörde ve basınç ortalama 50 psi şeklinde olmalıdır. Bu noktada gres hala reaksiyondan dolayı su içerir ve yağlama gresi üretmek için dehidre edilmesi gerekir. Bu, genellikle kalsiyum sülfonat jeli veya kalsiyum sülfonat gresi olarak adlandırılır.

Bu işlemi yaparken yüksek oranda bazlanmış kalsiyum sülfonatlar, tipik olarak kapalı ve basınçlı (50 psi) bir reaktörde, uygun asitlerin, stokiometrik hesaplamalarla kalsiyum oksit ve karbondioksit varlığında reaksiyona sokulmasıyla hazırlanması gerekmektedir.

Kalsiyum sülfonat greslerinin kimyasındaki dönüşüm sonrası kalsiyum oksit veya (genellikle) hidroksit ilavesi ve ardından borik asit/asetik asit ve 12-hidroksistearik asit ile reaksiyona sokulmasıyla komplekslik meydana gelmektedir.



Şekil 3: Kalsiyum sülfonat kompleks gresin kimyasal formülü

Yaşanmış saha tecrübeleri ve sektörde konusunda uzman kişiler ile yapılan görüşmeler sonrasında aşağıdaki teknik şartname oluşturulmuştur.

Tablo 1: Ürün için Hedef Şartname

Test	Standart	İstenen Değerler
Baz Yağ	--	Mineral
Baz yağ Vizkozitesi-(cSt)	ASTM D445	460 +/- 46
İşlenmiş Penetrasyon, 60 stroke @ 25°C/77°F – (1/10 mm)	ASTM D217	285 - 320
4 Bilye EP, Kaynama Yüğü-(Kgf)	ASTM D2596	Min 500
4 Bilye Aşınma Testi, Aşınma Çapı-(mm)	ASTM D 2266	Max 0.60
İşlenmiş Dayanım (100 k)25C, 60 st.değişim 1/10 mm- (%)	ASTM D 217	Max +/-10
Yuvarlanma dayanımı, RT, 1 saat, Penetrasyon değişimi-(%)	ASTM D 1831	Max +/- 10
Yuvarlanma dayanımı, RT, 3 saat, Penetrasyon değişimi- (%)	ASTM D 1831	Max +/- 10
Su ile yıkanma, 79C/175F-(%)	ASTM D 1264	Max 5.0
Su Spreyi, 100°F, 5 min-(%)	ASTM D 4049	Max 35.0
Pas Testi, 48 saat @ 52°C/126°	ASTM D 1743	Geçer

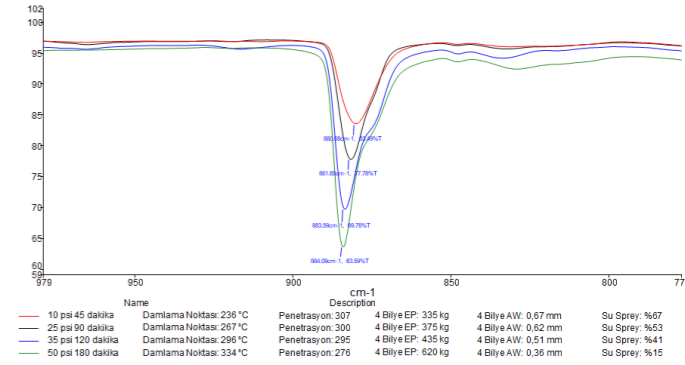
Üretim teknolojisinin geliştirilmesi için kalsiyum sülfonat gresler, fazla kalsiyum oksit veya hidroksitin tamamının amorf kalsiyum karbonata yükseltilmemesi gerekmektedir. Bu aşamada zaman ve basınç çok önemlidir. Yaptığımız laboratuvar çalışmaları neticesinde FTIR ve bazı performansların zaman ve basınca göre değişimi görülmektedir.

Üretim parametreleri:

- 10 psi basınç, 45 dakika
- 25 psi basınç, 90 dakika
- 35 psi basınç, 120 dakika
- 50 psi basınç, 180 dakika

Tablo 2: Performans Analiz Sonuçları

	Penetrasyon ASTM D217 (mm/10)	Kaynaklanma ASTM D2596 (Kgf)	Aşınma Çapı ASTM D2266 (mm)	Su Sprey ASTM D4049 (%)
1	307	335	0,67	67
2	300	375	0,62	53
3	295	435	0,51	41
4	276	620	0,36	15



Şekil 4: FTIR Analiz sonuçları

## 2.1. Laboratuvar ve Analizler

Ar-Ge çalışmaları sonucunda elde edilen ürünler ilgili ASTM standardı kapsamında test edilmiştir. Üründe penetrasyon, su dayanımı, yuvarlanma dayanımı, pas testi, yük dayanımı ve aşınma çapı analizleri yapılmıştır.



Şekil 5: Penetrasyon Testi (ASTM D217)



### 3. Sonuçlar ve Tartışma

Yapılan çalışmalar sonucunda elde edilen nihai ürün analizleri aşağıdaki gibidir:

Tablo 3: Nihai ürün analiz sonuçları

Test	Standart	Nihai Ürün
Baz Yağ	--	<b>Mineral</b>
Baz yağ Viskozitesi-(cSt)	ASTM D445	<b>460 +/- 46</b>
İşlenmiş Penetrasyon, 60 stroke @ 25°C/77°F – (1/10 mm)	ASTM D217	<b>285 - 320</b>
4 Bilya EP, Kaynama Yükü-(Kgf)	ASTM D2596	<b>620</b>
4 Bilya Aşınma Testi, Aşınma Çapı-(mm)	ASTM D 2266	<b>0,40</b>
İşlenmiş Dayanım (100 k)25C, 60 st.değişim 1/10 mm- (%)	ASTM D 217	<b>+/-6</b>
Yuvarlanma dayanımı, RT, 1 saat, Penetrasyon değişimi-(%)	ASTM D 1831	<b>+/- 5</b>
Yuvarlanma dayanımı, RT, 3 saat, Penetrasyon değişimi- (%)	ASTM D 1831	<b>- 1</b>
Su ile yıkanma, 79C/175F-(%)	ASTM D 1264	<b>1,1</b>
Su Spreyi, 100°F, 5 min-(%)	ASTM D 4049	<b>15</b>
Pas Testi, 48 saat @ 52°C/126°	ASTM D 1743	<b>Geçer</b>



Şekil 6: Dört Bilya Test Cihazı



Şekil 7: Su Sprey Testi

Tablo 4: Gres Kıyaslama Tablosu

	AVANTAJ	DEZAVANTAJ
Lityum Kompleks	-Çok amaçlı uygulamalarda kullanılabilir. -Pompalanabilirlik özelliği çok iyidir.	-Performans için ek katkıya ihtiyaç duyar. -Yüksek hammadde maliyeti gerekir. -Gıda sınıfı için uygun değildir.
Alüminyum Kompleks	-Çok amaçlı uygulamalarda kullanılabilir. -Suya dayanımı iyidir.	-Oksidasyona karşı direnci kötüdür.
Poliüre	-Kül/pislik bırakmaz. -Oksidasyon direnci yüksektir. Gürültü önleyici özelliğe sahiptir.	-Mekanik stabilitesi düşüktür. -Performans için ek katkıya ihtiyaç duyar. -Üretimde hammadde kaynaklı sorunlar yaşanır.
Kalsiyum Sülfonat Kompleks	-Mekanik stabilitesi yüksektir. -Pas ve korozyon koruması çok yüksektir. -Kendi yapısından kaynaklı yük ve aşınma direnci yüksektir.	-Düşük sıcaklık kullanımlarına uygun değildir. -Yüksek hız uygulamalarına uygun değildir.(Özel üretim gerektirir.)

Tablo 3 ve Tablo 4 incelendiğinde demir çelik sektöründe mevcut olan ağır çalışma şartlarında kalsiyum sülfonat kompleks gresler daha avantajlı durumdadır.

### 4. Sonuç

Kalsiyum sülfonat kompleks bazlı greslerin, ağır hizmet uygulamalarında genellikle problem çözücü oldukları görülmektedir. Çok iyi mekanik stabilite, pas ve korozyon koruması, kendi doğasından gelen basınç dayanımı ve aşınma direnci özellikleri ile diğer gres çeşitlerine oranla üstün performans özellikleri analiz sonuçları ile paylaşılmıştır.

### Teşekkür

Bilimsel ve laboratuvar çalışmalarında bizden desteğini esirgemeyen Osmaniye Korkut Ata Üniversitesi öğretim üyelerinden Doç.Dr. Murat Farsak ve Dr. Öğretim Üyesi Özkan Aydın'a teşekkürlerimizi sunarız.

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## Dişli Kutularında Sentetik Yağ Kullanımının Etkileri

Effects of Synthetic Oil Use in Gearboxes

Oğuzhan Baki, Ozan Yapıcı

YAZICI DEMİR ÇELİK • Türkiye

### Abstract

Although oil and lubrication technologies are becoming more and more important nowadays, it is aimed to use the equipment, oil and materials used for these issues, to save energy, reduce maintenance and downtime, extend maintenance periods, and reduce industrial hazardous waste.

### Özet

Yağ ve yağlama teknolojileri günümüzde gittikçe önem kazanmakla birlikte bu konularda yapılan çalışmalar ile kullanılan ekipman, yağ ve malzemelerin daha uzun süreli kullanımı, enerji tasarrufu, bakım ve arıza sürelerinin azaltılması, bakım periyotlarının uzatılması, endüstriyel tehlikeli atıkların azaltılması hedeflenmektedir.

### 1. Giriş

Ark Ocaklı çelik üretim tesislerinde ,ark ocağında elde edilen sıvı çelik alaşımlandırılmak için pota ocağına hazır olan çelik daha sonra da sürekli döküm makinesine gitmektedir. Bu işlemler çelikhanenin kapasitesine göre farklı tonajlardaki vinçler ile sağlanır. Yazıcı Demir-Çelik te bir dökümde alınan 90 ton sıvı çelik 150 ton kapasiteli döküm vinci ile sürekli döküm makinasına taşınmaktadır. Bu çalışmada 150 ton kapasiteli döküm vinci dişli kutularında aynı markaya ait ISO VG 460 sınıfı mineral ve sentetik yağ kullanımının performans ölçümleri yapılarak motorların çektiği akım değerleri kıyaslanmıştır. Aynı çalışma hurda sahası 25 ton vinçlerde, 85 ton şarj vincinde, sürekli döküm makinası osilasyon dişli kutusunda ve 15 tonluk vinçte de yapılmıştır.

### 2. Deneysel Çalışmalar

Yaptığımız çalışmada, 150 ton döküm vinci ana kanca mayna-vira dişli kutusuna sırasıyla mineral ve sentetik yağ konularak elektrik motorlarının çektiği akımların karşılaştırılması yapıldı. Buna göre, Tablo 1'den de

görülebileceği üzere mineral yağ ile sentetik yağ dolu iken çekilen elektrik akımı ortalamaları arasında yaklaşık % 6'lık fark vardır.

**Tablo 1.** 150 ton vinç motor akım değerleri

MİNERAL YAĞ					
BOŞ POTA		DOLU POTA		BOŞ KANCA	
MAYNA	VİRA	MAYNA	VİRA	MAYNA	VİRA
98	115	X	301	16	32
92	112	X	304	17	33
97	113	X	305	15	34
95	115	X	303	16	33
97	115	X	301	18	35
ORT:	95.8	114	302.8	16.4	33.4

SENTETİK YAĞ					
BOŞ POTA		DOLU POTA		BOŞ KANCA	
MAYNA	VİRA	MAYNA	VİRA	MAYNA	VİRA
95	118	X	322	15	33
94	115	X	328	14	34
93	115	X	325	14	32
95	124	X	320	15	32
98	125	X	314	15	33
ORT:	95	119.4	321.8	14.6	32.8

Enerji ve maliyet hesaplamalarımız için % 4 olarak kabul edilerek vincin ana kancası, iki adet yardımcı kancası, araba ve köprü yürütme sistemlerindeki enerji tasarrufu ayrı ayrı hesaplanmıştır. Ayrıca sentetik yağ kullanımı ile birlikte malzeme ömürlerinin uzaması ve değişim periyotlarının azalması incelenmiştir.

### 2.1. 150 ton vinç ana kanca

Ana kancada 2 adet 125 Kw lik elektrik motoru mevcuttur. Bu motorlardan herbiri 312, toplamda 624 amper çeker iken sentetik yağ kullanımı sonucu motorların her birinin çektiği elektrik akımının

624 x 0,04 = 24,96 Amper daha az olduğu görülmüştür.

Çekilen 1 amperlik akımın 0.5 kw/h'e karşılık geldiği bilinmektedir.

Buna göre;

24,96 A=12,48 kw/saat lik enerji kazancı

Söz konusu vinc günde yükte yaklaşık 4 saat (m/v) çalışmaktadır ve bununda 1 yıldaki karşılığını;

4 x 365=1460 saat/yıl ;

12,48 kw/saat x 1460 saat/yıl=18220 kw/yıl

vincin sadece ana kanca mayna-vira hareketinden elde edilen elektrik kazancıdır.

### 2.2. 150/35 ton yardımcı kanca 1

Kanca da 1 adet 150 Kw lik elektrik motoru mevcuttur. Bu elektrik motoru ortalama 276 amper çeker iken, sentetik yağ ile yapılan çalışma sonucunda motorun %4 daha az akım çektiği görülmüştür.

Sentetik yağ kullanımı ile çekilen akım değeri ,

276 x 0,04 = 11,04 amper daha azdır.

Kanca günde 4 saat çalışmaktadır

11,04 amper =5,52 kw/saat ise

5,52 x 4 = 22 kw/gün

Bu da 1 yıl için

22 x 365 = 8059 kw/yıl

### 2.3. 150/35 ton yardımcı kanca 2

Kanca da 1 adet 150 Kw lik elektrik motoru mevcuttur. Bu elektrik motoru ortalama 276 amper çeker iken, sentetik yağ ile yapılan çalışma sonucunda motorun %4 daha az akım çektiği görülmüştür.

Sentetik yağ kullanımı ile çekilen akım değeri ,

276 x 0,04 = 11.04 amper daha azdır.

Kanca günde 0,5 saat çalışmaktadır

11,04 amper =5,52 kw/saat ise

5,52 x 0,5 = 2,76 kw/gün

Bu da 1 yıl için

2,76 x 365 = 1007 kw/yıl

### 2.4. 150 ton vinç köprü yürütme sistemi

Köprü yürütme sisteminde 2 adet 30 'ar kw lik elektrik motoru mevcuttur. Bu elektrik motorları ortalama 66 amper çeker iken, sentetik yağ ile yapılan çalışma sonucunda motorun %4 daha az akım çektiği görülmüştür.

Sentetik yağ kullanımı ile çekilen akım değeri ,

66 x 2 x 0,04 = 5.28 amper daha azdır.

Vinç köprüsü günde 5,44 saat çalışmaktadır

5,28 amper = 2,64 kw/saat ise

2,64 x 5,44 = 14,36 kw/gün

Bu da 1 yıl için

14,36 x 365 = 5242 kw/yıl

### 2.5. 150 ton vinç araba yürütme sistemi

Araba yürütme sisteminde 1 adet 15 kw lik elektrik motoru mevcuttur. Bu elektrik motoru ortalama 35 amper çeker iken, sentetik yağ ile yapılan çalışma sonucunda motorun %4 daha az akım çektiği görülmüştür.

Sentetik yağ kullanımı ile çekilen akım değeri ,

35 x 0,04 = 1,4 amper daha azdır.

Vinç arabası günde 5,44 saat çalışmaktadır

1,4 amper = 0,7 kw/saat ise

0,7 x 5,44 = 3,8 kw/gün

Bu da 1 yıl için

3,8 x 365 = 1389 kw/yıl



## 2.6. Sentetik yağ kullanımının malzeme ömrüne etkisi

Sentetik yağ kullanımı ile birlikte vinç dişli kutularında dişli ve rulman ömürlerinin ortalama 5 katına çıktığı görülmüştür. Şöyle ki her yıl aşınmalardan ve pittingslenmelerden dolayı düzenli olarak değiştiğimiz ikiz dişli kutusu giriş pinyon ve tambur çarklarının ömürleri artarak 5 katına çıkmış, yine aynı şekilde 2002 yılında 43.000 € ya Konnecranes firmasına yaptırılarak değiştirdiğimiz vinç ana dişli kutusunun da değişim tarihinden itibaren 5 yıllık zamanda herhangi bir aşınma ve pittingslenme görülmemiştir.

Her yıl düzenli olarak değiştirdiğimiz,

İkiz Redüktör Giriş Pinyonu : 2000 €

İkiz Redüktör Tambur Çarkları : 9000 €

Ana Redüktör Çıkış Mili : 2800 €

Pinyon ve Dişli Çark Rulmanları : 2000 €

150 ton döküm vincinde her yıl düzenli olarak değişen ve toplam malzeme maliyetleri 15800 € olan bu ekipmanların, sentetik yağın kullanımı ile değişim ömürleri 5'e katlanmış olup  $4 \times 15800 \text{ €} = 63200 \text{ €}$  luk bir kazanç sağlanmıştır.

Söz konusu dişli,pinyon,tambur çarkı ve millerin değişimi için kaç elemanın ne kadar saat çalışacağını da inceleyecek olursak,

İkiz dişli kutusu giriş pinyonu : 5 eleman x 6 saat = 30 eleman.saat

İkiz dişli kutusu tambur çarkları : 5 eleman x 6 saat = 30 eleman.saat

Ana dişli kutusu çıkış mili : 5 eleman x 6 saat = 30 eleman.saat

Bu da sadece 1 yılda 90 eleman.saat yapmaktadır.

## 3. Sonuç

Yapılan çalışmadaki sonuçlara göre,sentetik yağ kullanımı ile birlikte motorlardaki çekilen akım değerlerinin ortalama % 5 azaldığı görülmektedir ve 150 ton döküm vincinde 1 yılda 33917 kw enerji tasarrufu sağlanmıştır. Bunun yanı sıra malzeme ömürlerinin,değişim periyotlarının 5 katına çıktığı görülmektedir.Yağ değişim periyodu da uzadığı için bertaraf tesisine gönderilen yağ miktarı da oldukça azalmış ve bu da bu çalışmanın çevresel boyutlardaki kazancını göstermektedir.

## Hidrolik Sistemlerde Filtreleme

Filtering in Hydraulic Systems

Burak Samur

HİDROHAN HİDROLİK • Türkiye

## ÖZET

Hidrolik sistemlerde meydana gelen arızaların %75'in üzerinde bir oranda, yağ kirliliğinden kaynaklandığı, uzun süren istatistikler sonucu belirlenmiş bir gerçektir. Arızalar sonucu duruşlar buna bağlı iş kaybı, donanım değişimi ve yağ değişimi masrafları gibi oluşan giderler çok yüksek boyutlara ulaşabilmektedir. Hidrolikte kullanılan filtrelerin asıl görevi yağın temiz tutulması değil, işletme masraflarının düşürülerek en aza indirilmesidir. Bu bildiri filtreleme ile ilgili basit temel bilgilerin toplandığı bir çalışmadır. Bu bağlamda endüstrinin her dalında hidrolik sistemlerle çalışan mühendislere veya bakım personeline doğru filtre seçimi ve kullanımı, uygun uyarı sistemleri kullanımı, periyodik yağ partikül seviyesi ve su oranı ölçümü yapılması sayesinde üretim artışı ve buna paralel olarak maliyetlerin azaltılmasında yardımcı olması amaçlanmıştır.

### 1.Giriş

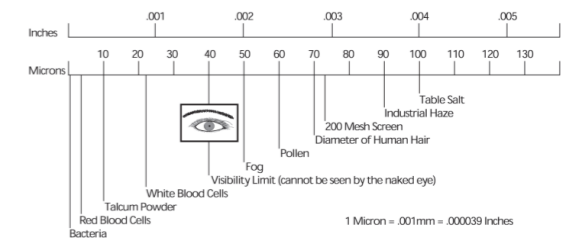
Bu çalışmada; Akışkanın tarifi, kirlilik derecesi, filtre malzemeleri, filtreleme kalitesi ve bunu belirleyen test ve standartlar, filtre elemanlarının ömrü, filtre tipleri, filtre boyutlama ve seçim kriterleri, filtreleme şekilleri gibi konular ele alınacaktır.

### 2.Kirlilik, Kirlilik Tip ve Sebepleri

#### 2.1 Kirlilik Tanımı

Yağlarda kirlilik konusu genel olarak yanlış anlaşılmaktadır. Rengi koyulaşmış yağlara kirli denilebildiği gibi, çoğu kez el ile muayene esnasında bir miktar yağda parmakla hissedilebilen parçacıklar kirlilik ölçütü olarak alınmaktadır. Oysa her iki yaklaşım da bir noktaya kadar gerçeklik payı taşımakla beraber kesinlikle yeterli olmayıp, aksine yanıltıcı bile olabilir. Triboloji biliminin en zarar verici kirlilik olarak değerlendirdiği partiküllerin büyüklüğünün, yağ filminin kalınlığı kadar büyüklükteki partiküller olduğu düşünülürse, ki endüstri genelinde bu değer 10 mikron civarındadır, o zaman bakteri/virus gibi

gözle görünmeyen bir dünya ile karşı karşıya olduğumuz anlaşılır. Yağda kirlilik denilince  $0.5 \mu\text{m}$  ile  $100 \mu\text{m}$  arasında partiküller kastedilmektedir. Ancak, genel uygulamada kullanılan çerçeve 2 ila  $50 \mu\text{m}$  arasındaki partiküllerdir. Karşılaştırma amacıyla Şekil 1 den faydalanılabilir.



Şekil 1. Boyutları bilinen bazı partiküller

### 2.2 Kirlilik Tip ve Kaynakları

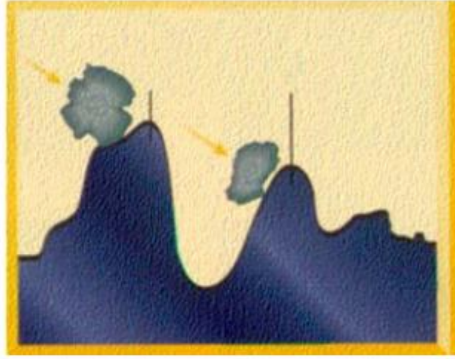
#### 2.2.1. Parçacık ( Partikül ) Kirliliği, Kaynakları ve Önlemler

Baz yağın rafineriden son kullanıcıya kadar imal edilişi, tankerler ile asıl imalatçıya taşınması , baz yağa katkı maddesi ilave edilmesi, tekrar varillere doldurulup kullanıcıya gönderilmesi gibi pek çok aşamadan geçen hidrolik yağın temiz olması beklenemez. İlk inceleyeceğimiz kirlilik tipi de bu aşamalarda oluşması çok kolay olan partikül kirliliğidir.

Partiküller yağa;

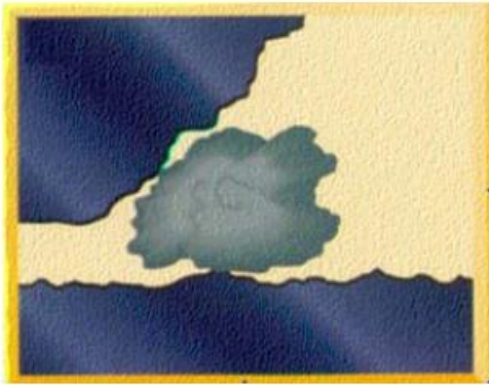
- Yeni hidrolik yağ ile
- Hidrolik sistem imalat-montaj aşamasında
- Çalışma esnasında dışarıdan
- Çalışma esnasında içeriden

Karışabilmektedir. Bu kirliliği birinci grupta  $5\mu\text{m}$  altı partiküller ikinci grupta ise  $5\mu\text{m}$  üstü partiküller olarak iki grupta değerlendirirsek;



Şekil 2. 5µm Altı Parçacıklar

Şekil 2. de görüldüğü üzere hidrolik yağ ile birlikte serbestçe dolaşan 5µm altı parçacıklar yüzeyleri zamanla aşındırır.



Şekil 3. 5µm Üstü parçacıklar

Şekil 3. de görüldüğü gibi 5µm üstü parçacıklar ise valflerde ya da pompalarda sürgü ile gövde arasına sıkışarak ani hasarlar verebilirler.

Partikül kirliliğinin önlenmesi için;

- Depo üstüne kapak yerine havalandırma filtresi takılması
- İmalat veya montaj sonrasında sistemin yıkanması ( Flushing )
- Hidrolik silindirlerin sızdırmazlık elemanlarının zamanında değişimi
- Hortum , blok , yağ giriş vb. noktaların montaj ve bakım sırasında plastik tapalar ile kapanması
- Sisteme verilmeden önce yağın filtre edilmesi

gibi önlemler alınabilir.

### 2.2.2 Su Kirliliği, Kaynakları ve Önlemler

Hidrolik akışkanın partiküllerden arındırılmış olması tam anlamıyla temizlendiği anlamı taşımaz. Yağ içinde bulunan su da partikül kirliliği gibi kirliliğe sebep olmakta ve sistemden uzaklaştırılması elzemdir. Su yağ içinde serbest ya da bağlı olarak bulunabilmektedir. Yağ içinde müsaade edilen su miktarı %0.03 dür.

Su yağa;

- Bozuk sızdırmazlık elemanları sayesinde
- Depo sızıntısı ile
- Yoğuşma ile
- Sulu soğutucu kaçakları ile Karışabilmektedir.

Hidrolik yağa karışan suyu sistemden atmak için çeşitli yöntemler kullanılabilir. Özgül ağırlık farkından dolayı depo altında biriken su boşaltma vanaları ile bertaraf edilebilir. Absorbsion metodu ile düşük debili sistemlerde kimyasallar kullanılarak serbest haldeki sular bağlanabilir. Santrifüj metodu ise yine özgül ağırlık farkının kullanıldığı ve merkezkaç kuvveti ile serbest suyun sistemden atıldığı yöntemdir verimleri ise düşüktür. Bütün bunların dışında vakum metodu ile normal şartlarda 100°C de kaynayan ve buharlaşan su vakum altında daha düşük sıcaklıklarda kaynamaya başlar ve buharlaşır bu yöntem sayesinde serbest ya da bağlı olan su yüksek bir verimle sistemden atılabilir.

Su ile kirlenmiş yağ hidrolik sistemlerde; metal yüzeylerde korozyon, viskozite değişimi, elektrik iletkenliğinin artışı, aşınma, yağ katkılarının özelliklerinin bozulması gibi olumsuz sonuçlar doğurur.

Su kirliliğinin önlenmesi için;

- Hidrolik silindirlerin sızdırmazlık elemanlarının zamanında değişimi
- Standart depo kapağı yerine silikajelli depo kapakları kullanılması
- Sulu eşanjörlerin bakımlarının yapılması
- Su tutucu özelliği olan filtre elemanlarının kullanılması
- Hidrolik ünite tankının atmosfer ile izole olmasının sağlanması

Gibi önlemler alınabilir.

### 2.2.3. Hava Kirliliği, Kaynakları ve Önlenmesi

Hidrolik akışkanın içerisinde yine su gibi serbest ya da bağlı olarak hava bulunabilmektedir. Akışkan içerisindeki bu hava özellikle serbest halde bulunuyorsa basıncında etkisi ile lokal olarak aşırı ısınmalara yol açar ve yağ katkıları yanabilmektedir hatta yağın kimyasal yapısını değiştirebilmektedir. Ayrıca yağ içerisindeki hava yağın sıkıştırılmazlık özelliğini de bozmakta ve sistem verimini düşürmektedir. Bütün bunların yanında

yağın köpüklenmesi, metal parçaların oksitlenmesi, oksitlenmeye bağlı olarak aşınma hızının artması gibi olumsuz sonuçlar doğurur.

Hava sisteme;

- Sistemde mevcut sızıntılardan
- Depo havalığından
- Pompanın hava emmesi ile

Karışabilmektedir.

Hava kirliliğinin önlenmesi için;

- Sistemlere hava alma vanaları öngörülmesi
- Pompa emişleri doğru tasarlanmalı
- Dönüş hatlarına merkezkaç difüzörler koyulmalı
- Depo tasarımı köpüklenmeyi engelleyici olmalı

### 3. Akışkanın Temizlik Standartları

Kirliliği tanımlamak için değişik standartlar kullanılmaktadır. ISO4406, Amerikan askeri standardı MILSTD1246A, NAS1638, SAE749 ve ACFTD gibi pek çok standart tanımlanmıştır. Bunlar arasında en çok kullanılan ISO ve NAS' dır.

#### 3.1. ISO4406 Standardı

ISO4406 standardı tanımında yağ numunesinin 1 ml' sinde bulunan 4µm ve daha büyük parçaların sayısını tanımlayan bir sayı, 6µm ve daha büyük parçaların sayısını tanımlayan bir sayı ve 14µm ve daha büyük parçaların sayısını tanımlayan bir sayıdan oluşan bir koddur.

ISO 4406:1999		
ISO Skalası	1ml'deki Partikül Sayısı Aralığı	
23	40,000	80,000
22	20,000	40,000
21	10,000	20,000
20	5,000	10,000
19	2,500	5,000
18	1,300	2,500
17	640	1,300
16	320	640
15	160	320
14	80	160
13	40	80
12	20	40
11	10	20
10	5	10
9	2.5	5
8	1.3	2.5
7	.64	1.3

Tablo 1. ISO4406'ya göre parçacık kirlilik kodları

#### 3.2. NAS1638 Standardı

NAS1638 Hidrolik ve yağlama sistemleri için kirlilik seviyesinin sınıflandırılması olarak tanımlanır.

Orijinalinde Aerospace uygulamalarında kullanılan sistemlerin değil de, sadece sıvı komponentlerinin (parçalar, hatlar ve bağlantı elemanları gibi) kirlilik seviyesinin sınıflandırılması için geliştirilmiştir. NAS1638 standardında belirlenen 2 partikül boyutu arasında parçacıkların sayısı dikkate alınmıştır.

NAS SINIFI	5-15µm	15-25µm	25-50µm	50-100µm	>100µm
00	125	22	4	1	0
0	250	44	8	2	0
1	500	89	16	3	1
2	1000	178	32	6	1
3	2000	356	63	11	2
4	4000	712	126	22	4
5	8000	1425	253	45	8
6	16000	2850	506	90	16
7	32000	5700	1012	180	32
8	64000	11400	2025	360	64
9	128000	22800	4050	720	128
10	256000	45600	8100	1440	256
11	512000	91000	16200	2880	512
12	1024000	182400	32400	5760	1024

Tablo 2. NAS1638'e göre parçacık kirlilik kodları

### 3.3. Hidrolik Ekipmanların Temizlik Gereksinimleri

Genelde tüm hidrolik ekipman üreticileri ekipman ömrünün ve performansının optimal olabileceği akışkanın temizlik standartlarını kataloglarında belirtmektedirler. Bu standartlarda yağ kullanılmaması ekipman ömrünü azaltmakta ve istenilen verimin alınmaması sonucunu doğurabilmektedir. En iyisi ve en doğrusu temizlik standardının sistemde kullanılan ekipmanın üreticisi firmalarla birlikte belirlenmesidir. Ancak bu şekilde doğru bir filtreleme düzeni kurulabilmektedir Tablo 3. de bazı hidrolik ekipmanlar için hedef kirlilik seviyeleri belirtilmiştir.

HİDROLİK EKİPMAN	ISO KODU	NAS KODU
SERVO VALFLER	16/14/11	5
ORANSAL VALFLER	17/15/12	6
PALETLİ VE PİSTONLU POMPALAR/MOTORLAR	18/16/13	7
YÖN VE BASINÇ KONTROL VALFLERİ	18/16/13	7
DİŞLİ POMPA/MOTORLAR	19/17/14	8
AKIŞ KONTROL VALFLERİ/SİLİNDİRLER	20/18/15	9
YENİ KULLANILMAMIŞ YAĞLAR	20/18/15	9

Tablo 3. Tipik hedef kirlilik seviyeleri



### 3.4. Yağ Kirliliği Neden Ölçülmelidir?

Taşınabilir ölçüm cihazlarının yanında hat tipi olarak da kullanılabilen ölçüm cihazları sayesinde her an kirlilik seviyesi takip edilebilir ve erken müdahale şansı artabilir. Bu ölçümlerin sistemli bir şekilde kayıt ve analiz edilmesi ile

- Makine ömrünü uzatmak, arızalarını azaltmak
- Filtre sisteminin verimli çalışıp çalışmadığını kontrol etmek
- Filtre sisteminde arıza olup olmadığını belirlemek
- Arızaları gelişme safhasında tespit etmek
- Filtre değişimine karar vermek

Gibi kazanımlar sağlanabilir. Bütün bunların yanında en büyük kazanım ise hattın yıllık/aylık duruş saatinin azaltılması ve üretimde kalmasıdır.

### 4. Filtre Çeşitleri ve Seçim-Değişim Kriterleri

Akışkanların filtrelendirilmesi için kullanılan bir çok gövde çeşidi vardır. Bunlar DIN 24550' de tanımlanmıştır.

#### 4.1. Emiş Filtreleri

Büyük kir partiküllerinden dolayı, pompaya yönelik bir hasar tehlikesinin söz konusu olduğu hidrolik sistemler mutlaka emiş filtreleri ile donatılmalıdır. Bu özellikle aşağıda yer alan iki durumdan dolayı gereklidir:

- Aynı akışkan kaynağından çeşitli hidrolik devrelerin beslenmesi
- Tankların tasarımından kaynaklı temizlenemediği durumlar.



Şekil 4. Emiş Filtreleri

Emiş filtreleri ile sadece pompaların fonksiyonelliğinin korunması mümkündür. Pompaların düşük basınç hassasiyetinden dolayı, filtredeki basınç farkı büyük olmamalıdır. Bu yüzden büyük yüzeyli filtreler kullanılır. Buna ek olarak sisteme by-pass valfi ve kirlilik göstergesi de monte edilmelidir. Emme bölgesinde, genellikle 100µm ve üstü kir partiküllerinin filtrelenmesi sınırlandırılmıştır.

#### 4.1.1. Gövdesiz Emiş Filtreleri

Gövdesiz emiş filtreleri, pompa emme hattına monte edilirler. Emiş filtresinin, minimum yağ seviyesinin yeterince altına takılmasına dikkat edilmelidir.

Gövdesiz özel emiş filtreleri, geri dönüş hattında akışkan dağıtıcısı olarak da kullanılabilirler. Bunlar, köpük oluşumunu ve bunun tank içine yerleşmesini önlerler.

#### 4.1.2. Gövdeli Emiş Filtreleri

Bu filtreler, tanktaki akışkan seviyesinin altına da monte edilebilirler. Böylece, eleman değiştirilirken, gövde boş kalmaz.

Genel olarak tüm emiş filtrelerinin avantajları;

- Kolay montaj
- Maliyet
- Hidrolik elemanları kaba kirlilerden korur

Dezavantajları;

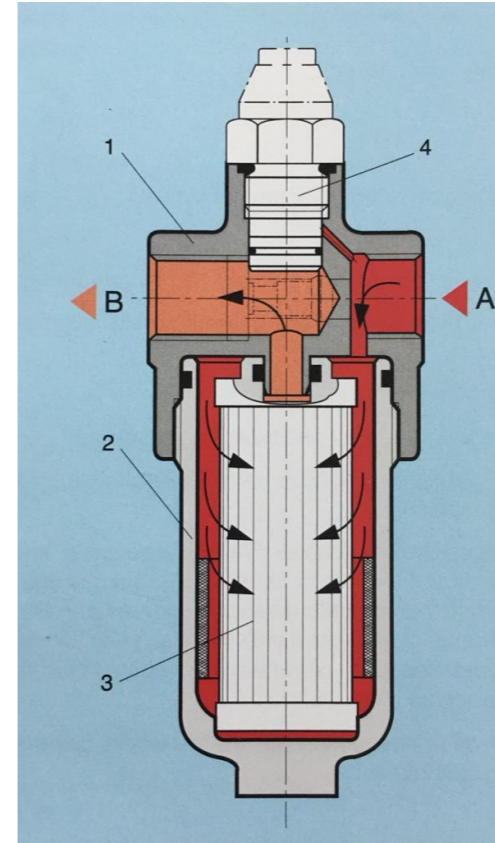
- Montajın hidrolik sistemdeki konumu kötüdür
- By-pass gereklidir
- Yağa batırılmış olduğundan bakım şartları kötüdür
- Kavite riski nedeni ile sadece kaba filtreleme mümkündür
- Kirlilik göstergelerinin montajı zordur.

#### 4.2. Basınç Hattı Filtreleri

Bu tip filtre çeşitleri, pompadan sonra gelen elemanların emniyetli çalışmalarını temin etmek için kullanılırlar. Bu nedenle bu filtreler korunması amaçlanan elemanlara mümkün olduğunda yakın bağlanmalıdır.

Sisteme basınç hattı filtresi bağlanıp bağlanmayacağına karar verirken;

- Sistemde, kirliliğe karşı özellikle hassas veya sistemin çalışması açısından önemli eleman var mı? (Servo valf, kontrol valfler gibi)
- Sistemde özellikle pahalı olan ve sistemin emniyeti açısından önemli olan eleman var mı? (Servo valfler, Paletli/Pistonlu Pompalar/Motorlar, büyük silindireler gibi)
- Sistemin boşta çalışma maliyeti yüksek mi?



Şekil 5. Basınç filtresi kesit görünümü

Basınç hattı filtreleri, emniyet filtresi ve/veya çalışma filtresi olarak kullanılabilirler. Bu filtrelerin görevleri aşağıda belirtilmiştir:

Emniyet filtreleri; elemanların fonksiyonelliğinin korunmasına, çalışma filtreleri ise elemanlarda aşınmaya karşı koruma sağlanması, istenen akışkan temizlik sınıfının sürekliliğinin sağlanmasına yardımcı olurlar.

Basınç filtreleri, daima kirlilik göstergeleri ile birlikte kullanılmalıdır. Özellikle kritik olan elemanlardan önce kullanılan basınç filtreleri by-pass valfsiz olmalıdır. Filtre gövdesi, maksimum sistem basıncına dayanabilmelidir.

Genel olarak basınç hattı filtrelerinin avantajları;

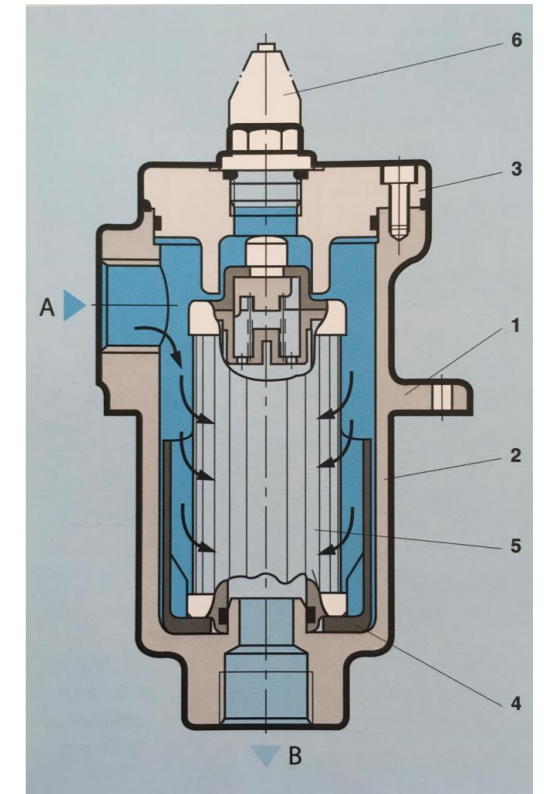
- Direkt olarak hassas elemanlar korunabilir
- Çok hassas filtreleme imkânı sağlar
- Bakım kolaydır
- Kirlilik göstergesi ile desteklenebilir
- Uzun servis süresi
- Pompa kaviteyonu yok

Dezavantajları ise;

- Akışkan direncine göre güç ısıya dönüştürülür
- Sağlam yapısından dolayı ağırlığı

#### 4.3. Tank üstü Dönüş Hattı Filtreleri

Bu filtreler, geri dönüş hattının sonuna yerleştirilirler ve tanka monte edilmek üzere tasarlanmıştır. Yani, sistemden gelen akışkan, tanka filtrelenmiş olarak döner. Böylece sistemin içinde var olan veya oluşturulan kirlilik partikülleri akışkan tanka dönmeye önce temizlenmiş olur. Filtre çıkışına bir boru veya akış dağıtıcısı monte etmek gerekli olabilir. Tankın altı ile borunun sonu arasındaki mesafe boru çapının 2-3 katından az olmamalıdır.



Şekil 6. Dönüş filtresi kesit görünümü

Dönüş filtrelerinin avantajları;

- Düşük maliyet
- Kolay bakım
- Kirlilik göstergesi bağlanabilir
- Hassas filtreleme mümkün
- Pompa kaviteyonu yok

Dezavantajları;

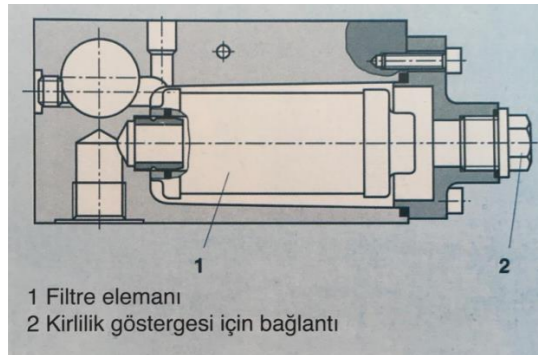
- By-pass valfi gereklidir
- Soğuk çalıştırmada veya pik basınçlarda kir partiküllerinin açık by-pass valflerinden girmelerine sebep olur.

Filtrelerin bakımı veya eleman değişimi için gereken duruş süresini azaltmak için ikili paralel filtreler kullanılabilir.

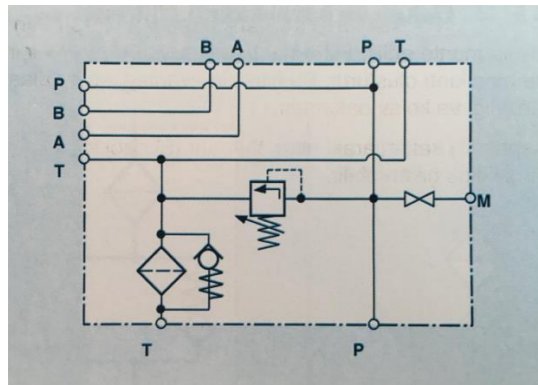
#### 4.4. Valf Bağlantı Blokları

Geri dönüş hattı filtrelerinin özel bir çeşidi, doğrudan valf bağlantı blokları üzerine monte edilebilir. Blok içerisinde valflerin kullanılması ile geri dönüş hattını borulamaya gerek kalmaz. H tipinde üst kısımda NG6 ve NG10 valfler için bağlantılar bulunmaktadır. L tipinde, üstteki flanşlarla NG6 ve NG10 olan sıralı bağlantı sistemi monte edilebilir.

RF serisinin standart elemanları ile birlikte kullanılabilirler. Kirlilik derecesini görmek için gösterge montajı yapılabilir.



Şekil 7. Valf bağlantı bloğu kesit görünümü



Şekil 8. Valf bağlantı sembolü

#### 4.5. Dolu ve Havalandırma Filtreleri

Geçmişte hidrolik sistemlerde bu filtreler, daha az önem verilirdi. Ancak günümüzde vazgeçilmez elemanlardan biri olmuştur. Hidrolik sisteme dışarıdan büyük miktarda toz girmesini önlemek amacıyla kullanılırlar. Havadaki nemi tutma özelliği olan silikajelli olan tiplerde yaygın kullanım alanına sahiptir.

#### 4.6 Kirlilik Göstergeleri

Kirlilik göstergeleri, filtrede önceden belirlenmiş geri basınç veya basınç farkına ulaşıldığında sinyal veren elemandır. Kirlilik göstergesinin çalışma noktası veya gösterge noktası, filtrenin hala filtreleme yapabileceği ve bir miktar daha kir tutabileceği şekilde seçilmelidir. Üç çeşit kirlilik göstergesi mevcuttur; geri basınç, basınç farkı ve düşük basınç göstergesi.

#### 5. Filtre Seçimi

##### 5.1. Filtreleme Tasarımı

Hidrolik sistemlerde etkili bir filtreleme, hem arızaları önler, hem de önemli ve pahalı parçaların ömrünü uzatır. Bir filtrenin verimi, en önemli faktör olmasına karşın, filtre tasarımını belirleyen tek faktör değildir. Bir filtre, yanlış noktaya monte edilirse veya yanlış bir görev için tasarlanırsa verimsiz olabilir.

Bir sistemin filtreleme fonksiyonu tasarlanırken, aşağıdaki temel kurallar göz önüne alınmalıdır:

- Uygun sızdırmazlık elemanlarının contaların kullanımında ve yüksek verimli dolmuş ve havalandırma valflerinin montajında, dışarıdan sisteme kir girmesi engellenmelidir.
- Sisteme kir ve pislik girerse ya da sistemde oluşursa, mümkün olduğunca çabuk temizlenmelidir.
- Hidrolik filtreler her zaman, aşınmayı azaltacak şekilde kullanılmalıdır; yani filtre gözenek büyüklükleri hidrolik elemanın kritik boşluk toleransına göre seçilmelidir.
- Filtrenin, en fazla akışın beklendiği yerlere monte edilmesi gerekir.

##### 5.2. Filtre Tasarım Kriterleri

Hidrolik elemanlarda, fonksiyonel emniyetin ve uzun ömürün yanı sıra, hidrolik filtre sistemi tasarımında işletme ve sistem maliyeti de önemlidir.

Bir filtre sistemi tasarlanırken aşağıdaki kriterler göz önüne alınmalıdır:

- Hidrolik elemanların kirlenmeye karşı hassasiyeti
- Tüm sisteme uygulanması
- Debinin kararlaştırılması

- Müsaade edilen fark basınç ya da geri basınç
- Filtre malzemesi ile akışkanın uyumu
- Çalışma sıcaklığı
- Akışkan viskozitesi
- Tasarım sıcaklığı
- Ek cihazlar ( kirlilik göstergesi gibi )

#### 5.3. Filtre Elemanının Seçimi

Temiz elemanlarda tavsiye edilen basınç kayıpları ve çalışma viskozitesi, tüm filtre için ( gövde ve eleman ) aşağıda verilen değerleri aşmamalıdır:

$$\text{By-passız hat filtresi} \quad \Delta P_A = 0.2 \times \Delta P_{\text{Gösterge}}$$

$$\text{By-passlı} \quad \Delta P_A = 0.15 \times \Delta P_{\text{Gösterge}}$$

$$\text{Geri dönüş hattı filtresi} \quad \Delta P_A = 0.2 \times \Delta P_{\text{Gösterge}}$$

Filtrenin boyutu belirlenmeden önce, gerekli gözenek büyüklüğü tespit edilmelidir. Bunun tespiti için aşağıdaki tablodan faydalanılabilir:

HİDROLİK EKİPMAN	ISO KODU	NAS KODU	MUTLAK FİLTRE DELİĞİ ( $\beta_x \geq 200$ )
SERVO VALFLER	16/14/11	5	X=5 $\mu$ m
ORANSAL VALFLER	17/15/12	6	X=5 $\mu$ m
PALETLİ VE PİSTONLU POMPALAR/ MOTORLAR	18/16/13	7	X=5 $\mu$ m
YÖN VE BASINÇ KONTROL VALFLERİ	18/16/13	7	X=5 $\mu$ m
DİŞLİ POMPA/MOT ORLAR	19/17/14	8	X=5 $\mu$ m
AKIŞ KONTROL VALFLERİ/Sİ LİNDİRLER	20/18/15	9	X=10 $\mu$ m
YENİ KULLANILM AMIŞ YAĞLAR	20/18/15	9	X=10-20 $\mu$ m

Tablo 4. Tavsiye edilen filtre gözenegini bulmak

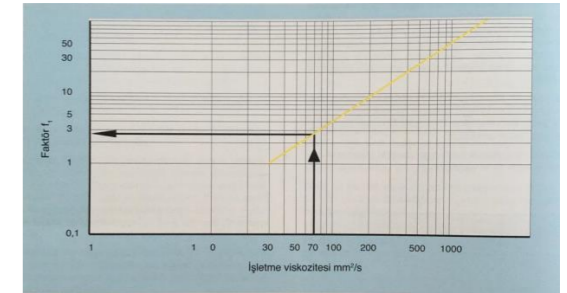
Gerekli filtre gözenek büyüklüğüne karar verildikten sonra, uygun filtre büyüklüğünün seçimi yapılır. Filtre büyüklüğünün belirlenmesi için gerekli formüller Tablo 5. de verilmiştir.

Filtre Tipi	Filtre gövdesi ve filtre elemanı için ayrı diyagramlar kullanarak	Tasarım diyagramları kullanarak
Geri dönüş hattı filtresi	$f_2(\Delta p_{\text{gövde}} + f_1 \times \Delta p_{\text{eleman}}) \leq \Delta p_A$	$Q_T = Q_S f_2 f_1$
By-pass Valfli hat filtresi	$f_2(\Delta p_{\text{gövde}} + f_1 \times \Delta p_{\text{eleman}}) \leq \Delta p_A$	$Q_T = Q_S f_2 f_1$
By-pass valfsiz hat filtresi	$f_2(\Delta p_{\text{gövde}} + f_1 \times \Delta p_{\text{eleman}}) \leq \Delta p_A$	$Q_T = Q_S f_2 f_1$
Emiş Filtresi	$f_2(\Delta p_{\text{gövde}} + f_1 \times \Delta p_{\text{eleman}}) \leq 0.01$	$Q_T = 5 \dots 10 Q_P f_2$

$$Q_P = \text{POMPA DEBİSİ} \quad Q_T = \text{TASARIM DEBİSİ} \quad Q_S = \text{SİSTEM DEBİSİ}$$

Tablo 5. Filtre büyüklüğünün seçimi

Tablo 5. de yer alan formüllerde kullanılacak olan  $f_1$  ve  $f_2$  Tablo 6. Ve Tablo 7. den tayin edilebilir.



Tablo 6. Viskozite dönüştürme faktörü (  $f_1$  )

Hidrolik sistemin servis ve bakımı	Makina ortamındaki Kirlilik derecesi		
	1) düşük	2) orta	3) yüksek
- Filtrelerin düzenli kontrolü - Filtre elemanlarının hemen değiştirilmesi - Düşük kirlilik nüfusiyeti girışı - İyi tank sızdırmazlığı	1.0	1.0	1.3
- Filtrelerin seyrek kontrolü - Az silindir kullanımı	1.0	1.5	1.7
- Filtrelerin hiç ya da çok seyrek kontrolü - Bir çok korunmasız silindir - Sisteme yüksek seviyede kirlilik nüfusiyeti	1.3	2.0	2.3

Tablo 7. Çevresel Şartlar için  $f_2$  faktörü

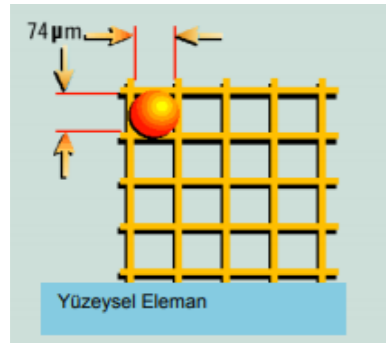


#### 5.4. Filtre Elemanının Tipleri, Malzemeleri ve Performansları

Filtre elemanının yapıldığı malzeme; filtrenin kirliliği tutan asıl kısmıdır. Filtre elemanı genellikle tabaka şeklinde imal edilir ve böylelikle akışkanın içerisinden geçeceği geniş yüzeyli bükülmüş bir yapı haline getirilir. Bu, kirlilik tutma kapasitesini artırırken, basınç farkını düşürür. Bazı uygulamalarda, filtre elemanı kesin performans kriterlerini sağlayabilmek için çok katmanlı yapılı ve ağ örgü ile desteklenir. Elemanın kıvrımları yapıldıktan sonra uygun boyalarda kesilerek, her iki ucundan özel kancalar kullanılarak bağlanır, yapıştırılır veya diğer dikme metotları ile dikilirler. Tüm filtre elemanları, tel örgü, kağıt, fibreglas, kompozitler veya sentetik malzemeler içerirler. Filtre elemanları genellikle iki şekilde sınıflandırılırlar. Yüzeysel filtreleme yapan elemanlar ve derinlemesine filtreleme yapan elemanlar.

##### 5.4.1. Yüzeysel Filtre Elemanı

Yüzeysel filtre elemanlarında, yağ akışı aslında akış yoluna paralel olarak hareket eder. Kirlilik filtre elemanının akış yüzeyinde yakalanır. Yüzeysel filtre elemanları genellikle dalgalı tip örgüden yapılırlar. İmalat prosesinin başlangıcında, örgülü tel çok hassas olarak kontrol edilir ve yüzeysel elemanda gözenek boyutlarının birbirini tutması istenir. Bu tutarlı gözenek boyutları, özel test şartları altında, küresel sert partiküller gözeneklerden geçirilerek test edilirler. Bunun yanı sıra eleman yüzeyindeki kirliliğin artması ile birlikte, eleman üzerindeki gözeneklerden daha küçük boyutlarda olanlar da yakalanacaktır. Aynı zamanda, çap olarak daha küçük fakat uzunlamasına büyük olan partiküller de filtre elemanını geçip gidecektir.

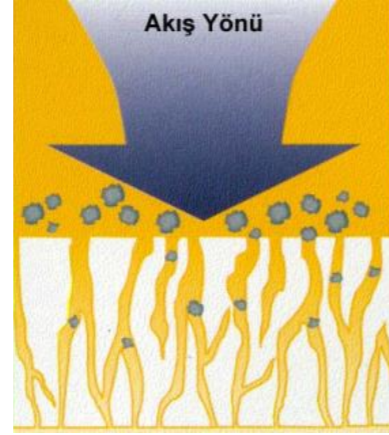


Şekil 9. Yüzeysel eleman

##### 5.4.2. Derinlemesine Filtre Elemanı

Derinlemesine çalışan filtre elemanlarında, (Şekil 10.) akışkan filtre elemanının yapısından dolayı eleman içerisinde indirekt olarak hareket edecektir. Filtre elemanın içerisinde, bir labirent gibi partiküllere tuzak

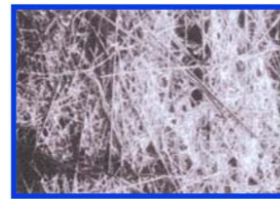
kurulmuştur. Bu yapıdan dolayı, derinlemesine filtre elemanları değişik boyutlarda gözeneklere sahiptirler. Bu boyutsal farklılığın dağılımına göre, filtre elemanı çok yüksek kapasitelerde küçük boyutlu partikülleri yakalayabilecektir.



Şekil 10. Derinlemesine Filtreleme

Selüloz ve fibreglas olmak üzere iki tip derinlemesine çalışan filtre elemanı vardır. Selüloz elemanlı filtrede liflerin biçimi ve boyutları düzensiz şekilde olup, geniş gözenek yapısına sahip bir eğilim gösterirler. Fibreglas eleman ile karşılaştırıldığında ise, fibreglas elemandaki liflerin yapısı ve boyutları oldukça düzenlidir. Selüloz liflerine göre fiber elemanda lifler genellikle daha incedir. Bu tip farklılıktan dolayı fibreglas elemanın performansı selüloza göre daha avantajlıdır. Daha ince lif yapısının anlamı aynı alanda daha fazla gözenek sayısı demektir. Bu sayede, daha ince liflerle küçük gözenekler birbirine daha yakınlaşmakta ve çok hassas filtrasyon için gerekli olan yapıyı sağlamaktadır. Sonuç olarak filtre elemanında, kir tutma kapasitesi ve filtrasyon verimi artmaktadır.

Filtrasyon Gerçeği: Yüzeysel filtreleme yapan elemanlar temizlenerek tekrar kullanılabilirler. Basit temizleme yöntemleri mevcut olup, genellikle ultrasonik temizleme bu işlem için en iyi metottur. Derinlemesine çalışan filtre elemanları ise temizlenmeye ve tekrar kullanıma uygun olmayan elemanlardır.



Şekil 11. İnce yapıdaki fibreglas (100X)

Filtre Elemanlarını Genel Karşılaştırması					
Eleman Malzemesi	Yakalama Verimi	Kir Tutma Kapasitesi	Basınç Düşümü	Sistemdeki Ömrü	İlk Kurulum Maliyeti
Fiberglass	Yüksek	Yüksek	Orta	Yüksek	Yüksek Değil
Selüloz(Kağıt)	Orta	Orta	Yüksek	Orta	Düşük
Tel Eleman	Düşük	Düşük	Düşük	Orta	Yüksek

Tablo 8. Filtre elemanlarının belirli kriterlere göre karşılaştırılması

##### 5.4.3. Multipass Testi

Filtrasyon endüstrisinde, filtre elemanının performansını değerlendirebilmek için ISO 4572 "Multipass Test Prosedürü" kullanılmaktadır. Bu prosedür ANSI ve NFPA tarafından da onaylanmıştır. Multipass testi sırasında akışkan tüm şartları gözlenen ve tam olarak kontrol edilen bir devre içerisinden geçirilmektedir. Test elemanı üzerindeki basınç düşümü sürekli olarak kaydedilmekte ve temiz akışkana belirli miktarda "kirlilik" enjekte edilmektedir. Test elemanın girişi ve çıkışı üzerinde on-line olarak bir lazer partikül sayıcı sensör vasıtasıyla kirlilik seviyesi ölçülmektedir. Bu ölçümler sonucunda filtre elemanın doğal performansını veren ve birkaç tip partikül boyutu dikkate alınarak tespit edilen "Beta Oranı" elde edilir.

Multipass Testi sonucunda elemanın performans karakteristiği ile ilgili olarak üç önemli sonuç elde edilir.

1. Elemanın kir tutma kapasitesi,
2. Test edilen filtre elemanındaki basınç düşümü,
3. Ayırıştırma veya filtrasyon verimi olarak tanımlanan "Beta Oranı"

##### 5.4.4. Beta Oranı

Beta oranı (filtrasyon oranı da diyebiliriz) filtre elemanının partikül yakalama veriminin ölçüsüdür. Bu yüzden performans oranı olarak da tanımlanabilir. Multi pass testinden elde edilecek olan giren-çıkan partikül sayısı verileri ile Beta oranının nasıl hesaplandığına dair örnek yapılır ise;

$$\beta_x = \frac{\text{Giren Partikül Sayısı}}{\text{Çıkan Partikül Sayısı}} \quad \text{Verim}_x = \left[ 1 - \frac{1}{\beta} \right] \times 100$$

x: Özel Partikül boyu

yukarıda yer alan formülde giren partikül sayısını 50.000, filtreden çıkan partikül sayısını 10.000 olarak yerine koyarsak Beta oranı 5 olarak bulunur. Bu oranı da verim formülünde yerine koyduğumuz zaman bize filtrenin %80 verimle filtreleme yaptığını gösterir.

	Filter Paper				Microglass			
	SF620	SF621	SF610	SF611	SF630-MG	SF631-MG	SF634-MG	SF635-MG
	10µm	10µm	25µm	25µm	12µm	12µm	25µm	25µm
Diameter	93.5 (3.68)	93.5 (3.68)	93.5 (3.68)	93.5 (3.68)	93.5 (3.68)	93.5 (3.68)	93.5 (3.68)	93.5 (3.68)
Length	147.6 (5.81)	203.2 (8.00)	147.6 (5.81)	203.2 (8.00)	147.6 (5.81)	203.2 (8.00)	147.6 (5.81)	203.2 (8.00)
Element Thread	1/12-16 UNF	1/12-16 UNF	1/12-16 UNF	1/12-16 UNF	1/12-16 UNF	1/12-16 UNF	1/12-16 UNF	1/12-16 UNF
Beta Ratio	β <sub>10</sub> = 2	β <sub>10</sub> = 2	β <sub>25</sub> = 2	β <sub>25</sub> = 2	β <sub>12</sub> = 200	β <sub>12</sub> = 200	β <sub>25</sub> = 200	β <sub>25</sub> = 200
Dirt Holding Capacity ACFTD (g)	14	22	19	29	24	37	29	44
Filtration Area	2431 cm <sup>2</sup> (376.9 in <sup>2</sup> )	3725 cm <sup>2</sup> (577.4 in <sup>2</sup> )	2077 cm <sup>2</sup> (322.0 in <sup>2</sup> )	3183 cm <sup>2</sup> (493.3 in <sup>2</sup> )	2268 cm <sup>2</sup> (351.5 in <sup>2</sup> )	3486 cm <sup>2</sup> (540.4 in <sup>2</sup> )	2268 cm <sup>2</sup> (351.5 in <sup>2</sup> )	3486 cm <sup>2</sup> (540.4 in <sup>2</sup> )
Maximum Working Pressure	27.5 bar (400 PSI)	27.5 bar (400 PSI)	27.5 bar (400 PSI)	27.5 bar (400 PSI)	27.5 bar (400 PSI)	27.5 bar (400 PSI)	27.5 bar (400 PSI)	27.5 bar (400 PSI)
Carton Quantity	12	12	12	12	12	12	12	12
Carton Weight	7.3 kg (16 lb)	11 kg (24 lb)	7.3 kg (16 lb)	11 kg (24 lb)	7.3 kg (16 lb)	11 kg (24 lb)	7.3 kg (16 lb)	11 kg (24 lb)

Tablo 9. Bazı filtrelerin beta oranları

Tablo 9. Dan kağıt ve mikroglass olarak iki farklı materyalden yapılmış aynı mu hassasiyetine sahip SF6610 ve SF6634-MG kodlu iki ürünü kıyaslırsak;

SF6610'nun 25µ da beta oranı 2'dir, SF6634-MG'nin ise 25µ da beta oranı 200'dür. Yani SF6610 kodlu ürün %50 verimle çalışırken SF6634-MG kodlu ürün %99.5 verimle çalışmaktadır. Bu örnekten de görüldüğü gibi katalog değerlerinden alacağımız beta oranları ile seçtiğimiz filtrenin verimliliğini kolayca hesaplayabiliriz.

## 6. Sonuç

Bu bildiri filtrasyonla ilgili basit temel bilgilerin toplandığı bir çalışmadır. Bu bildirinin amacı endüstrinin her dalında hidrolik sistemlerle çalışan mühendislere veya bakım personeline doğru filtre seçimi ve kullanımı konusunda yardımcı olmak ve üretim artışı sağlamaktır. Hidrolikte kullanılan filtrelerin görevi yağın temiz tutulması değil, işletme masraflarının düşürülerek en aza indirilmesi ve hidrolik sistemlerin ömrünü uzatmaktır. Arızalar sonucu duruşlar buna bağlı iş kaybı, komponent değişimi ve yağ değişimi masrafları gibi oluşan giderlerin çok yüksek boyutlara ulaşmadan önlenmesi amaçlanmıştır.

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## Superior Cold Rolling Solutions of Primetals Technologies for the Production of NGO Electrical Steels - MQL

NGO Elektrik Çeliği Üretimi için Primetals Technologies' in Soğuk Haddeme Teknolojileri

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### Abstract

Today's e-mobility trend calls for new generations of high-silicon electrical steels with superior magnetic properties, higher strength and thinner gauges. With this growing demand for electrical steels, steel producers are faced with the challenge in producing materials that strain or exceed the capabilities of existing mill equipment and automation originally designed to produce electrical steels with low to medium silicon content and strip thicknesses above and equal to 0.35 mm.

### 1. Introduction

In case of cold rolling, major levers to improve rolling mill capability are optimized work roll diameters, powerful flatness actuators, high-torque spindles and more effective and flexible roll-gap lubrication systems.

A novel roll-gap lubrication technology MQL® supports the implementation of a product-based lubrication by direct control of the in-bite oil film thickness independent of the rolling speed. This allows especially on the first rolling passes to significantly improve the friction and lubrication conditions compared to conventional recirculation emulsion lubrication.

In case of a strip induction heater in front of the cold rolling mill, which is beneficial especially for the production of edge-crack sensitive high-grade electrical steels, MQL® has a further decisive advantage because it does not reduce the strip temperature at tandem mill entry as observed for conventional roll-gap lubrication with emulsion. This may lead to reduced strip material deformation resistance, reduced strip breakage ratio and consequently to improved operational costs. Therefore, MQL® and a strip induction heater represent a congenial combination resulting in increased rolling stability and productivity as well as optimized energy consumption for the production of high-Si electrical steel.

### 2. Minimum Quantity Lubrication

Minimum Quantity Lubrication [3] is a new roll-gap lubrication technology for cold-rolling mills, applying neat rolling oil atomized with air directly onto the surfaces of the work rolls. This technology is beneficial for the production of silicon steels for electrical appliances or advanced high-strength steel grades (AHSS) for automotive applications.

Figure 8 shows that with MQL the entry side emulsion application is completely replaced by neat oil with low flow rates through the top and bottom MQL headers with quick-exchange oil/air mixing nozzles. The homogeneous oil film layer thickness on the work roll surface can be precisely controlled and the amount of oil supplied to the roll bite can be adjusted in a flexible and efficient way. Therefore, MQL allows for an intelligent control of the oil film thickness in the roll-gap, depending on the rolling process requirements. Based on actual process and product parameters, the innovative solution allows control over the optimum amount of oil to maximize rolling efficiency and to secure rolling stability (intelligent forward-slip control).

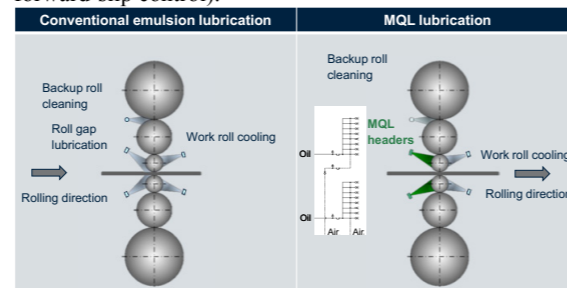


Figure 8. Typical MQL installation, oil/air schematic of spray headers

MQL not only ensures optimum product-specific lubrication, but the effortless and rapid change of lubrication settings lead to a much higher degree of flexibility than has been previously possible with classical emulsion systems.

Comprehensive tests at three different European steel producers proved its strength, and also showed

conclusively that MQL leads to considerably lower rolling forces and motor torques (electrical energy savings), as it maximizes the level of oil concentration in the roll bite. These savings can be converted into more reduction or a wider strip.

Another major advantage of the system is the ability to achieve better strip surface cleanliness by improved lubrication and friction. This results in less generated strip wear and hence reduced amount of iron fines on the strip surface after cold rolling.

MQL can be installed in one or more mill stands (cf. Figure 9). Each stand is equipped with two spray headers for the top and bottom sides of the strip. These spray bars feature several zones, with only those zones active that are required for a particular strip width. The oil flow, depending on the specific product and pass schedule, is controlled by a process unit that is coupled to the mill automation system through a defined interface. Product-specific lubrication strategies are configured in a presettable integrated into the existing Level 2 system.

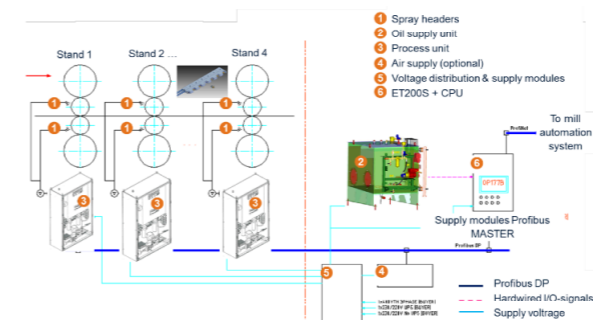


Figure 9. MQL system architecture

Figure 10 shows an example of a fully integrated emulsion and MQL header (top and bottom header) which allows maximum roll-gap lubrication flexibility for each rolling product and enables a supplement lubrication if required (e.g. at reduced weld rolling speed or for UHSS production).

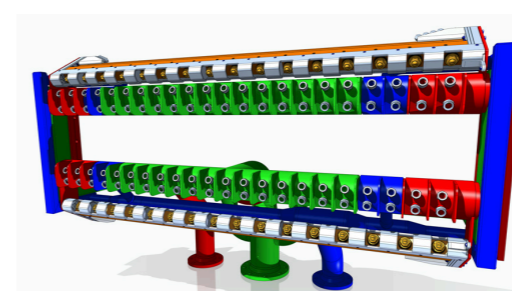


Figure 10. Combined spray header for emulsion and MQL

MQL supports the implementation of a product-based lubrication by direct control of the oil film thickness on the work roll independent of the rolling speed. Consequently, the friction conditions and therefore the rolling force can be flexibly adjusted even within one coil.

Figure 11 shows an example of an industrial installation where MQL was applied on stand 1 of a tandem cold rolling mill. The rolling force level is influenced by the amount of oil applied through MQL. In the first (left) part of the coil, the oil flow rate in ml/min was increased with rolling speed in order to maintain a constant oil application in mg/m<sup>2</sup> (work roll surface). In the second (right) part of the coil, the oil application in mg/m<sup>2</sup> was increased at constant rolling speed of app. 410 m/min. In both cases, the rolling force reacts instantly to oil flow rate and speed changes, and further decreases when the oil application is increased towards the coil tail end. Reduced rolling forces and lower friction levels lead to significant advantages for rolling high-strength materials in the first rolling stands (at low rolling speed and low thickness reduction levels) or during low rolling speeds (e.g. during weld rolling).

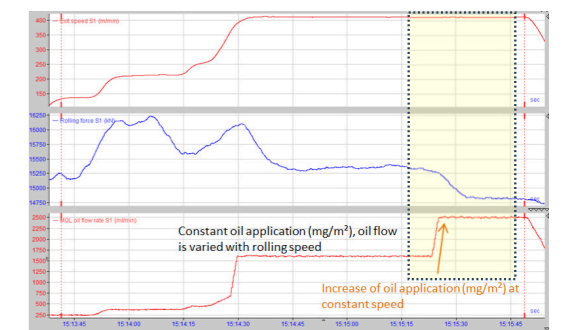


Figure 11. Instant rolling force adjustment by MQL oil application variation within a coil

Therefore, MQL allows higher reductions on early stands for high-strength steels compared to recirculation emulsion lubrication, because the oil film thickness is not limited by the low mill speed and insufficient film formation.

In case of a strip induction heater in front of the cold rolling mill, MQL has a further decisive advantage because it does not reduce the strip temperature at tandem mill entry as observed for conventional roll-gap lubrication with emulsion. Therefore, MQL and a strip induction heater represent a congenial combination resulting in increased rolling stability and productivity as well as optimized energy consumption for the production of high-Si electrical steel.

MQL is installed on two industrial tandem cold rolling mills in Europe. In the first installation the conventional



emulsion lubrication was completely replaced by MQL on mill stand 1 and 2 of a batch-type 4-stand tandem cold rolling mill. The system is now in permanent operation since January 2017. In the latest reference MQL is installed on mill stands 1, 2 and 4 of a continuous 5-stand tandem cold rolling mill of a leading European steel producer and uses a combined spray header as shown in Figure 10. MQL is in operation since mid-2019 and suitable for the entire product mix incl. UHSS and high-grade NGO silicon steels.

### 3. Conclusion

This paper introduces key technologies of Primetals Technologies to support steel producer for a successful, stable and high-quality production of NGO electrical steels.

A novel roll-gap lubrication technology MQL® supports the implementation of a product-based roll-gap lubrication by direct control of the in-bite oil film thickness independent of the rolling speed. This allows to significantly improve the friction and lubrication conditions compared to conventional recirculation emulsion lubrication, which leads to significant benefits in terms of lower rolling forces, increase reduction capability, reduced energy consumption and improved strip surface cleanliness of the final cold rolled product. MQL® in combination with a strip induction heater represents a congenial combination resulting in increased rolling stability and productivity as well as optimized energy consumption for the production of high-Si electrical steel.

### References

[1] M. Bergmann, K. Krimpelstaetter, B. Nilsson, S. Karakavaf, R. Leffers (2019), Intelligent roll-gap lubrication improves strip surface cleanliness in thyssenkrupp steel's tandem cold rolling mill, 4th European steel technology and application days ESTAD 2019, Duesseldorf, Germany, June 24-28, 2019.

## HYPER UC-Mill - Superior Cold Rolling Solutions of Primetals Technologies for the Production of NGO Electrical Steels

Toru Nakayama

<sup>1</sup>PRIMETALS TECHNOLOGIES JAPAN • Japan

### Abstract

Today's e-mobility trend calls for new generations of high-silicon electrical steels with superior magnetic properties, higher strength and thinner gauges. With this growing demand for electrical steels, steel producers are faced with the challenge in producing materials that strain or exceed the capabilities of existing mill equipment and automation originally designed to produce electrical steels with low to medium silicon content and strip thicknesses above and equal to 0.35 mm.

### 1. Introduction

In case of cold rolling, major levers to improve rolling mill capability are optimized work roll diameters, powerful flatness actuators, high-torque spindles and more effective and flexible roll-gap lubrication systems.

Primetals Technologies' Hyper UC-Mill\* represents a new generation of mill stand technology especially designed for the high-quality production of high-grade NGO silicon steels and ultra-high strength steels (UHSS). The 6-high Hyper UC-Mill features a significantly reduced work roll diameter, driven work rolls and a newly designed high-torque gear type spindle [2].

\* *HYPER UC-MILL* is a registered trademark of Primetals Technologies Japan, Ltd

The key to successful production of high-silicon electrical steels and UHSS is to make best use of the capabilities of all available mill stands. This includes making as much reduction as possible in the earlier rolling passes when the material is still relatively soft. Smaller work roll diameter solutions especially on the later rolling passes allow to further extend the mill reduction capabilities towards thinnest gauges.

### 2. Characteristics of HYPER UC-MILL

#### 2.1. Inheriting UC-MILL core technology

HYPER UC-MILL inherits the core technology of UC-MILL [1], which has been widely delivered to the cold rolling industry to date. The most significant characteristic of UC-MILL is that the deflection of the

work rolls caused by the rolling load can be significantly reduced compared with 4H-MILL (4-high rolling mill). Figure 1 compares the characteristics of UC-MILL with those of 4H-MILL. UC-MILL is a breakthrough technological innovation in which undesirable contact areas between the work roll and the back-up roll existing on the outer sides of the rolled material in the case of 4H-MILL is eliminated by applying an intermediate roll between the two. The specific effects of this UC-MILL core technology are shown below.

- (1) The diameter of the work rolls can be made smaller because the deflection is reduced, which makes it possible to roll harder materials and thinner materials.
- (2) The excellent shape control ability is achieved due to the large bending effect of the work roll and the intermediate roll.
- (3) A roll crown to compensate for deflection is not required, so roll inventory can be improved.

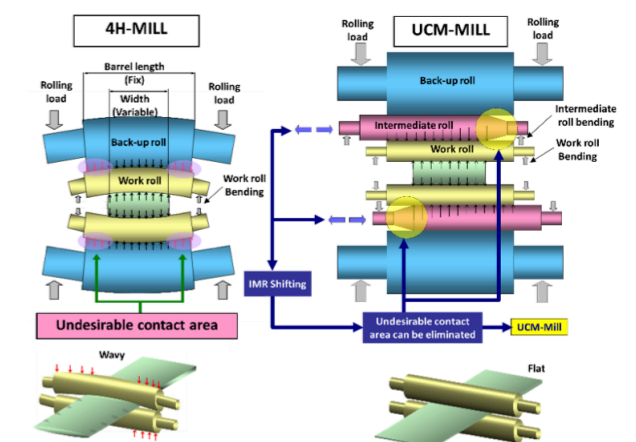


Figure 1. Features of UC-MILL

#### 2.2. Work rolls 20-30% smaller in diameter

For HYPER UC-MILL, a reduction in diameter of 20-30% compared with the existing standard UC-MILL described above were attained.

Figure 2 compares HYPER UC-MILL and the standard UC-MILL. As shown in this figure, the diameter of the work rolls of HYPER UC-MILL was reduced, while the diameter of its intermediate rolls was made larger compared with the standard UC-MILL. The combination of these roll diameters results in the following significant advantages.

- (1) The smaller-diameter work rolls make it possible to roll even higher-strength materials and thinner materials.
- (2) The combination of the small-diameter work roll and the large-diameter intermediate roll improves the shape control capability.
- (3) The adoption of the large-diameter intermediate roll reduces hertz stress (contact pressure) between the intermediate roll and the back-up roll.

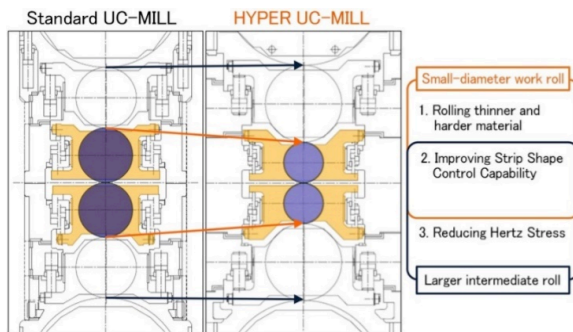
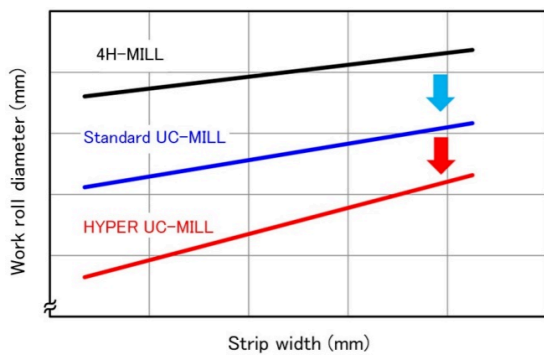


Figure 2. Comparison of HYPER UC-MILL and standard UC-MILL

Figure 3 compares typical examples of the relationship between the work roll diameter and the strip width by mill type. The development of UC-MILL significantly reduced the diameter of work rolls compared with 4H-MILL, which was the mainstream in the past, and the development of HYPER UC-MILL achieved a similar degree of reduction in the work roll diameter compared with UC-MILL.



HYPER UC-MILL: 20% to 30% smaller than Standard UC-MILL

Figure 3. Work Roll Diameter and Strip Width

### 3. Effects brought about through the use of HYPER UC-MILL

This section presents two revamp examples of the effects brought about through the use of HYPER UC-MILL.

Figure 4 presents an example of the revamp of a reversing cold mill at Maanshan Iron & Steel (China) from a standard UC-MILL to HYPER UC-MILL in 2018. This mill, dedicated to the production of electrical steel sheets, was made capable of producing even higher-strength and thinner products by this revamp, earning the technology a good reputation.

As shown in Figure 4, the rolling data before and after the revamp indicate the significant effect that in the case of rolling a material of the same steel type and same entry/exit thickness, both the number of passes and the rolling load in each pass can be reduced.

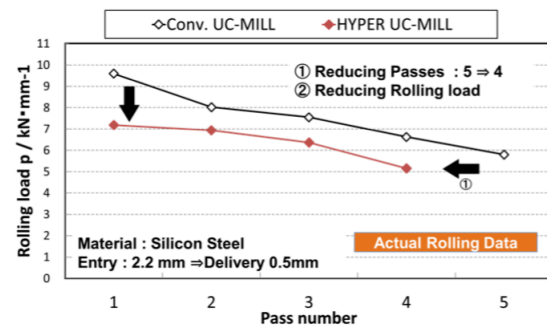


Figure 4. Example of revamp to HYPER UC-MILL on Reversing Cold Mill

The following is an example of applying HYPER UC-MILL to a tandem mill. Revamping a 4Hi-MILL of the existing 5-stand tandem mill to a HYPER UC-MILL significantly improved the rolling reduction ratio of its stand and made it possible to roll high-strength steel thinner as a result.

### 4. Applying HYPER UC-MILL to TCM for producing electrical steel sheets

Table 1 lists the orders received for HYPER UC-MILL, three of which are for reversing cold mills and four of which are for tandem cold mills. In terms of the type of project, four are for revamps and three are for new construction. All of these orders aim to improve the production capability of high-strength materials and thin materials such as high-tensile strength steel sheets and electrical steel sheets.

Table 1. Supply references of HYPER UC-MILL

Customer	Project Type	Summary
Maanshan Steel No.3 RCM [Running]	Reversing Cold Mill : New	Type: Single Reversing Cold Mill Start Up: 2013 Material: Electrical Steel
Maanshan Steel No.1 RCM [Running]	Reversing Cold Mill : Revamped to HYPER UC-MILL	Type: Single Reversing Cold Mill Start Up: 2018 Material: Electrical Steel
A Company [In Progress]	Tandem Cold Mill : Revamping to HYPER UC-MILL	Type: 4-stand Tandem Cold Mill Start Up: 2020 Material: Electrical Steel, HSS
B Company [Running]	Tandem Cold Mill : Revamped to HYPER UC-MILL	Type: 5-stand Tandem Cold Mill Material: AHSS
C Company [In Progress]	Tandem Cold Mill : Adding HYPER UC-MILL to Existing Line	Type: 6-stand Tandem Cold Mill Start Up: 2021 Material: AHSS
D Company [In Progress]	Reversing Cold Mill : New	Type: Single Reversing Cold Mill Start Up: 2021 Material: Low Carbon Steel ( 0.2mm )
Shougang Qian'an [In Progress]	Tandem Cold Mill : New All HYPER UC-MILL with Work Roll Shifting Function	Type: 6-stand Tandem Cold Mill Start Up: 2022 Material: Electrical Steel, AHSS

One point to be noted in this table is the case of application to a tandem mill producing electrical steel sheets of Shougang Qian'an Electric Vehicle Electrical Steel Co., Ltd. (China). This tandem cold mill consists of all HYPER UC-MILL with work roll shifting function. electrical steel sheets.

#### 4.1 Edge drop control

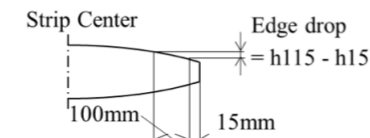


Figure 5. Definition of edge drop

Edge drop defined by Figure 5 is caused by the combined effects of work roll deflection and work roll compressive deformation. Work roll deflection is caused by the bending moment due to the undesirable contact between work roll and back-up roll as described previously. The work roll compressive deformation is related with the roll diameter. The work roll diameter is larger, roll separating force is larger and which causes not only roll deflection but also roll compressive deformation. Therefore, the features of HYPER UCM (1) High crown controllability, (2) small work roll diameter are very suitable to restrain Edge drop.

Furthermore, we developed HYPER UCMW (HYPER UC-MILL with Work Roll Shifting Function), as shown in Figure 6, and enabled edge drop control positively.

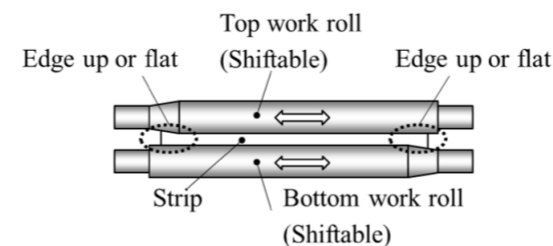


Figure 6. Conceptual sketch of edge drop control with work roll shifting

Figure 7 illustrates the technology required for a tandem mill for producing high-grade electrical steel sheets. Such a mill for producing electrical steel sheets must be ① a smaller-diameter work roll mill that meets the increasing demand for harder and thinner materials aiming at higher efficiency and smaller sizes, ② a continuous tandem mill that satisfies the requirements for high-quality and high-productivity, and ③ a work roll shifting mill that responds to the strict strip thickness accuracy in the strip width direction (minimizing of the edge drop) as a quality requirement specific to electrical steel sheets. Thus, HYPER UCMW enabled to meet all of requirements ① to ③ for a tandem cold mill for producing electrical steel sheets.

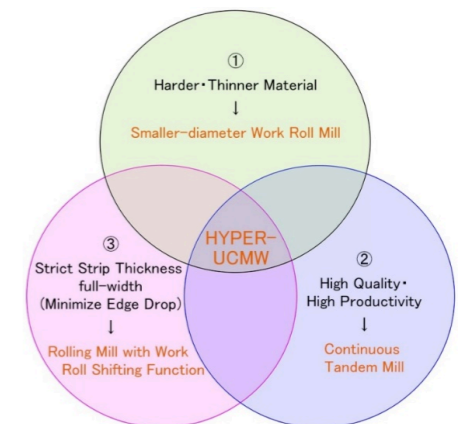


Figure 7. Technologies required for producing High-Grade Electrical Steel

### 5. Conclusion

This paper introduces key technologies of Primetals Technologies to support steel producer for a successful, stable and high-quality production of NGO electrical steels.

Primetals Technologies' Hyper UC-Mill represents a new generation of mill stand technology. This mill features a significantly reduced work roll diameter, driven work rolls and a newly designed high-torque gear type spindle, which are very suitable especially for the high-quality production of high-grade NGO silicon steels and ultra-high-strength steels (UHSS). The system is further improved by a work roll shifting function featuring edge drop control to offer a more stable and high-quality mass production of electrical steel sheets.



## References

- [1] Kazunori Hata, Yasutsugu Yoshimura, et al., "Universal Crown Control Mills", Hitachi Review, Vol. 34 No. 4, 1985, pp. 168-174.
- [2] Shin-ichi Yasunari, Kenji Yamamoto, et al., "Development of New Universal Crown Control Mill", Journal of the Japan Society for Technology of Plasticity, Vol. 55 No. 647, 2014, pp. 1088-1091

## Increasing the Hydrostatic Capacity of MORGOIL® Bearings in a Tandem Cold Mill

Thomas Wojtkowski, Peter Osgood, Ian Ward

PRIMETALS TECHNOLOGIES USA • USA

### Abstract

Primetals Technologies has successfully upgraded the hydrostatic oil film bearings in a Tandem Cold Mill to achieve a higher force capacity in a cost effective manner by introducing direct replacement, custom, dual pad bushings while at the same time retaining the existing hydrostatic pump and supply system.

### 1. Introduction

Primetals Technologies has provided metal producers a means of generating higher rolling forces at low speeds by developing new MORGOIL® dual pad hydrostatic bushings which replace the old single pad bushings. In doing so, the existing hydrostatic pumps and feed lines are retained, resulting in a highly economical solution.

### 2. Overview of MORGOIL® bearings

#### 2.1 Bearing characteristics

Figure 1 below shows the typical operating envelope for an oil film bearing.

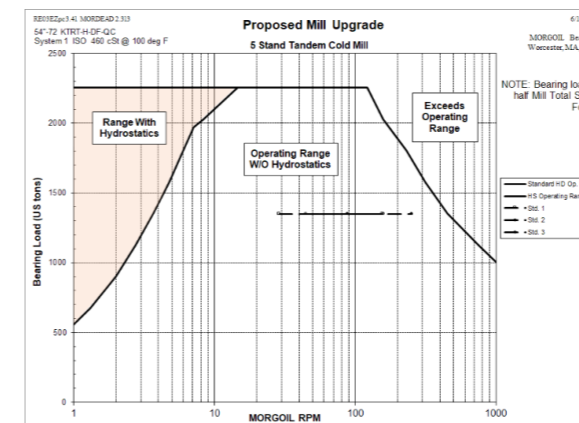


Figure 1. Bearing operating envelope

The area of interest is at the left of the bearing map (highlighted) where either the speed is insufficient and/or

the force is high enough that it is not possible to maintain a hydrodynamic oil film. Should it be necessary to roll at a low speed and/or stop and start the mill under rolling load, then it is also necessary to provide an external means of generating the oil film, such as a hydrostatic system.

#### 2.2 Hydrostatic system components

Figure 2 below shows the components of a hydrostatic system.

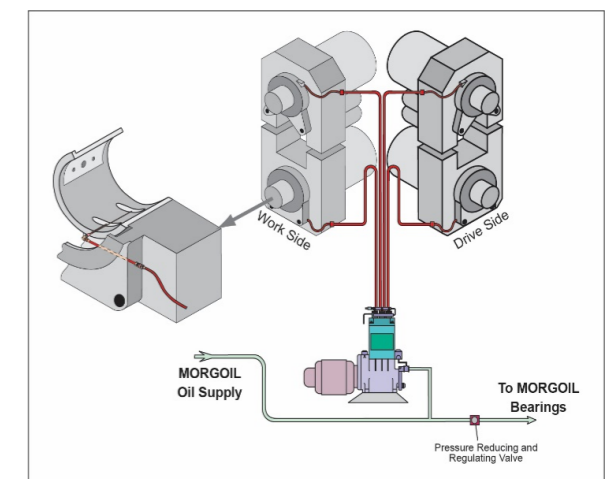


Figure 2. Hydrostatic system components

Filtered oil is supplied to the hydrostatic pump from the hydrodynamic lubrication system. In this mill, the hydrostatic pump is capable of supplying pressure up to 10,000 psi at a flow rate of 2.6 gpm with a relief valve set to 11,500 psi. From the hydrostatic pump, the oil is separately piped to each of the four chocks.

#### 2.3 Characteristics of the hydrostatic system

The system uses a fixed displacement pump which provides a constant flow rate. The pressure loss through the piping to the chocks is constant. Also, the relationship between changes in roll force and hydrostatic pressure are relatively

linear. Figure 3 below shows these characteristics with the system relief valve setting for both the existing bushings and the upgraded bushings.

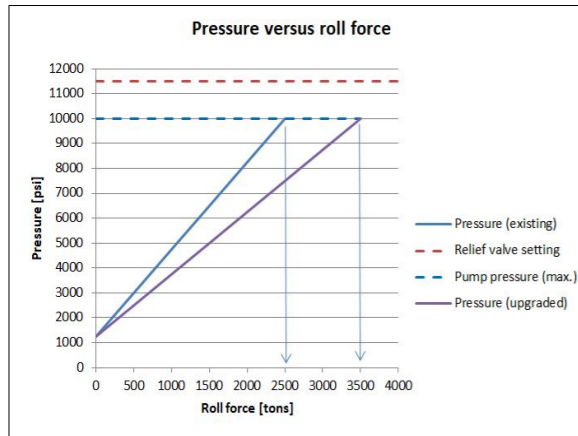


Figure 3. Hydrostatic system characteristics

As can be seen in figure 3, to provide for higher rolling forces while retaining an existing hydrostatic pump system, it is necessary to change the hydrostatic pressure versus roll force relationship.

### 3. Plant Description

#### 3.1 Overall

The Tandem Cold Mill is a part of an integrated steel making facility manufacturing a range of flat products including advanced high strength steels, API pipe grades, steel for electrical lamination applications, exposed automotive panels, martensitic grades and aluminized steels.

#### 3.2 Tandem Cold Mill

The 5 stand Tandem Cold Mill was originally built in the mid 1960's. The bearings are the same on all five stands and each stand has its own hydrostatic system.

The mill produces a wide range of cold rolled product, threading at low speed and regularly stopping under load in order to perform coil division.

In line with industry trends, the mill is looking to the future and to the increased production of advanced high strength steels. With this combination of low speed and high force, an upgrade to the hydrostatic system is required to maintain optimal bearing performance.

### 4. Hydrostatic upgrade

In order to increase low speed rolling force, the integrated force produced by the hydrostatic pressure field must be increased to compensate. Since the existing pump will be retained the hydrostatic pressure will be the same, so the volume of the pressure field must be increased by other means. The technique used to do this was to convert from a single pad hydrostatic bushing to a two pad bushing thus producing a wider pressure field, increasing its integrated volume, shown in 2 dimensions in Figure 4 and 3 dimensions in Figure 5 below.

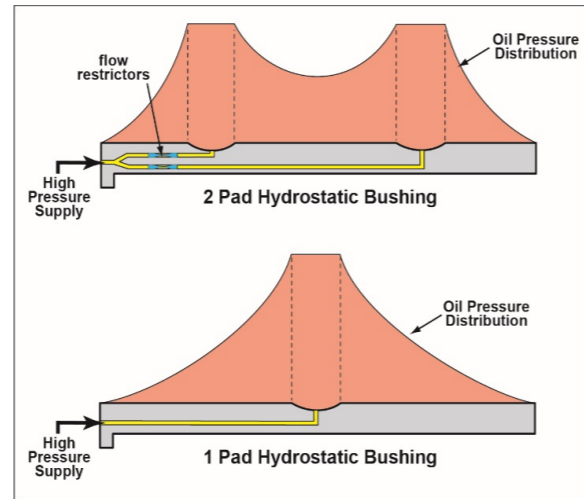


Figure 4. Two pad versus single pad hydrostatic bushing cross section

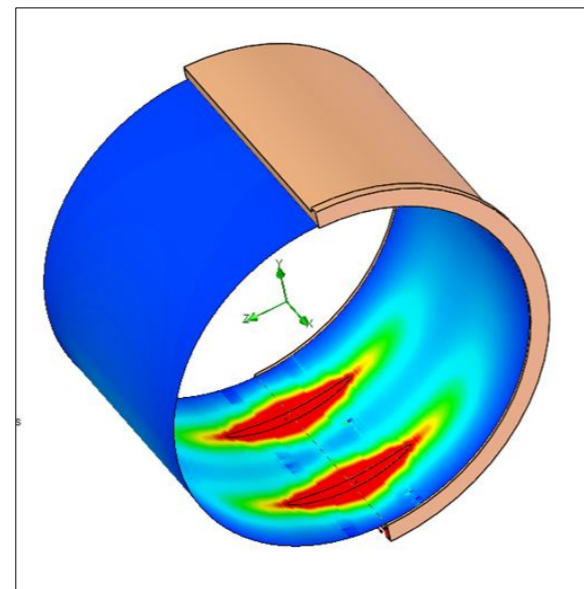


Figure 5. Two pad hydrostatic bushing pressure field 3D view

### 4.1 Key parameters of two pad hydrostatic design

The key design parameters for a hydrostatic bushing are:

- flow resistance in each of the two hydrostatic feeds
- pad spacing from the bearing centerline
- pad width
- pad angle
- pad cross section

The pad geometry along with the oil viscosity, flow rate, and bearing geometry (sleeve diameter, bearing width and bushing clearance) determine the hydrostatic pressure field. Some of the key parameters are shown in Figure 6 below.

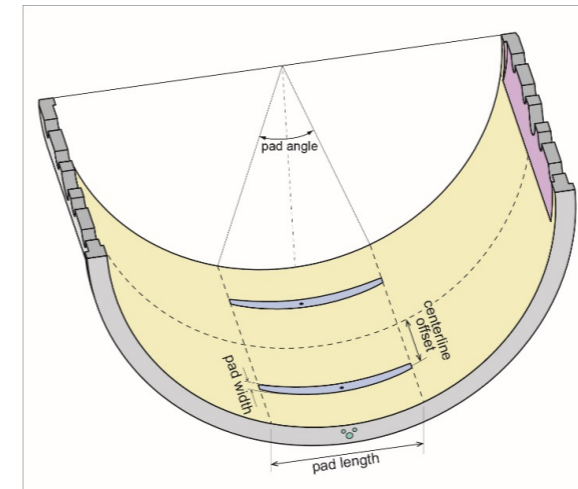


Figure 6. Two pad hydrostatic bushing geometry

### 4.2 Discussion of parameter optimization

Flow resistance in the bushing feed passages for inboard and outboard pads should ideally be equal. However, when the roll deflects causing the bearing sleeve to tilt in the bushing, the flow resistance is reduced to the pad with increased clearance, shown in Figure 7. This decreased resistance allows a higher flow through the pad with greater clearance. To prevent this resistance imbalance, flow restrictors are added to the feed passages. Resistance of the flow restrictor increases as flow increases. This causes more oil to flow through the pad with smaller clearance, thus increasing the pad pressure. This helps to realign the sleeve in the bushing to the optimal position.

Pad centerline offset is an important design parameter. If the pads are too close together then the two pads approximate a single pad bushing. If the pads are too far apart, then this places the point of maximum pressure close to the boundary condition of atmospheric pressure at the edge of the bushing. This causes oil pressure to be wasted

as it escapes to atmosphere. There is an optimum spacing that lies between the two extremes described.

The width of the pads is also of interest. The pads need to have some practical minimum width but if they are too wide, then this may compromise the hydrodynamic capacity of the bearing.

Ideally the cross section of the hydrostatic pad form is rectangular with a width considering the factors previously mentioned and a depth that does not introduce excessive pressure losses. However, a rectangular pad cross section has sharp corners at the ends resulting in stress concentrations that can be high enough to bring about babbitt cracking at the corners of the pad.

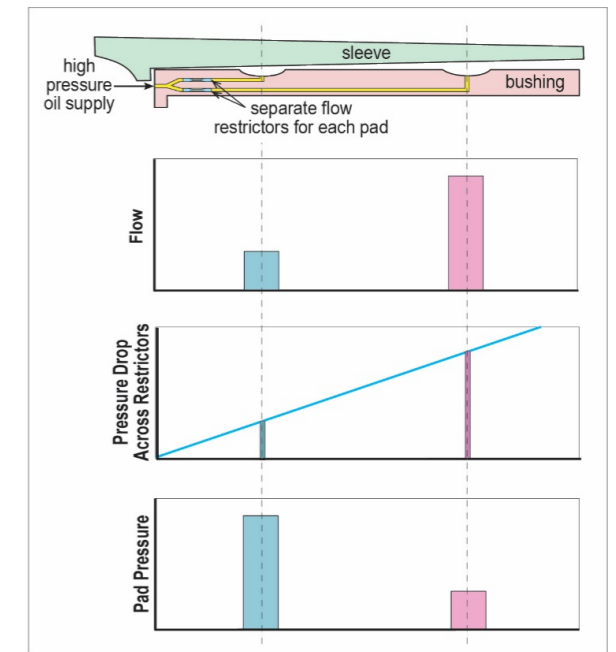


Figure 7. Adding flow restrictors to reduce imbalance

The pad angle directly affects the pad length as shown in Figure 6. The longer the pad length the better, however this can only be taken so far. Factors that need to be reviewed are the sleeve to bushing diametral clearance, the position of the sleeve in relation to the bushing shown in Figure 8 and the elastic deformation of the two. Should the pad be too long, then oil pressure will be lost though the end of the pad where the gap between the sleeve and bushing opens.

### 5. Analysis, design, manufacturing and implementation

In November 2016 the mill consulted with Primetals Technologies on upgrading the hydrostatic capacity of their bearings. With a maximum hydrostatic pump pressure of



10,000 psi the maximum roll force with the mill stationary was approximately 2,500 US tons. The aim of the project was to increase the maximum roll force to 3,250 US tons while maintaining the existing hydrostatic pumps and piping.

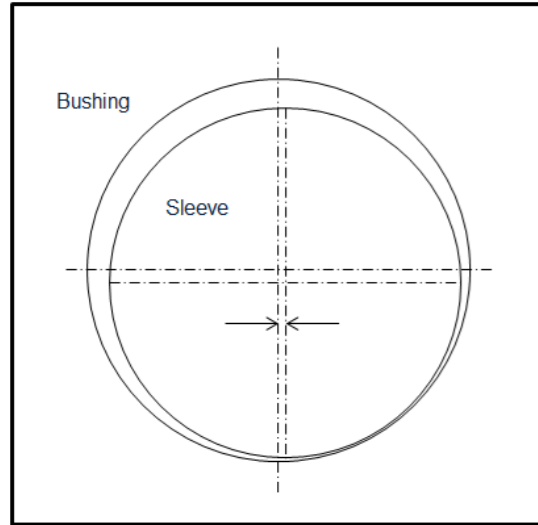


Figure 8. Position of the sleeve within the bushing

Existing mill data was supplied by the mill and analyzed by Primetals Technologies. By March 2017 the upgraded bushing design was complete including upgraded hydrostatic fittings. The purchase order for the project was received in June and four bushings were completed and assembled ready for mill testing in November 2017. Figure 9 shows a bushing in final inspection.

The four test bushings were installed in Stand 4 of the Tandem Cold Mill for a planned period of a week after which time they would be removed from service and inspected. During this time data was also gathered and analyzed. Based on the performance, additional improvements were made to the design. Manufacturing of the remaining bushings began in February 2018 and progressively installed during the remainder of that year.

## 6. Results

Figure 10 shows the relationship between hydrostatic pump pressure and total force for various backup roll speeds. During the project, data was recorded from the original design and the final configuration. For example in Stand 4 of the original design, when the mill is stationary at the maximum hydrostatic pump pressure, the maximum total roll force is limited to 2500 tons. In the final configuration, the maximum total roll force is increased to 3250 tons, an increase in hydrostatic force capacity of 30%.



Figure 9. Final inspection of a dual pad bushing prior to shipping

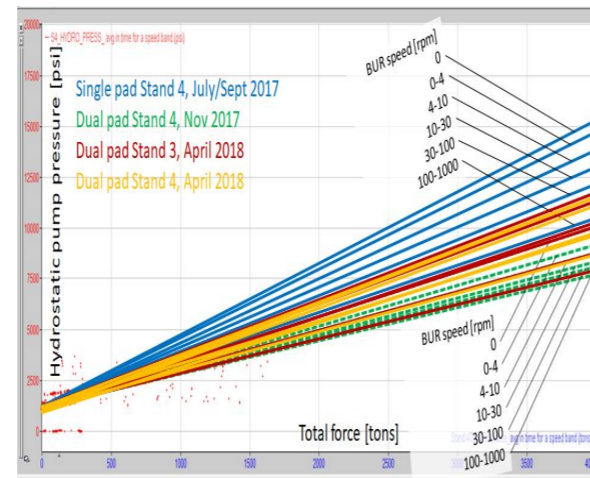


Figure 10. Dual pad versus single pad hydrostatic pressure

## Summary

Primetals Technologies has developed a cost effective solution to significantly increase the hydrostatic force capacity of MORGOIL® oil film bearings. This allows mill operators to increase rolling force without the expense to upgrade existing hydrostatic pumps and feed lines and no mill downtime for installation.

## Sıcak Haddelene Sonrası Yapı Profillerinde Soğutma Parametrelerinin Mikroyapı ve Mekanik Özelliklere Etkisinin İncelenmesi

Examine of Effects to Microstructure and Mechanical Properties of Cooling Parameter in Building Profiles After Hot Rolling

Aytaç Bulut, Atakan İpekkan

KARDEMİR HADDECİLİK • Türkiye

## Abstract

Steel has a very common usage area through many mechanical properties in order to its high strength, hardness, abrasion resistance, workability, impact resistance. Building profiles are also one of these areas. This study examines the microstructure and mechanical properties of a S275JR+AR quality profile under the appropriate cooling system. For this purpose, in the present cooling system, the microstructure and mechanical properties of the two samples with the same chemical composition and different thicknesses were cooled by different design and with this now cooling system of cooling operation to rolling products have been examined. In this context, hardness measurement tensile and notch impact test were carried out and also microstructure examines have been done.

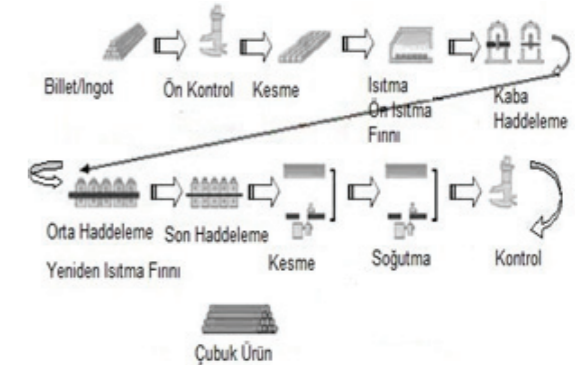
## Özet

Yüksek mukavemet, sertlik, aşınma direnci, işlenebilirlik, darbe direnci gibi birçok mekanik özelliklerinden dolayı çeliğin çok yaygın bir kullanım alanı vardır. Yapı profilleri de bu kullanım alanlarından biridir. Bu çalışmada, S275 JR+AR kalite bir profilin uygun soğutma sisteminin altında göstermiş olduğu mikroyapı ve mekanik özellikler incelenmiştir. Bu amaçla aynı kimyasal bileşime sahip ve farklı kalınlıktaki iki numunenin mevcut soğutma düzeninde, gerçekleştirilen farklı bir tasarımla soğutulması ve bu soğutma sistemiyle soğutma işleminin hadde ürününün mikroyapı ve mekanik özelliklerine etkileri incelenmiştir. Bu kapsamda, sertlik ölçümleri, çekme ve çentik darbe deneyleri gerçekleştirilmiş, mikroyapı incelemeleri yapılmıştır.

## 1. Giriş

Haddelene, malzemeyi kendi eksenlerinde birbirine zıt şekilde dönen iki veya daha fazla silindirik şeklindeki merdanenin arasından geçirmek şekliyle gerçekleştirilen bir plastik şekil verme yöntemidir. Haddelenede bazı etkin olan parametreler malzeme özelliklerine doğrudan etkide bulunmaktadır. Bu parametreler kütük kalitesi, ezme kuvvetleri, sıcaklık, merdane yüzey pürüzlülüğü, tufal miktarı, soğutma suyu sıcaklığı şeklinde

sıralanabilmektedir. Bu işlem için genelde silindirik şekilde olan merdanelere uygun ürün şeklini sağlamak için belirli şekillerde kalibreler açılır. Bu kalibrelerin açıldığı her geçiş yolu paso olarak adlandırılır. İşlem sıcaklığına göre rekristalizasyon sıcaklığının üzerinde yapılan plastik şekil değişimi sıcak haddelene olarak adlandırılır.

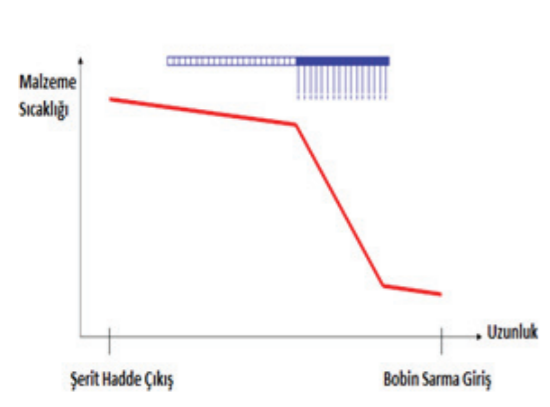


Şekil 1.1. Haddelene işlem basamakları.

Haddelene prosesinde yarı mamül olarak ilk kullanılan ürünler ingot, slab, blum, levha veya kütük olarak adlandırılmaktadır. Yarı mamül ürünlerin hadde tezgahlarındaki çeşitli kalibrelerle sahip merdane pasolarından geçirilmesiyle nihai ürün olan çubuk, sac, ray, boru, yapı profilleri gibi çok çeşitli şekilde ürünler elde edilebilmektedir.

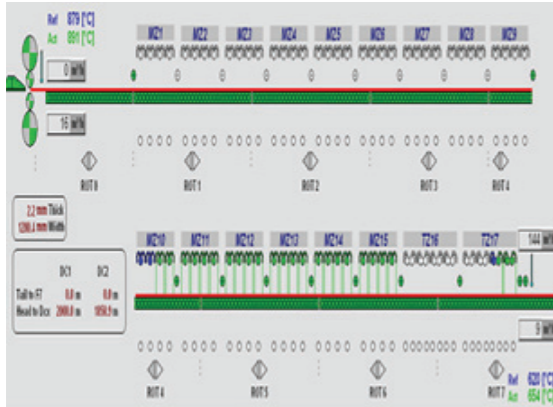
Hadde tesislerinde, tesisin kapasitesine ve ürün çeşitliliğine bağlı olarak, sıcak haddelene işlemlerinde iş parçasındaki kalıntı gerilmeleri ve distorsiyonları (çarpılmaları) gidermek üzere su verme işlemi belli bir prosese bağlı olarak uygulanmalıdır. Özellikle yapı profillerinde beklenen mekanik özelliklerin sağlanabilmesi için soğutma işleminin kontrollü yapılması gerekmektedir. Bu işlem prosenin devamındaki ürünün boyut ve ölçü kontrolü için kritik işlemlerden birisidir. Yapı profillerinde soğutma karakteristiğine uygun soğutma koşullarının oluşturulabilmesi ile kalitesi daha iyi olan nihai ürün özellikleri elde edilebilmektedir. Sac üretimi yapan şerit

haddehanelerin soğutma platformlarında erken hızlı, erken yavaş, geç hızlı, geç yavaş, çift fazlı soğutma gibi pratikler uygulanmaktadır. Uygulanan bu pratikler sayesinde katma değeri daha kaliteli ürün elde edilebilmektedir.



Şekil 1.2. Geç soğutma pratiği görünümü.

Geç soğutma pratiğinin geç hızlı ve geç yavaş olmak üzere 2 farklı kullanımı mevcuttur. Geç hızlı pratiğinde malzeme şerit haddeden çıkıp son aşama olan soğutma bölgesinin başında duşlu masa başlıkları açılarak malzeme aralıksız olarak tüm nozullar açık şekilde soğutma bölgesinden çıkar. Bu pratiğe ait nozul sisteminin gösterimi Şekil 1.3 'de verilmiştir.



Şekil 1.3. Geç hızlı soğutma pratiği

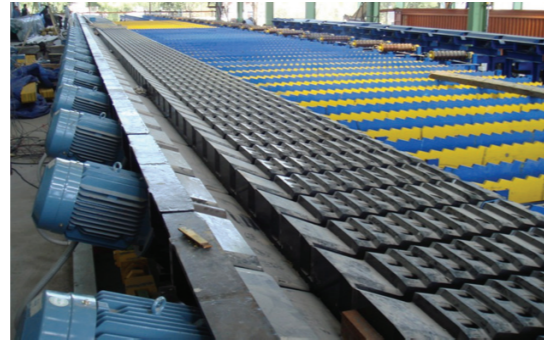
Şerit haddehanelerinde ki bu soğutma pratikleri malzeme kalitesine göre ürünün son özelliklerine uygun şekilde uygulanmaktadır. Ülkemizde sac üretiminde nihai ürün şeklinden dolayı daha kolay ve homojen uygulanabilen bu soğutma pratiklerinden esinlenerek profil haddehanelerinin temel üretiminde ciddi paya sahip olan köşebent profili için soğutma pratiği geliştirilmeye çalışılmaktadır. Yapı profillerinin sahip olduğu çeşitli şekillerden dolayı taraklı platform sisteminde soğuması gerçekleşmektedir.

Bu çalışma kapsamında Kar-Demir Haddecilik San.Tic. A.Ş Ar-Ge Merkezi'nde, yapı profillerinin sıcak haddelenmesinde uygulanan

geleneksel soğutma yöntemlerinin dışında yeni bir pratik geliştirilmiştir. Bu pratik geliştirilirken işletmedeki mevcut soğutma düzenindeki sorunlar değerlendirilmiştir. Mevcut soğutma düzeninde özellikle ince profillerde oksidasyon, su vermenin bölgesel uygulanmasından dolayı homojen olmayan soğuma koşulları, distorsiyonlar gibi istenmeyen durumlar gözlenmektedir. Bu durum soğutma sonrası proses işleminin devamı olan doğrultmada da verimli sonuçların alınamamasına neden olmaktadır. Bu çalışmadaki temel amaç bu istenmeyen durumlarının oluşumunu taraklı soğutma sistemiyle engelleyip ürün kalitesini daha çok karşılayabilen ürün geliştirmektir.

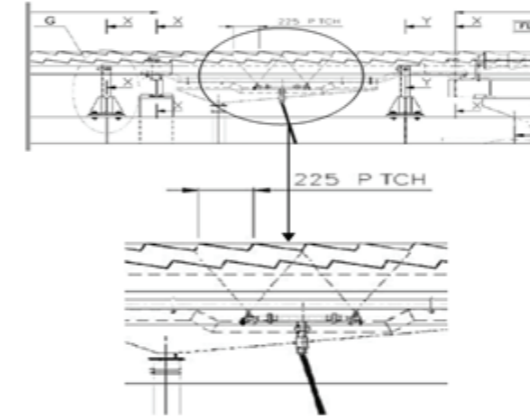
## 2. Taraklı Soğutma Sistemi

Sıcak haddeleme prosesi sonunda finish tezgahından çıkan sıcak mamul uçar makasta soğutma platformuna uygun boyutlarda kesildikten sonra soğutma platformuna iletilmek üzere role yoluna girmektedir. Role yolu sonunda bulunan kaset sistemi ile mamul taraklı platform üzerine bırakılır. Mamulün taraklı platforma giriş sıcaklığı yaklaşık 900 °C 'dir. Şekil 2.1'de taraklı soğutma platformu görünüşü verilmiştir.



Şekil 2.1. Taraklı soğutma platformu görünümü.

Taraklı soğutma platformu 45 adet taraktan oluşmaktadır. Mamul ilk 25 taraktan geçerken havada soğumakta, soğutma platformunda ilerlerken Şekil 2.1'de uygun soğutma bölgesi olarak tayin edilen 5 taraklık kısımda (25T1-30T1) tarakların altına yerleştirilen nozullar yardımıyla su verme işlemine tabi tutulmaktadır. Su verme sonrası mamul doğrultma role yoluna girene kadar (30T1-45T1) tekrar havada soğumaya bırakılmaktadır. Şekil 2.2'de su verme işleminin uygulandığı 5 taraklık bölgede nozulların yerleşimi gösterilmiştir. Sistemde iki farklı nozul bölgesinden ticari nozulların sahip olduğu püskürtme açılarında ve basınç değerlerinde su verme işlemleri uygulanmaktadır. Bu aşamada hadde hızı, su verme süresi, su verme sıcaklığı, hadde ürünü boyutları önemli parametreler olarak değerlendirilmektedir. Çalışmanın ilerleyen bölümlerinde bu parametrelerin yapı profillerinin soğuma karakteristiğine etkileri incelenmiştir.



Şekil 2.2. Nozulların soğutma platformu altındaki yerleşimi.

## 3. Materyal ve Metot

Bu çalışmada, S275JR+AR kalite genel yapı çeliğinden sıcak haddelenmiş 90X90X10 mm ve 130X130X13 mm boyutlarındaki Çizelge 3.1 'de kimyasal bileşimleri verilen iki farklı köşebent profile, Kar-Demir Haddecilik San. Tic. A.Ş Ar-Ge Merkezi bünyesinde gerçekleştirilen tasarım ve projelendirme çalışmaları ile üretilen soğutma sistemi prototip deney düzeneğinde farklı basınçlarda ve su verme yüksekliklerinde soğutma işlemi uygulanmıştır.

Çizelge3.1. S275JR+AR genel yapı çeliğinin kimyasal bileşimi.

90x90x10 mm Köşebent Profil							
C	Si	Mn	P	S	Cr	Ni	Mo
0,17	0,18	0,65	0,01	0,02	0,09	0,08	0,01
130x130x13 mm Köşebent Profil							
C	Si	Mn	P	S	Cr	Ni	Mo
0,15	0,19	0,61	0,02	0,01	0,01	0,09	0,01

Deney düzeneği, Şekil 3.1 'de verilen üretim hattındaki soğutma platformu su verme bölgesi referans alınarak üretilmiş, gerçek soğutma pratiği parametreleri uygulanmıştır. Deneysel çalışmalarda kullanılan soğutma deney düzeneği Şekil 3.1'de gösterilmiştir. Deney düzeneği, şase, 24 litre kapasiteli su tankı, pompa ve iki farklı tip nozuldan meydana gelmektedir. Deney düzeneğinde Nozul 1 (type JBU 1780 – 1/ 4 " - 90°) ve Nozul 2 (type JCQ 2310 B31- 3/8" - 60°) kodlarıyla verilen ve ticari olarak temin edilebilen nozullar kullanılmıştır. Çalışmada, iki farklı su

basıncı (1,2 ve 2 bar) iki farklı su verme (nozul-numune arası) yüksekliği (350 ve 500 mm) kullanılmıştır.



Şekil 3.1. Soğutma pratiği deney düzeneği.

300 mm boyundaki numuneler ikinci hadde yüksek sıcaklık fırınlarında üretim sıcaklık değerine kadar (yaklaşık 1100°C) 10 dakika süreyle tavlama işlemine tabi tutulmuştur. Tavlama sonrası ısıtılan numunelere, parametreler doğrultusunda sırasıyla 1,2 bar ve 2 bar basınçta, 350 mm ve 500 mm yükseklikte iki farklı nozuldan su verilmiştir.

Su verme süresi, iki farklı köşebentin hadde hızlarına göre Denklem 1'de verilen bağıntıya göre hesaplanmıştır.

$$t_{su\ verme} = \frac{L_p}{V_{hadde}}$$

Denklem 1'de verilen  $t_{su\ verme}$  : su verme süresi,  $L_p$  : soğutma platformu toplam boyu (48 m) ve  $V_{hadde}$  : hadde hızıdır.

Platformda verilen 5 taraklık (25T1-30T1 arası) uygun soğutma bölgesinde, otomasyon sistemi tarafından belirlenen hadde hızlarında ve Denklem 1'e göre hesaplanan su verme sürelerinde su verme işlemi gerçekleştirilmiştir. Çizelge 3.2'de iki farklı köşebent profil için hadde hızları ve su verme süreleri, Çizelge 3.3'te 90x90x10 mm köşebent profil için Çizelge 3.4.'te 130x130x13 mm köşebent profil için su verme parametreleri verilmiştir.



**Çizelge 3.2.** İki farklı köşebent profili için su verme süreleri ve hadde hızları.

	Hadde Hızı (m/s)	Bir tarak için su verme süresi	Toplam su süresi
		(s)	(s)
90x90x10 mm Köşebent Profil	3,4	14	70
130x130x13 mm Köşebent Profil	2,84	17	85

Su verme pratiği tamamlandıktan sonra malzemenin sıcaklığı termal kamera ile takip edilmiştir. Bu takibin sebebi soğutma dan sonra malzemenin bir sonraki proses aşaması olan doğrultmada sorun çıkarmaması için belli bir sıcaklığın altında kullanmak istememizdir.

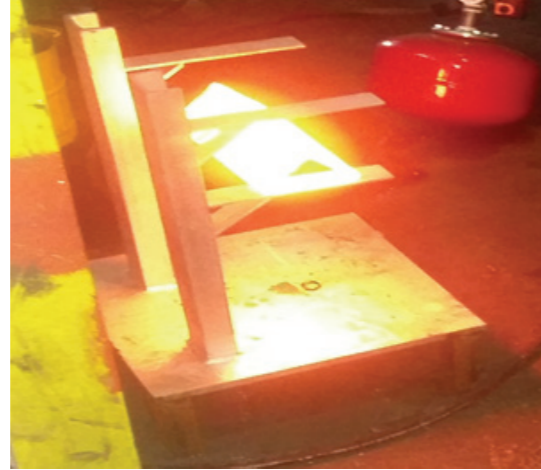
**Çizelge 3.3.** 90x90x10 mm köşebent profil için su verme pratik parametreleri

90x90x10 mm Köşebent Profil					
Deney No	Nozul	Nozul-Parça arası (mm)	Basınç (Bar)	Su verme Sıcaklığı (°C)	İşlem sonrası sıcaklık (°C)
1	1	350	1,2	400	50
2	1	350	2	400	48
3	1	500	1,2	400	55
4	1	500	2	400	51
5	2	350	1,2	400	26
6	2	350	2	400	26
7	2	500	1,2	400	23
8	2	500	2	400	25

**Çizelge 3.4.** 130x130x13 mm köşebent profil için su verme pratik parametreleri.

130x130x13 mm Köşebent Profil					
Deney No	Nozul	Nozul-Parça arası (mm)	Basınç (Bar)	Su verme Sıcaklığı (°C)	İşlem sonrası sıcaklık (°C)
9	1	350	1,2	450	76
10	1	350	2	450	60
11	1	500	1,2	450	80
12	1	500	2	450	78
13	2	350	1,2	450	35
14	2	350	2	450	30
15	2	500	1,2	450	50
16	2	500	2	450	30

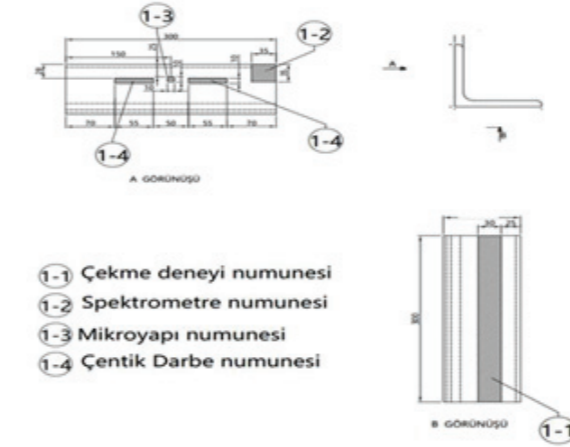
Şekil 3.2'de 950°C sıcaklıkta deney düzeneğine yerleştirilen 90x90x10 mm boyutlarındaki köşebent profilin 350 mm nozul mesafesindeki görüntüsü, Şekil 3.3'de 130x130x13 mm boyutlarındaki köşebent profile Nozul 1 ile 350 mm nozul mesafesinden su verme işlemi görüntüsü verilmiştir.

**Şekil 3.2.** 90x90x10 mm köşebent profilin 350 mm nozul mesafesindeki konumu**Şekil 3.3.** 130x130x13 mm köşebent profilin 350 mm nozul mesafesindeki Nozul 1 ile su verme işlemi

#### 4. Sonuç

Su verme işlemleri sonrası numunelerin mekanik özelliklerini belirlemek üzere çekme ve Charpy çentik darbe deneyleri uygulanmış, sertlik ölçümleri gerçekleştirilmiştir.

Mekanik deneyler Kar-Demir Haddecilik San. Tic. A.Ş Ar-Ge Merkezi laboratuvarında bulunan çekme deney cihazı, Charpy çentik darbe deney cihazı ve sertlik ölçüm cihazı ile gerçekleştirilmiştir. Deneylerde kullanılan numuneler, köşebent profillerin uygun bölgelerinden standartlara uygun olarak talaşlı imalat ile hazırlanmıştır. Şekil 4.1'de 90x90x10 mm boyutlarındaki köşebentten numune alınan bölgeler ve imalat resimleri gösterilmiştir. Çekme numunesi EN ISO 6892-1:2019 darbe numuneleri EN ISO 148-1:2016 standardına göre hazırlanmıştır.

**Şekil 4.1.** Köşebent profiller için numune çıkarma bölgeleri

Çizelge 4.1'de 90x90x10 mm boyutlarındaki köşebent profil için, Çizelge 4.2'de 130x130x13 mm boyutlarındaki köşebent profil için çekme testi deney sonuçları verilmiştir.

**Çizelge 4.1.** 90x90x10 mm köşebent çekme deneyi sonuçları.

90x90x10 mm Köşebent Profil			
Numune No	Çekme Mukavemeti (N/mm <sup>2</sup> )	Akma Mukavemeti (N/mm <sup>2</sup> )	Uzama (%)
1	485	320	27
2	483	318	29
3	475	316	30
4	480	314	29
5	479	312	27
6	481	316	30
7	482	317	29
8	480	311	31
A	470	296	34

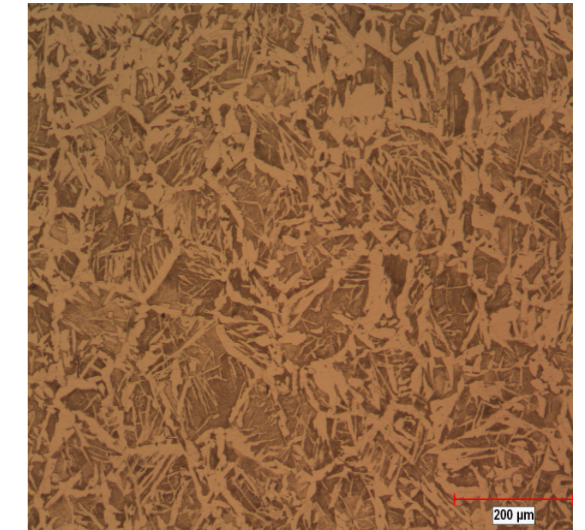
\*A: Su verilmemiş numune

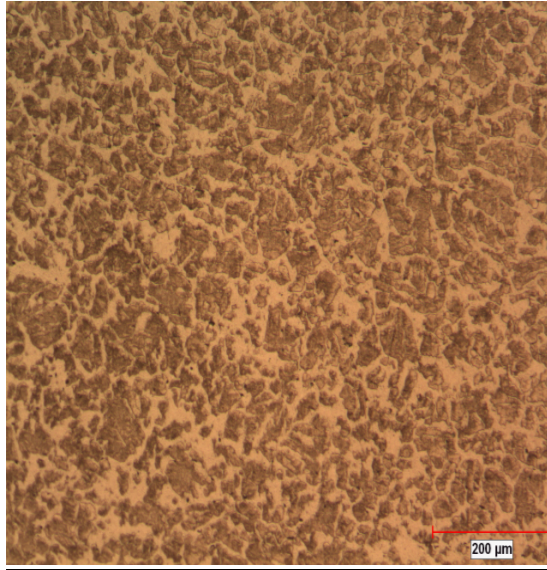
**Çizelge 4.2.** 130x130x13 mm köşebent çekme deneyi sonuçları.

130X130X13 mm Köşebent Profil			
Numune No	Çekme Mukavemeti (N/mm <sup>2</sup> )	Akma Mukavemeti (N/mm <sup>2</sup> )	Uzama (%)
9	472	300	30
10	468	280	32
11	470	303	30
12	461	281	33
13	470	299	31
14	467	272	32
15	461	295	31
16	463	283	32
B	460	279	34

\*B: Su verilmemiş numune

Numunelerin mikroyapı özelliklerini belirlemek üzere, Kardemir Haddecilik Metalografi Laboratuvarı'nda optik mikroskop incelemesi gerçekleştirilmiştir. Şekil 4.2'de 90x90x10 mm boyutlarındaki 1 numaralı köşebent profilin, Şekil 4.3'de ise 90x90x10 mm boyutlarındaki A kodlu köşebent profilin mikroyapısı verilmiştir.

**Şekil 4.2.** 90x90x10 mm ebadındaki 1 numaralı köşebent profillerin mikroyapı görüntüsü.



**Şekil 4.3.** 90x90x10 mm ebadındaki A kodlu köşebent profillerin mikroyapı görüntüsü.

Çizelge 4.3'de 90x90x10 mm köşebent profil için, Çizelge 4.4'de 130x130x13 mm köşebent profil için, çentik darbe deneyi ve sertlik ölçüm sonuçları verilmiştir. Sonuçlar malzemenin uygulanan soğutma pratiklerinde değişen enerji absorbe miktarı ile sertliği hakkında değişimleri yorumlamamıza yardımcı olmuştur.

**Çizelge 4.3.** 90x90x10 mm ebadındaki köşebent profillerine ait numunelerin çentik darbe ve sertlik ölçüm sonuçları.

90x90x10 mm Köşebent Profil		
Numune No	Darbe enerjisi (J)	Sertlik (HRB)
1	81	171
2	82	167
3	85	166
4	80	164
5	86	164
6	88	166
7	83	167
8	86	163
A	92	168

\*A: Su verilmemiş numune

**Çizelge 4.4.** 130x130x13 mm ebadındaki köşebent profillerine ait çentik darbe ve sertlik ölçüm sonuçları.

130x130x13 mm Köşebent Profil		
Numune No	Darbe enerjisi (J)	Sertlik (HRB)
1	71	137
2	79	134
3	71	137
4	78	133
5	80	136
6	82	136
7	79	138
8	73	137
B	89	139

\*B: Su verilmemiş numune

Bu çalışmada, Kar-Demir Haddecilik San. Tic .A.Ş. Ar-Ge Merkezi'nde, yapı profillerinin sıcak haddelemesinde uygulanan soğutma pratiklerinden farklı yeni bir soğutma pratiği geliştirilerek, mevcut soğutma düzenindeki; ince profillerde oksidasyon, su vermenin bölgesel uygulanmasından dolayı homojen olmayan soğuma koşulları, distorsiyon (çarpılma) gibi istenmeyen durumların giderilmesi amaçlanmıştır. Bu kapsamda "Taraklı Soğutma Sistemi" olarak adlandırılan yeni bir soğutma sistemi tasarlanmış ve iki farklı boyuttaki köşebent profile prototip olarak üretilen deney düzeneğinde yeni soğutma pratiği uygulanmıştır. Gerçekleştirilen çalışmaların sonunda aşağıda verilen sonuçlar elde edilmiştir.

1. Sıcaklık ölçümleri, deney şasesin de malzemenin ayakları uç kısımlarda kaldığı için orta bölgeden yapılmıştır. Su gelmeyen ayak ucu bölümleri sıcaklık olarak değişkenlik göstermiştir.
2. Sonuçlar üzerinde nozullar çok önemli etkiye sahip olduğu görülmüştür. Nozul-2'nin, Nozul-1'e oranla daha etkili soğutma sağladığı ve tam soğutmayı sağladığı görülmüştür. Buda Nozul-2'nin kullanımının daha uygun olacağını göstermiştir.
3. Beklendiği gibi nozul malzeme arası mesafe arttıkça soğuma da azalma görüldüğü için optimum mesafe tayini şarttır.
4. Mevcut soğutma düzeneğine göre, özellikle ikinci nozul da, mesafe farkı olmaksızın homojen tam soğuma görülmüştür. Birinci nozulda ise soğutma platformunun geri kalan uzunluğu da dikkate alınarak, üretim akışında doğrultma öncesi malzemenin uygun sıcaklığa kendi bünyesinde inip iyi bir doğrultma için gerekli durumu sağlayabileceği görülmüştür.

5. Profil boyutlarının değişiminin sıcaklık koşullarını etkilediği görülmüştür. Bundan dolayı her ebada göre bir soğutma pratiği geliştirilmesi gerektiği sonucuna varılmıştır. Kalın profilin, hadde hızının düşük olup tarakta geçirdiği süre daha fazla olmasına rağmen, uygun soğutma bölgesinde geçirdiği sürede, ince profile göre soğutma bölgesi çıkışında daha yüksek sıcaklığa sahip olduğu görülmüştür.

6. Mevcut soğutma düzeneğine göre yeni soğutma pratiğindeki düzenlemenin, her iki köşebent için genel olarak sertlik ve tokluk değerlerini az da olsa düşürdüğü görülmüştür.

7. Sıcaklık ölçüm sonuçlarına göre, geliştirilen yeni soğutma sisteminin, mevcut sisteme göre daha homojen (bölgesel olmayan) bir soğutma sağladığı görülmüştür.

8. Su verme işlemi sonrası mikroyapının asiküler ferrit-perlit mikroyapısına dönüşme eğiliminde olduğu görülmüştür. Müşteri talepleri doğrultusunda, mikroyapıda su verme hızları ve sürelerine göre beyrit-martenzit dönüşümü sağlamak üzere çalışmaların gerçekleştirilmesiyle katma değerli ürün geliştirmede farklı değerlendirmeler yapılabileceği öngörülmüştür.

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## Sıcak Haddede Haddanelerde Kullanılan Yolluk Sistemindeki Değişikliğin Malzeme ve Ekipman Üzerindeki Etkileri

Effects of Changes in the Guide System on Materials and Equipment Used to Hot Rolling Mill

Didem Kılıç, Orhan Akyol, Gencay Tosun

KARDEMİR HADDECİLİK • Türkiye

### Abstract

It is very important to keep the rolled material under control in rolling mill. The most important element of this is the guide. Especially, it is very important that these cases and guide work with the calibrators on the roller in the correct settings. This is an issue that needs more attention due to the high speeds in the production of fine products. After advancing over the roles of the processed material from the annealing, it reaches the counter and is rolled. When rolling, the guide allow the processed material to enter the rollers in proportion.

The processed material that passes through the static guide reaches the rollers and moves to the other machine by rolling. On the other bench, it passes through the guide and enters between the rollers. However, processed material that passes through static guide is subject to friction, which causes wear on both the guide and the material. In addition, more labor force is spent for the axis adjustment of static guide.

This study is about the elimination of some faults and adjustment difficulties caused by the abrasion experienced in static guide previously used in Kardemir Haddecilik firm with new design roller guide.

### Özet

Haddecilikte haddelenen malzemeyi kontrol altında tutmak çok önemlidir. Bunun da en önemli unsuru yolluklardır. Özellikle bu kasa ve yollukların merdane üzerindeki kalibreler ile doğru ayarlarda çalışması çok önemlidir. Bu durum ince mamul üretimlerindeki yüksek hızlardan dolayı daha çok dikkat edilmesi gereken bir husustur. Tavlama sonrası işlenmiş malzemenin roller üzerinde ilerledikten sonra tezgaha ulaşır ve haddelenir. Haddelene malzemenin yolluklar işlenmiş malzemenin merdanelere orantılı olarak girebilmesini sağlar.

Statik yolluklardan geçen işlenmiş malzeme merdanelere ulaşır ve haddelenerek diğer tezgaha ilerler. Diğer tezgaha yine yolluktan geçerek merdaneler arasına girer. Ancak

statik yolluklardan geçen işlenmiş malzeme, sürtünmeye maruz kalır ve bu da hem yolluk üzerinde hem de malzeme üzerinde aşınmaya sebep olur. Bunun yanında statik yollukların eksen ayarı için daha çok işçi gücü harcanmaktadır.

Bu çalışma, Kardemir Haddecilik firmasında daha önce kullanılan statik yolluklarda yaşanan aşınmanın malzeme yüzeyinde oluşturduğu bazı hataların ve ayar zorluğunun yeni tasarım makaralı yolluklar ile giderilmesi ile ilgilidir.

### 1. Giriş

Kardemir Haddecilik, demir çelik sektöründe büyük bir paya sahip olan genel yapı çelikleri üretimini gerçekleştirmektedir. Bu üretim esnasında öncelikle kaliteli ürün ve tam verimle üretim ilkeleri esas alınmaktadır. Bu sebep ile hadde yaşanan ve yaşanabilecek olumsuzlukların minimize edilmesi gerekmektedir.

Hadde sisteminde yer alan ekipmanlarda, sürekli üretimden kaynaklı aşınmalar görülmektedir. Bu aşınmalar bir süre sonra üretilen ürünün yüzey kalitesinin azalmasına neden olan etmenlerin başında yer almaktadır. Ürünün yüzey kalitesine direkt olarak etki eden etmenlerin en önemlilerinden biri de yolluklardır.

Yolluklar üretilen ürünün merdaneler tarafından doğru geometri ile kapılmasına kılavuzluk etmektedir. Yolluklarda yaşanan aşınmalar ürünün yüzeyinde kendisini göstermektedir.

Üretim sisteminde kullanılan statik döküm yolluklar yüzey kalitesi konusunda yetersiz kaldığı için makaralı yolluk kullanımına geçilmiştir. Bu yeni makaralı yollukların sisteme montaj-demontajı ve bakım kolaylığı için yeni bir mühendislik tasarımı ile geliştirilmiştir.

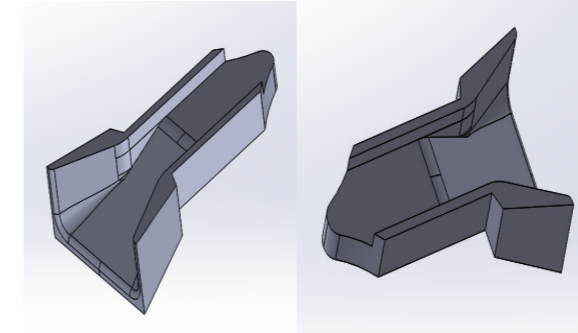
### 2. Tasarım Çalışmaları

Tasarımda öncelikle tasarımın çalışma şartları incelenmiştir. Sıcak haddeleme prosesinde kullanılan yolluk makaraları ekstra ağır şartlar altında çalışmaktadır. 1000 ° C sıcaklık, tufal içerikli soğutma suyu, yüksek devir sayısı, malzeme girişlerinde koç darbeleri gibi şartlar altında çalışmaktadır. Üzerinde çalışma yapılan yeni yolluk tasarımları tüm bu şartların en ağır olarak

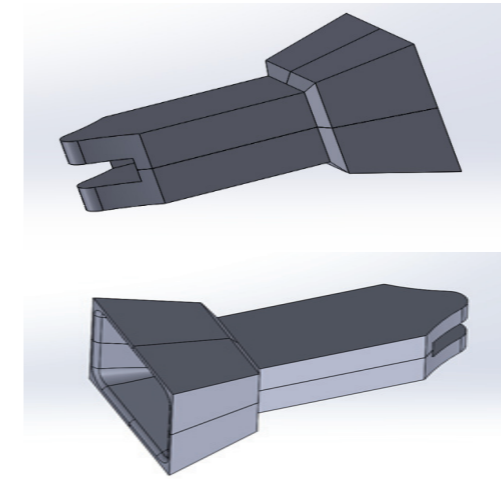
yaşandığı noktalarda çalışmaktadır. Yüksek devirlerden dolayı sıcak malzeme ile en uzun süre temas halinde kalan bölgedir.

### 2.1 Tasarım Öncesi Durum

Daha önce kullanılan statik yolluklarda yaşanan aşınma, sürtünme kaynaklı malzemenin yüzey kalitesi düşmekte ve yine bunun sonucunda kasaya ait bağlantı elemanlarında tahribatlar yaşanmaktadır.



Şekil1. Statik Yolluk Katı Model Kesit Görüntüsü

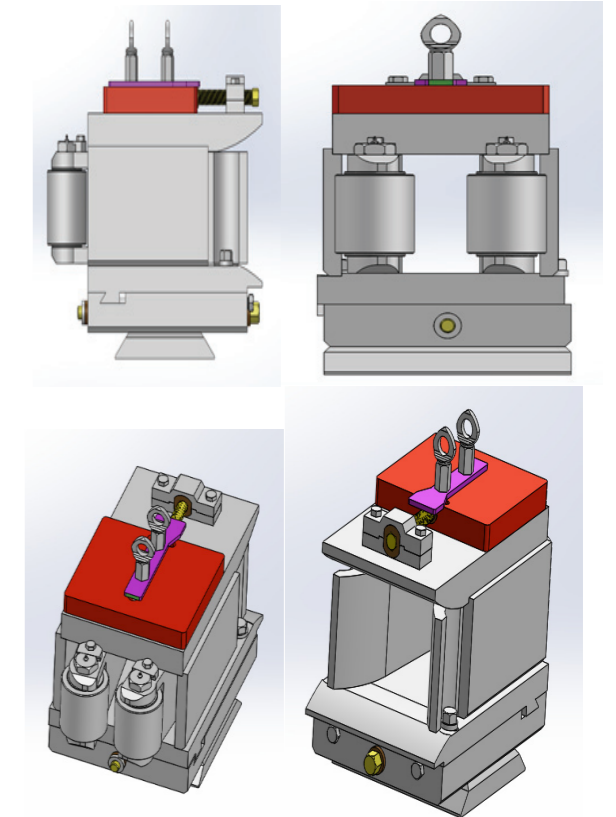


Şekil2. Statik Yolluk Katı Model Görüntüsü

### 2.2 Tasarım Çalışmaları

Endüstriyel tavlama fırınından gerekli sıcaklık ve sürede tavlama işlenmiş malzeme tezgaha ulaşır. Tezgaha ulaşan malzeme yolluk ile kontrollü bir şekilde merdaneler arasına girer. Bu aşamada yolluğa ulaşan işlenmiş malzeme sağ ve sol kollar ile öncelikle kontrol altına alınır. Yolluk içerisinde ilerleyen malzeme makaraların arasından geçerek

merdanelere ulaşır. Tasarımda kullanılan makaralar malzemenin yolluk ile arasında oluşan sürtünmeleri ortadan kaldırarak malzemeye kılavuzluk eder. Sıcak iş takım çeliğinden üretilen makaraların uzun ömürlü olması sağlanmaktadır. Giriş yolluklarının tasarımı bir önceki tezgahın, çıkış yollukları bir sonraki tezgahın kalibre şekline göre dizayn edilmektedir. Böylece malzemenin merdaneler arasına girmeden daha iyi kontrol edilmesi sağlanmaktadır. Yüksek hadde hızlarında küçük makara çaplarından dolayı makaraların yüksek devirlerde dönme gereksinimi olmaktadır. Ayrıca hadde tufalı ve merdane soğutma suları da rulmanlar için risk oluşturmaktadır. Makaralarda kullanılan bu rulmanların seçiminde ağır çalışma şartlarına uygun bakım teknikleri dikkate alınmaktadır.



Şekil3. Yeni Makaralı Yolluk Katı Model Görüntüsü

Yeni tasarım yolluklar; makara, kaide, kırılmaç, ayar plakası, ayar vidası, taban sacı, sağ ve sol ayar vidası, ara sac, ayar takozu kısımlarından oluşmaktadır. Tezgahtan gelen malzemenin haddelenmesini sağlamak amacıyla tezgahlar ile uyum içinde çalışmaktadır. Yolluklar merdanelerle uyumlu 2 adet makaraya sahiptir Tezgahtan gelen malzeme makaralar ile kontrol altında tutulmaktadır.

Makaralar ile gelen darbe kuvvetlerini sönümlemesi ve sürtünmeyi azaltılmaktadır.

Tasarım malzemeye yön vermek ve kontrol altında tutmak için merdanelere karakterize çalışmaktadır. Tezgah üzerinde merdanelerin önünde yer almakta ve makaralar avare çalışmaktadır. Bu sayede akuple edildiği tezgah ile uyumlu hızda çalışır. Bir ürünün uygun kalibrasyondaki farklı ebatları için de makara ayarı yapılarak kullanılabilir ve bu sistem ile malzemedeki çapak oluşumunu büyük oranda azaltılmıştır.

#### 4. Sonuç

Yeni tasarım makaralı yollukların getirmiş olduğu özellikleri şu şekilde sıralayabiliriz;

- Makaralar ile sürtünmeyi engellemesi,
- Makaraların kalibreye uygun olmasıyla malzemeyi daha iyi kontrol etmesi,
- Kolay ayarlanabilirliği sayesinde pratik olması,
- Statik yolluklara nazaran bakım yapılabilme imkanı olması,
- Daha az tufal birikimi sağlaması,
- Hadde sisteminde kullanılan yeni tasarım yolluklar üretimin daha kaliteli olması ve önceki sisteme göre daha pratik ayar yapılabilmesi,
- Makaralar merdane kalibrelerine uygun tasarlanmıştır.
- Bakım ve revizyon yapılarak tekrar kullanılabilir olması,
- Pratik şekilde hadde eksenine göre ayarlanabilir olması,
- Aşınma ve deformasyona karşı dayanıklı olması,
- Makaralı olmasından dolayı uzun ömürlü kullanıma uygun olması,
- Malzemenin merdanelere maksimum kontrol ile girmesinin sağlanmasıdır.
- Malzeme kalitesinin aratmasının sağlanmasıdır.

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## Gel Bonded Cement Free Shotcrete

Jel Bağlı Çimentosuz Shotcrete Refrakter

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#### 1.Abstract:

Gel bonded shotcrete is a cost effective, cement free single component system that delivers improved performance versus cement bonded shotcrete systems. Gel bonded shotcrete requires no liquid addition other than water for mixing. It has no special handling requirements. The gel bond system contains no chemically combined water allowing dry-out time to be reduced to half that required for cement bonded shotcretes. Significantly improved hot mechanical properties are achieved by eliminating fluxing agents. For a 60% Al<sub>2</sub>O<sub>3</sub> shotcrete, 1399°C hot modulus of rupture increases from 10,0 to 14,0 MPa. Refractoriness under load improves from 1611 to 1671°C.

#### 2.Introduction:

Refractory castables are commonly categorized as conventional (>2,5% CaO), low cement (1,0 to 2,5% CaO), ultralow cement (0,5 to 1,0% CaO) and no cement (<0,5% CaO). Low cement castables are used in a wide variety of industrial applications. They are available in vibration casting mixes, pump mixes, shotcretes and self-flow products. They are further used to produce complex pre-cast shapes. Low cement castables utilize less cement and fine reactive powders to increase refractoriness and improve mechanical properties.

The cement binder is the weak link in the low cement system as it reacts with aluminosilicate mix components to form liquid phases at elevated temperatures. When the liquid phase is present in sufficient quantity, a loss of strength and reduced load bearing capability result. Therefore, it is desirable to keep cement to a minimum.

Several approaches have been used to improve the mechanical properties of low cement castables. Perhaps the easiest and most straight forward approach is to simply reduce the cement content to create ultra-low cement castables. Cement free systems may provide additional improvements as all of the deleterious CaO component is eliminated from the matrix of the castable.

Cement free systems bonded with silica-sol are widely used in steel and industrial applications. They are two component systems consisting of graded refractory materials and a silica-sol binder. The principle advantages of the silica-sol bonded materials are reported to be fast dry-out, improved high temperature mechanical properties and improved adhesion to existing refractory surfaces. Disadvantages of silica-sol binders include their high cost and special storage requirements. Silica-sol binders must be stored above 2°C and below 43°C to avoid irreversible gel formation or precipitation of silica. Precautions must be taken in transit and on construction sites to ensure silica-sol is properly stored. The silica-sol binder may represent as much as 30% of the cost of a 60% alumina shotcrete.

Gel bonding represents a new cement free bonding concept. It is a cost effective, single component system that is mixed with water. It requires no special handling characteristics and is mixed exactly the same as its cement bonded counterparts. Gel bonded refractories have excellent mechanical properties at elevated temperatures as they are completely cement free. They can be used in harsh environments where cement bonds may be attacked by process gases (chlorine as an example). They can be fired more rapidly than cement bonded shotcretes.

#### 3.Experimental Results:

The compositions listed in Table 1 are commercial shotcrete products. Test specimens were cut from 40x40x10 cm shotcreted panels for all of the physical property testing.

Table 1: Test compositions of castables in weight percent.

Component:	Cement	Gel Bond
60% Al <sub>2</sub> O <sub>3</sub> Aggregate	Major	Major
Alumina	Minor	Minor
Microsilica	Minor	Minor
70% Alumina Cement	Minor	No
Hardener	No	Yes

#### 3.1.Density and Porosity

Density and porosity for the cement and gel bond products do not change significantly over a broad temperature range for either bond type. The gel bonded product appears to be slightly superior to the cement bonded product, but the improvement results largely from differences in bulk composition and not bond type.

Table 2: Density and porosity of shotcrete samples.

	Bulk Density, kg/m <sup>3</sup>		Apparent Porosity, %	
	Cement	Gel Bond	Cement	Gel Bond
816°C	2483	2499	15	17
1093°C	2499	2547	17	16
1399°C	2371	2483	19	17
1500°C	2371	2483	18	17

#### 3.2.Abrasion Testing

The ASTM-C-704 abrasion test consists of abrading a 11,43 cm by 11,43 cm refractory pad, pre-fired to 816°C with SiC grit at a 90° angle to the pad. Abrasion loss is reported in cubic centimeters (A) where A is determined by:

$$A = (M1-M2) / B \quad (1)$$



M1 = weight before testing; M2 = weight after testing; B = bulk density.

Abrasion resistance is a key metric for many industrial, cement and petrochemical applications. Gel bonding leads to improved abrasion resistance. The example in Table 3 shows the gel bonded shotcrete is 35% more abrasion resistant.

Table 3: ASTM C-704 Abrasion test results of shotcrete samples reported in cubic centimeters abraded.

	Cement	Gel Bond
816°C	11,9	7,7

**3.3.Strength Testing**

Figures 1 and 2 present cold and hot strength data for the cement and gel bond shotcretes. Gel bonding significantly improves strength. The cement bonded shotcrete strength is largely unchanged between 816 and 1500°C. Gel bonding provides steady strength gains in the same temperature range. Gel bonded shotcrete has nearly double the strength of the cement bonded product after firing to 1399°C.

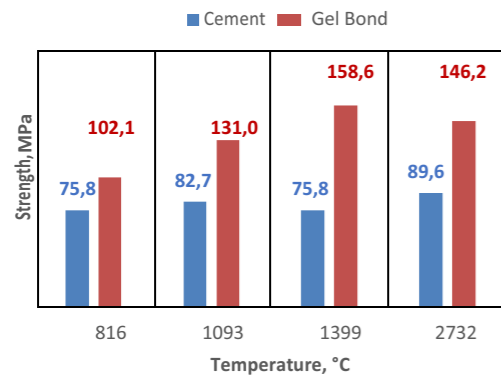


Figure 1: Cold crushing strength of shotcrete samples after firing.

Cement reacts with the aluminosilicate aggregates and fine powders at elevated temperatures to form an Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub>-CaO liquid phase that significantly lowers strength when present in sufficient quantity. Gel bonding eliminates cement and improves hot strength. Gel bond hot strengths range from 21,4 MPa at 1093°C to 6,2 MPa at 1500°C. Hot strengths for the cement bonded shotcrete range from 7,3 MPa at 1093°C to 0,9 MPa at 1500°C.

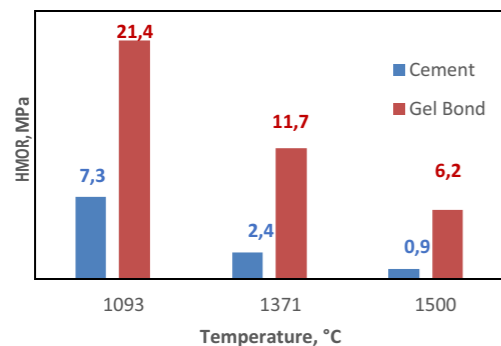


Figure 2: Hot modulus of rupture of shotcrete samples.

**3.4.Refractoriness Under Load**

Refractoriness under load measures the dimensional changes that occur to a cylindrical sample as it is heated at a constant rate of temperature increase. Temperatures corresponding to a fixed amount of sample deformation are determined.

Cement and gel bonded samples were cast and dried at 104°C prior to RUL testing. The cement bonded sample displayed shrinkage between 816 and 982°C. Mullite formation between 1399 and 1482°C produced a slight expansion before liquid formation produced a 1% deformation at 1523°C. The cement bonded shotcrete reached 5% deformation at 1611°C.

Gel bonded shotcrete had more pronounced sintering shrinkage between 982 and 1093°C. Mullite formation between 1399 and 1482°C produced expansion of the test piece. 1% deformation occurred at 1593°C. The gel bonded shotcrete reached 5% deformation at 1671°C.

Table 4: RUL deformation temperatures for each bond type.

Deformation	Cement	Gel Bond
1%	1523°C	1593°C
2%	1560°C	1634°C
5%	1611°C	1671°C

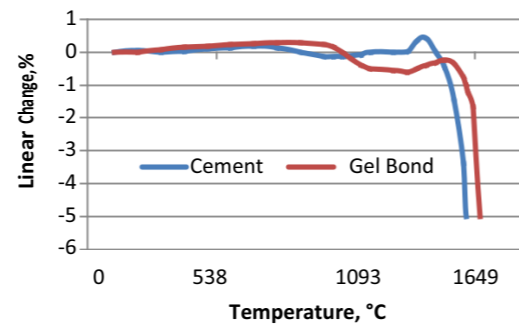


Figure 3: Refractoriness under load test results for shotcrete samples. (DIN 51053/ISO 1893 RUL, Stress = 0,20 MPa)

**3.5.Adhesion Test**

Shotcrete is frequently applied onto existing refractory to repair the lining rather than removing good refractory and relegating that good material to a waste recycler or landfill. Good bonding between the old refractory and shotcrete is critical for long lining life.

An adhesion test was devised to measure the bond strength between existing refractory and the newly applied shotcrete. The test consisted of casting 22,9x11,4x7,6 cm brick, drying those brick at 104°C for 24 hours and pre-firing to 816°C for 5 hours to obtain the substrate. The pre-fired brick were broken in half to expose a roughened surface for the shotcrete. The substrate was placed into a steel mold (Figure 4) and shotcrete was cast against it (Figure 5). The composite was cured overnight at 22°C, dried at 104°C for 24 hours and fired to 816°C for 5 hours. 20,3x3,8x3,8 cm bars were cut from the composite block and broken in 3 point bend.



Figure 4: Substrate positioned in mold

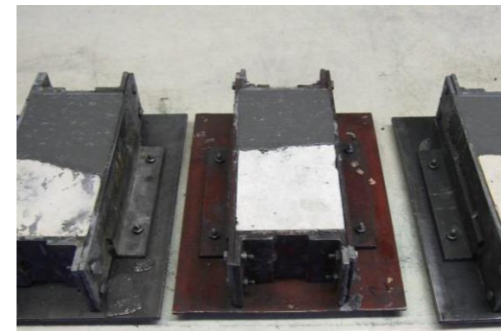


Figure 5: Shotcrete cast against substrate prior to de-molding

Figure 6 shows cut cross-sections of the cement bonded shotcrete cast against the cement bonded substrate (top), gel bonded shotcrete cast against the cement bonded substrate (middle) and the colloidal silica bonded shotcrete against the cement bonded substrate (bottom). All of the shotcretes bonded well with cement bonded substrate. There are no obvious cracks or imperfections.

Adhesive strength is reported in Table 5. Gel bond shotcrete and cement bonded shotcrete have very similar adhesive strengths. The adhesive strength of the colloidal silica shotcrete is 50% lower than those of the other bond types.

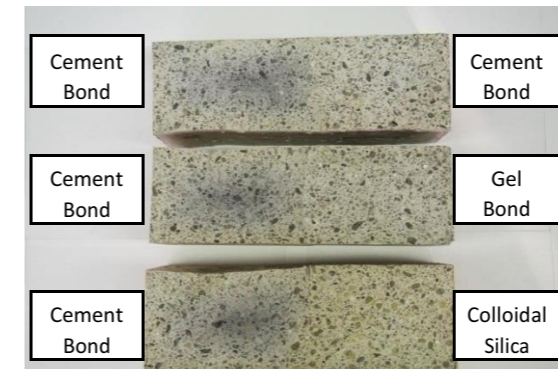


Figure 6: Cross-section of composites after firing to 816°C

Table 5: Adhesive strength of each shotcrete bonded to the cement bonded substrate.

	Modulus of Rupture, MPa
Cement	7,2
Gel Bond	7,3
Colloidal Silica	3,6

**3.6.Dry-out study**

5x5x5 cm cubes were cast and cured in sealed plastic bags at 22°C for 24 hours. All cubes were dried at 104°C. A sub-set of the cubes were dried for 24 hours at temperatures ranging from 149 to 427°C.

The gel bonded and colloidal silica shotcretes lost 95.8 and 97.8%, respectively, of the total liquid addition after drying at 104°C. Water was completely removed after drying to 149°C.

The cement bonded shotcrete only lost 73.9% of the water added after drying at 104°C. Of the water added, 20.6% was combined in calcium aluminate hydrate phases that yielded their water loss at temperatures at or above 177°C.

Table 6: Weight loss of shotcretes with increasing temperature.

Temperature, °C	Weight Loss,%		
	Cement	Gel Bond	Colloidal Silica
104	73,90	95,82	97,75
149	5,51	4,18	2,25
177	4,41	0,00	0,00
204	4,60	0,00	0,00
232	2,94	0,00	0,00
260	2,57	0,00	0,00
288	2,02	0,00	0,00
316	1,29	0,00	0,00
371	2,76	0,00	0,00
427	0,00	0,00	0,00

The absence of high temperature hydrate phases enables the use of a shorter dry-out schedule for gel bonded shotcrete. Schedules for a 1204°C dry-out for 22,9 cm thick linings of cement bonded or gel bonded shotcretes are shown in Figure 7. Total dry-out time for the cement bonded shotcrete is 62 hours and for the gel bonded shotcrete is 38 hours. One full day (24 hours) of downtime is eliminated from the dry-out.

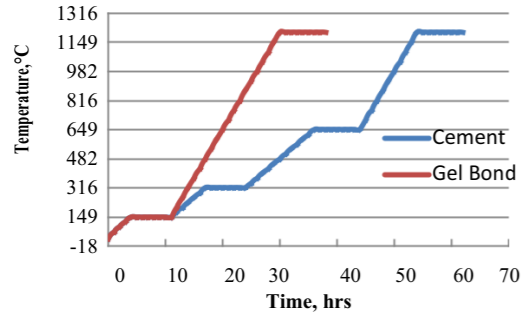


Figure 7: Dry-out schedule for a 22,9 cm thick lining.

**3.7. Acid Resistance Testing**

Cement bonded refractories normally are not chosen for high acidic environments, because the acid will corrode the cement bond increasing the erosion of the material and reducing the strength. Cement Free products are more suited for the acidic environment because the bond better resists the acid attack since the bond is not alkaline based.

The test developed consisted of submerging refractory samples in an HCl acid solution with a concentration of 1 Molarity and removing the sample after a set amount of time. The containers with the samples and acid solution were stored at room temperature. After a set amount of time, the samples were removed, rinsed, and dried in a 104°C oven. Once dried, the samples would be weighed and compared to the weight before being placed into the acid bath to determine the weight loss.

Cement bonded, gel bonded, and colloidal silica shotcretes were cast into 5x5x5 cm cubes, cured at 22°C for 24 hours. All cubes were dried at 104°F. Cubes of each product were pre-fired to five different temperatures (204°C, 427°C, 649°C, 871°C, 1093°C) before being placed in the acid solution. Samples were removed from after two weeks and four weeks,

Figure 8 illustrates the weight loss of each product after 2 weeks and 4 weeks in the acid bath. The gel bonded and colloidal silica products had little to no weight loss regardless of the pre-fired temperature or the time in the acid bath. The cement bonded product with the low pre-fired temperature had significant weight loss. At the higher pre-fired temperatures, the cement bonded product had about 1% weight loss, compared to the gel bond and colloidal silica products which had no more than 0,5% weight loss.

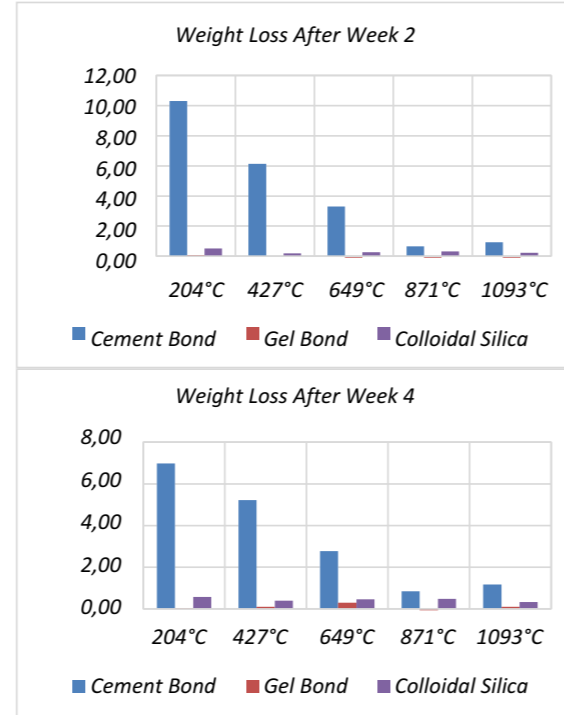


Figure 8. Weight loss of samples after 2 and 4 weeks in acid bath.

Figure 9 and 10 show the samples after being removed from the acid bath after 2 and 4 weeks, respectively. After 2 weeks, none of the samples had any visual reduction in the bonding matrix. However, after 4 weeks, the cement bond had noticeable wear in the bonding matrix at the low pre-fired temperatures. This correlates to the weight loss shown in Figure 8. The gel bond and colloidal silica had no observable wear in any sample.



Figure 9. Samples after being removed from acid bath.

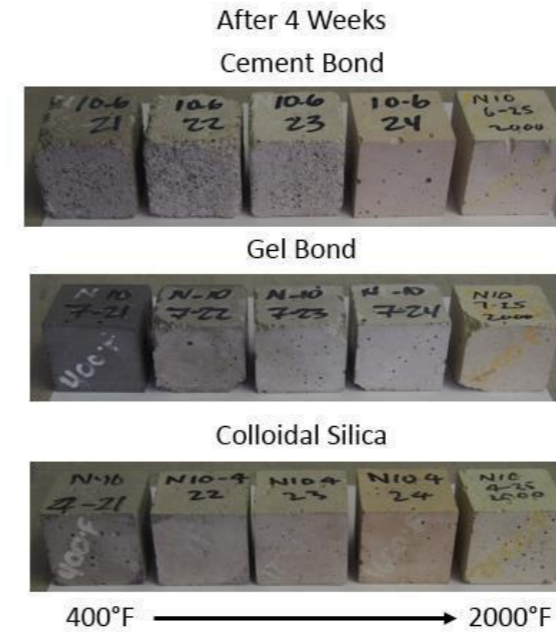


Figure 10. Samples after being removed from acid bath.

**4. Conclusion:**

Gel bonded shotcrete is a unique new material that makes a seamless transition from low cement to no cement technology. Gel bonded shotcrete is a cost effective, single component system that handles exactly like a low cement shotcrete. Gel bonded shotcrete uses exactly the same mixing, pumping and accelerator pumps that are used with low cement shotcrete.

Low cement shotcretes continue to be widely used in many different applications, yet situations do arise where cement bonded products cannot be utilized. Harsh chemical environments may preclude the use of a cement bonded product. Needs for high temperature load bearing or high hot strength will favor gel bond shotcrete. Gel bonded shotcrete saves money by reducing downtime as faster dry-outs can be used. Gel bonded shotcrete is an excellent repair material as it bonds much better than silica-sol shotcrete to existing refractory. Gel bonding eliminates expensive silica-sol binders.



## The Use of Colloidal Silica Bonded Refractories in Reheat Furnaces

Tav Firmalarında Kolloidal Silika Bağlı Refrakterlerin Kullanımı

Donald Park

MAGNECO/METREL UK • United Kingdom

Firstly, to the organisers- thank you for your kind invitation, and it is my pleasure to represent Magneco/Metrel at this prestigious event.

Today I want to talk to you about the unique and innovative refractories developed and manufactured by Magneco/Metrel. In order to understand where we are today, firstly, we need to look at the history of refractories.

To the outsider, refractories are seen merely as a commodity item- bought and sold, used and disposed of. To us they are a lifeline, a vital functioning item in many manufacturing processes.

Take a moment to think about everyday things in our lives that we take for granted. Refractories are indispensable for all high temperature processes such as in the production of metals, cement, glass, and ceramics. Then imagine a world without refractories- there would be no cars, no planes, no gas or electricity and we would be eating from wooden plates and living in mud brick huts.

Is it little wonder that refractories should rightly be awarded the accolade of being the backbone of modern industry? Manufacturing in its current form could not exist if not for the technological advancements in refractory materials since the Industrial Revolution.

The history of refractory materials starts in the days when humanity just discovered fire. Because of their chemical composition and reactions, refractories are fairly complex. However, the basic principles behind them are remarkably simple. In fact, these principles were present as early as 3000 BC. When people began to dig primitive pit kilns in the ground to fire their earthenware such as bowls, plates etc. It is reasonable to presume that these pits were dug into some form of soil resistant to fire. The desired form of the soil was to retain the heat and not to deform under the heat.

Refractory technology began in earnest during the Iron Age (2000 BC). Nature provided the first refractories, crucibles of rock where metals were softened and shaped into primitive tools.

Using charcoal in a furnace, iron was produced by reducing the iron ore with extreme heat. Furnaces used in

iron production featured very elementary refractory lining, usually consisting of unshaped fireclay, carbon-added composite materials, and silica rock, although blocks cut from natural stones or fireclay brick were also used.

All through the Iron age from ancient times up till now, refractories have been closely engaged in Iron and Steel making, contributing to human civilisation.

Modern refractory technology is considered to have begun during the era of the Industrial Revolution (the 18<sup>th</sup> & 19<sup>th</sup> centuries). After originating in the United Kingdom on three pillars- steam engines, coal and steel, the Industrial Revolution expanded to many other countries.

From the simple (e.g. fireplace brick linings) to the sophisticated (e.g. re-entry heat shields for the space shuttle), refractories are used to contain heat and protect processing equipment from intense temperatures. The range of use is so vast that there is no single universal refractory, and therefore there are specific products used to line boilers and furnaces of all types, reactors, ladles, kilns, and the like. An enormous variety of refractories exist, designed to meet the temperature and process requirements of each application.

Not all processing equipment is the same size or shape and therefore there is a vast array of refractory products available to line the vessel. Traditionally, these products were formed shapes- bricks, blocks etc. In some circumstances, these are designed to form arches, crowns, turn circles, some are very simple shapes or can be complex, for example, "squares" or "chequers" used to line the regenerators of glass furnaces, or blast furnace stoves.

End users often impose tighter and tighter specifications on the dimensions of the fired shapes. Inevitably there will be some variability in the size due to vagaries in the manufacturing and firing processes and in order to meet the specification, some additional processing is essential, adding further costs to the price of the refractory and extra time to the availability. Further complications can occur when the process technologists want higher and higher operating temperatures and refractories to meet their requirements. So, it becomes a greater problem for the

producers, not only to develop the refractory, but sometimes the refractory to line the kilns used to fire the refractories!

World-wide refractory production is around 35-40 million tonnes per year determined largely by the Iron & Steel sector which has remained the driving force, consuming 60-70% of the total demand. Consequently, any developments in Iron & Steel production technology have knock-on effects on the refractories industry. A significant trend in refractory technology is the increased use of monolithic materials.

Refractory products are supplied in two forms, shaped or unshaped. Monolithic is the term generally applied to unshaped refractories. Shaped refractories include fired or unfired materials with predetermined structures, precast shapes and fusion cast refractories. Monolithic materials include plastic mixes, castables, ramming materials, dry vibrable, gunning materials, fettling materials, coatings, and mortars. Monolithic materials have evolved over the years into a widely used class of refractory materials that offer performance and cost effectiveness. Monolithic materials differ from refractory bricks in that they are not shaped and fired before being supplied to the end user. These materials do not have high energy requirements, are more readily available, take shorter times to install and require less skilled manpower. They account for more than half of the total production in many countries due their quicker and cheaper installation and to properties that approach those of formed products.

The first "plastic" refractories were mixtures of plastic clay and crushed "grog" (a term basically meaning reclaimed refractory bricks) supplied in a wet mouldable form, installed chunk by chunk by workers using hammers. Crude castables consisting of refractory aggregates and a form of Calcium Aluminate cement [CAC] were only introduced after 1928. Over the decades there was a steady increase in the popularity of castables as new forms of CAC were introduced to the marketplace, firstly as low cement versions and then ultra-low cement versions, combined with advances in the quality and type of binders, aggregates and additives and to innovations in their design and installation. Ultra-fine materials such as clay, Microsilica or Alumina replaced some of the cement. By the mid 1980's, castable products accounted for around 20-30% of total global production.

The need for monolithic, joint free refractories arose from the problems associated with traditional brick-mortar refractory constructions as joints are often the performance limiting area of the lining. Even if the refractory bricks are of outstanding characteristics, the joint is often preferentially attacked. Channelling of gases or liquids into the lining through joints can cause damage

behind the refractory lining. Joints are also associated with thermal inefficiencies within the furnace.

Vessels requiring a refractory lining are seldom flat or without irregularities. As a result, flat-sided bricks rarely can be installed without voids which must be back-filled, or which result in a permanent weakness in the refractory lining. The cutting of bricks can reduce the number of voids but cannot eliminate them and involves more labour in the installation. The installation of brick linings requires skilled labourers and is very time consuming. The availability of the skilled labour has steadily declined and becomes a premium cost consideration in any new project. Each bricklayer can only install a limited number of bricks per hour.

Whilst monolithic products were growing in usage, nevertheless, there were inherent problems including strict control of the water quality, temperature and ambient temperature, (in hotter climates, the dry aggregates often have to be placed in refrigeration units to maintain the product at a lower temperature), short working time, difficult moisture removal, long dry-out times as the product required strict temperature /time constraints to allow for the various hydration phases to develop if steam spalling or drying flaws were to be avoided. It is not uncommon for the dry-out of such products to take several days.

In the mid 1980's, the founder of Magneco/Metrel and eminent Chemist, Mr. Charles Connors began to explore the use of Colloidal Silica [CS] as a binder for refractory castable products and brought about the most dramatic change in castable technology. By replacing the Calcium Aluminate Cement with Colloidal Silica, most of the disadvantages of conventional castables were eliminated whilst retaining the advantages of the now familiar low and ultra- low cement castables. By the end of the decade, the first "Cement-Free" monolithic castable refractories based on a patented "sol-gel" bonding nanotechnology were commercially available. The technical and commercial acceptance of Magneco/Metrel's products has been a great challenge, especially considering that switching from conventional and low moisture castables to Magneco/Metrel's products represents a complete change in technology for the customer. The first products utilising the unique Colloidal Silica binding system were "pumpables" which could of course be cast but also could be moved through hoses at a great distance. These products use a Colloidal Silica binder (not water) that is mixed with the dry powder/aggregate at the job site prior to installation. The Colloidal Silica is a proprietary aqueous formula that incorporates nanometer size, ionised Silica particles. Special setting additives in the dry

component cause the material to gel and set at a controlled rate. The gelation is due to a condensation reaction that involves the release of water. Unlike Calcium Aluminate Cement bonding, which produces chemically bonded water, the Colloidal Silica bonded material liberates chemically attached water and creates a chemical bond that does not break down through dehydration as the material is heated. Since the water is not chemically bonded, most of the water in the gel structure is free to be released at very low temperatures (100°C). However, a very small quantity of water in the form of attached hydroxyl groups can still be released at much higher temperatures. This release of water, although nearly undetectable, results in the formation of additional Si-O-Si bonds that further enhance strength development.

At low temperatures, the CAC materials are very dense and have very low permeabilities. As the refractory is heated, the physical water is driven off, followed by the chemically bonded hydrated water over a broad temperature range. As each of these phases gives up its chemically bonded water, bonding strength decreases, and permeability and porosity increase until all the water has been removed. At high temperatures the porosity can become very high and leave the refractory more prone to gas attack and penetration by the molten product and by-products such as slag etc.. With CS bonded refractories, once the physical water has been removed, the porosity remains relatively constant to much higher temperatures. The lower porosity at intermediate temperatures leaves the CS bonded refractory more resistant to oxidation, gas attack and penetration. The presence of chemically bonded hydration phases in cement bonded materials results in very low permeability which makes it difficult for gases and liquids to exit. In the case of CS bonded castables the lack of hydration phases results in higher permeabilities and easier gas and liquid removal at drying temperatures.

The absence of any cement in CS bonded products means there are fewer low melting point phases, the hot strength is considerably higher than competitive low cement products. The softening associated with low melting point phases can result in shrinkage in low cement castables. The cement bonded product exhibits sintering and shrinkage with temperature resulting in a less volume stable material. This can cause cracks to form that may lead to penetration. With the cement free products, the expansion curve is constant and positive indicating volume stability at temperature.

Creep is the deformation with time that can result as a consequence of applied pressure at elevated temperatures. An analysis of the creep resistance of CS and CAC bonded

materials indicates that the CS product shows virtually zero creep under typical test conditions. Again, the lack of lime based low melting point phases in the matrix is the principle reason for this. The volume stability and matrix purity of the CS bonded products have significant impact on their thermal shock resistance.

One of the major and initial applications of Colloidal Silica bonded refractories was in the blast furnace cast-house trough, iron and slag runners. At one time the majority of the blast furnace troughs in the USA had been lined and maintained by using Colloidal Silica bonded pumpable products. A significant number of troughs are still lined with these products throughout the world. The ease of application, quicker dry-out and heating along with their superior, thermal shock resistance, oxidation resistance and adhesion characteristics allow the prolonged use of these refractories with accompanying reduction in cost. The experience gained in this application and the extreme versatility in most varieties of refractory compositions, led to the development of a family of products allowing for the technology to be applied in numerous industrial applications where monolithic refractories are increasing the share of applicability such as in ferrous and non-ferrous metals, glass and other markets.

The Colloidal Silica bonded materials can easily be placed via concrete pumping equipment. The ability to pump the material over long distances means that the equipment can be located away from the immediate work area thus providing a less congested and safer working environment. The self-levelling characteristics of these materials allow placement without the aid of vibration. Cement based products cannot be pumped without dilution and any increase in water addition has detrimental effects leading to inferior properties and poor performance. It is not uncommon for such materials to set prematurely in the pipes causing lengthy delays in the installation. One newer installation technique, originally developed in the civil construction sector, is that of "shotcreting". This technique allows for rapid placement without the need for complex formwork. This process differs from the more commonly used and widely understood term of gunning. The major difference is that shotcreting utilises a wet slurry pumped to the work area whereas in gunning the dry powder is pumped and mixed with water at a nozzle. Compressed air is used to project the mixed slurry onto the target area and an accelerant is injected into the airstream which causes the material to thicken, losing flowability in a matter of seconds rather than hours, as is the case of normal pumpables. Shotcreting is also advantageous for repairs where time is of the essence, typical installation rates of

approximately 10 tonnes per hour can easily be achieved, depending upon the type of equipment used. An added feature is that shotcrete version of CS bonded refractories can be applied to very hot surfaces without the risk of steam spalling, explosion or laminations.

The high cost and extended downtime required for conventional refractory removal and replacement requires significant amounts of capital. Many industries were motivated to seek alternatives and to consider a reduction in refractory consumption, improve performance and increase production, extend the lifetime time of some critical areas and maintain the refractory in a serviceable condition.

Replacing spent brick linings involves replacing many undamaged bricks as well as many partially damaged. Although only a small portion of brick may be damaged, it is typically required to replace the entire brick. It is estimated that perhaps upto 40% of good brick is often removed unnecessarily. These spent bricks must be disposed of in environmentally safe landfill that is now a significant cost.

The ultra-fine nature of the Colloidal Silica binder and the nature of the siloxane bond formation allows for excellent bonding to existing clean refractory linings. The nanometer sized particles are much finer than the typical micron sized cement particles and more easily penetrate the surface of existing linings. Siloxane bonds can then form and penetrate into the surface material of the lining. Cement bonds do not extend into the refractory lining, but only allow for a physical interlocking with voids or cracks in the surface. The unique bonding allows for multiple pours without producing laminations and for quick and cost-effective repair by casting or shotcreting. The materials wear at a predictable rate and it is therefore easy to introduce a maintenance regime to minimise downtime whilst utilising the optimum lining thickness.

Pusher type, walking beam, walking hearth and rotary hearth furnace hearths used to be lined with high alumina plastics. Traditionally, the sub-hearths and roofs were lined with brick. Colloidal Silica bonded products have been applied in the sub-hearth and roof of these furnaces with significant improvement in lives. Also, the heated steel slabs, bars and billets come out less defective due to gouging since the reaction of the mill scales with the refractory is minimal. At process temperatures, CS bonded products are also very abrasive resistant compared to conventional cement bonded castables and can withstand abrasion better than some grades of shaped refractories. However, it must be recognised that because they do not

contain cement, CS bonded products exhibit a lower, as poured, strength at room temperature than cement bonded castables, until they are heated above 200-300°C. After such heating, strength improves significantly, and consequential abrasion resistance also increase accordingly.

The absence of Calcium Aluminate Cement in Colloidal Silica bonded materials makes them very resistance to Acid and Alkali attack and therefore suitable for use in pickling tanks, soaking pits etc.

The Colloidal Silica bonded products can also be used to manufacture shapes which are supplied pre-fired and ready for installation. These shapes exhibit superior properties.

In a recent study, a comparison was made to determine the benefits that an owner/operator could derive from using Colloidal Silica bonded refractories rather than Cement bonded products in a rotary reheat furnace having a diameter of about 25metres. The work was only to demolish and renew the inner and outer curbs, the working lining and sub-hearth layer. Both the cool down and demolition would each take the same length of time, about 4 days. The total amount of refractory product to be installed was approximately 500tonnes. One contractor estimated that for Cement bonded products it would take approximately 26 days and only 14 days for the CS bonded products. This is attributed to the fast pumping rate of 10t per hour. Dry out for the cement bonded products was given as 7 days, compared to only 3 for the Colloidal Silica products.

Overall, the duration for the Cement bonded products would be 41 days and only 25 days for the CS products. A time saving of 16 days.

If the throughput is 140t/hour, this equates to 3360t/day. If a modest profit of \$100 per tonne is assumed, then there is potential for additional profit of \$5,376,000 over the 16-day period. This is but one example of what is possible and the huge benefits to end users.

Of course, you can have the best refractories, but if they are not installed correctly this seriously compromises the as installed properties and ultimately, performance will be adversely affected and they are unlikely to achieve the desired life-time.

Magneco-Metrel will provide operators and equipment of the highest standards and work with contractors who are competent and experienced to assist with the various facets



of the installation work to help the end user achieve his goals and objectives in a cost efficient way.

Colloidal Silica bonded, pumpable refractory linings provide significantly reduced installation time, require

minimal dry-out, enable reduced downtime, demonstrate exceptional performance, improved lifetime, increased production often with less energy and the ability to postpone conventional relining.

The author acknowledges the help and assistance of colleagues in the preparation of this paper.

[During the Oral presentation, a number of slides will be used to illustrate salient points and examples of different types of furnace repairs]

## Slab Movement Optimisation by Automated Suggestion Modelling

Otomatik Öneri Modeli İle Slab Hareket Optimizasyonu

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İSKENDERUN DEMİR VE ÇELİK • Türkiye

### Abstract

In this slab movement optimization approach; we focused on lowering excessive handling by homogenizing the stacks and boosting lot-shifting system. The project is implemented and tested in a pilot area of the Iskenderun Iron and Steel Co. (ISDEMİR) Slab Stock Yard.

Due to the (dimensional and steel grade) homogenization of the stacks; improvement in occupational safety, 5S and process safety has become more efficient. Lot shifting between slabs has become easier due to the combination of identical slabs. The effective capacity of the slab yard has been increased. Scheduling of rolling mill programs has become easier.

The results are recorded and compared with the past data. The average number of slab handlings per day was reduced by more than 30%. Great reduction in dimensional average absolute deviation has been observed. Diversity of steel grades in each stacks has been decreased.

### 1. Introduction

Isdemir slab yard is a hot slab yard where mainly the slabs are sorted and stacked according to production schedule and charged into slab reheating furnaces. Addition to this main task, slabs are stacked destined to move on scarfing, trimming, shipping, or batching at outside yards. Stacking of different types of slabs with different dimensions and steel grades is a very complex activity for any crane operator.

Heterogeneous stacks like this bring some problems;

- These stacks have risk of collapse.
- The stack cannot be used at full capacity
- When a long-hot slab is stacked on a short slab, it bends and causes problem while charging into reheating furnaces
- With the mix of different manufacture lot number of slabs, the slab excessive handling increases

To solve these problems, an automated optimization model is created and implemented in a pilot area of ISDEMİR slab

yard which is pointing the slab to the best point with the parameters, predetermined.



**Figure 1.** A Stack Formed By Operators Judgment Before the Project

### 2. Experimental Procedure

To see the homogenization of stacks;

- Annual, mean value of average absolute deviation of slab widths in each stack
- Annual, mean value of average absolute deviation of slab lengths in each stack
- Annual, mean value of number of steel grades in each stack

To see the count of Shuffling

- Annually mean number of slab handlings of each day

These performance indicators are recorded and tracked after implementation of the algorithm.

#### 2.1. Second-level subheading

Crane monitoring system includes; X-Y lasers and reflectors, crane system (Level2 application) and Slab Stock Management System (Level-3 application) inside

the crane cabin. Slab stock fields are coordinated by dividing them into symbolic addresses in certain x-y value ranges. (See: Figure.2)

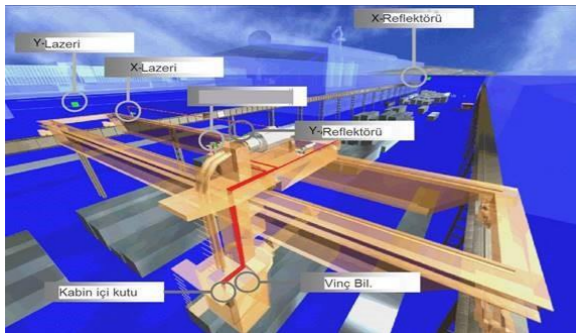


Figure 2. X-Y Lasers on which is being used for virtual mapping

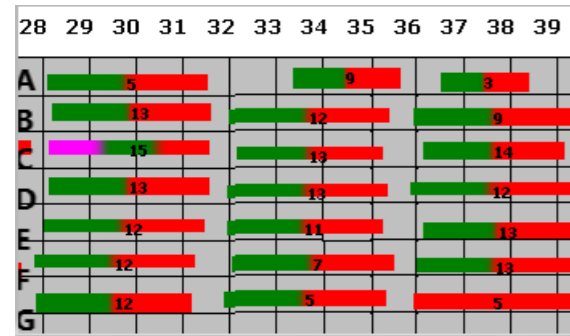


Figure 3. Level3 Virtual Map of a Small Part of The Slab Stock Yard

Slab movements and locations are recorded in the Slab Stock Management System by transmitting the values read from X-Y lasers from Level2 application to Level3 application.

All field registration procedures and crane work order management are performed in Slab Stock Management System.

Slab transfer handling operations were carried out under the control of crane operators. All field information was recorded on a daily basis for this decision mechanism to be realized by the software.

The field changes were examined by performing data analysis on the formed data. Proposal algorithm was supported with operational practices, crane operator feedback and research. Tracking, control and development in the software is facilitated by using the created algorithm with a flow chart.

In order to respond to Level2-Level3 communication in the fastest way and to conclude the analysis on the data in

the shortest time, the flow diagram created was processed in database procedures. The suggestion algorithm runs when any slab is picked and destination address is displayed on the Crane Tracking System Level2 Operator Screen.

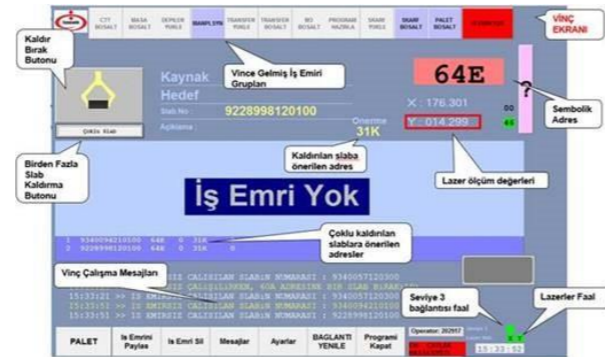


Figure 4. Level2 Operator Screen

### 3. Results and Discussion

After implementation of the suggestion system at the 17<sup>th</sup> of May 2019, improvement in the slab stock yard by means of stack homogenization and slab manipulation number are seen visually and numerically.



Figure 5. Pictures, Before and After the Project

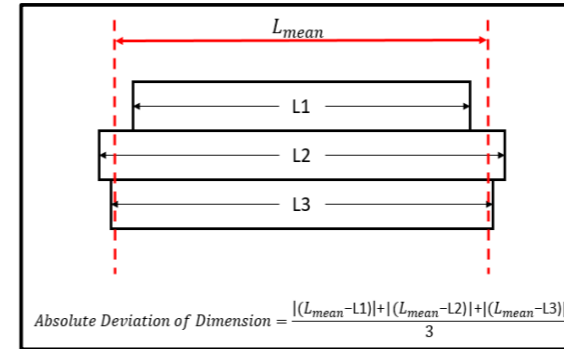


Figure 6. Formula of Average Absolute Deviation of Length For a Stack with 3 Slabs

Average absolute deviation is calculated for each stack by widths and lengths. And the the results showed the general condition of the slab yard.

If each stack had composed with the slab with same length, the average absolute deviation number would be zero. The more the number converges to zero, the more stacks homogenize dimensionally.

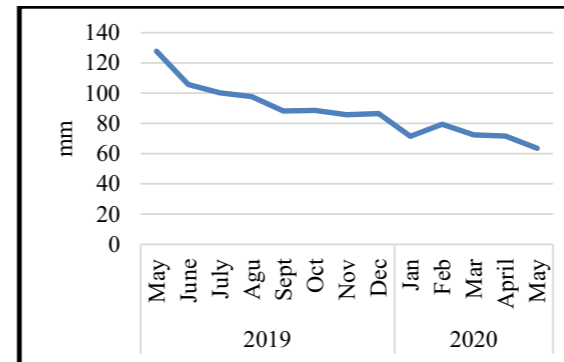


Figure 7. Average absolute deviation of widths for each stack

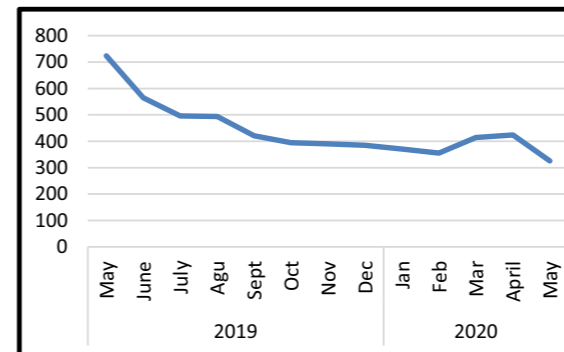


Figure 8. Average absolute deviation of lengths for each stack

As seen in the Figure 7 and Figure 8, great reduction is observed after the project implemented.

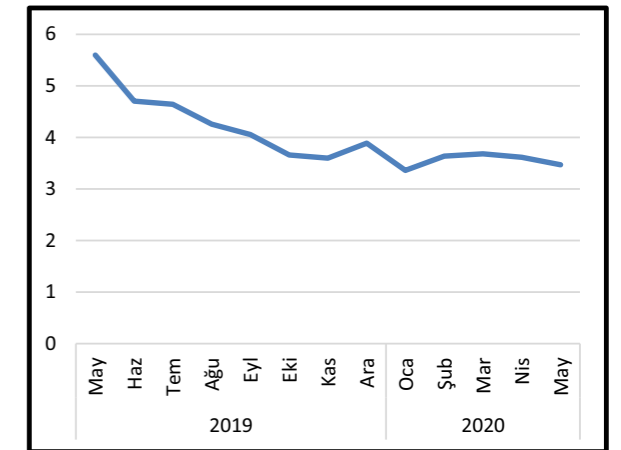


Figure 9. Variety of Steel Grades in Each Stack  
Variety of steel grades in each stack is dropped. Same steel grades are stacked together more.

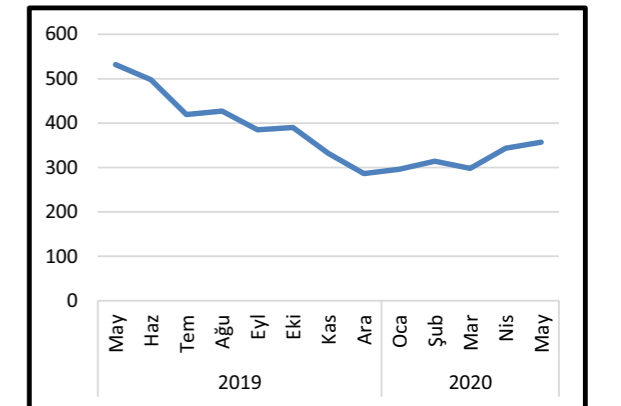


Figure 10. Average Daily Slab Handling Numbers

Average daily slab handlings dropped from around 500 a day to around 300 a day saving more than 300.000TRY a year.

### 4. Conclusion

Slab handling optimizations are rarely studied and only a few article is published similar to this project. Most of these studies are theoretical and they only focus on coil schedule. But in this unique study, all types of slabs are sorted differently and scheduling of the coil is also supported by embedding inside of the algorithm. The algorithm is implemented to ISDEMIR slab stock yard and tested on the area. The results were achieved only by the implementation of the algorithm without taking any other action, such as fully or partially rearranging any stacks.



## INC718 Alaşımının Sıcak Dövme Prosesinin İncelenmesi

Investigation of Hot Forging Process of INC718

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### Abstract

Inconel 718 high temperature superalloy is the main material used in aero engine which has high strength, resistance to oxidation, good high temperature fatigue and creep properties at 700°C. Aero engine components such as turbine disc, blade, case, shaft, seal and fastener are all fabricated by Inconel 718 [1]. In this study, the microstructure and mechanical properties of fine-grained Inconel 718 pancake forging were investigated. The most suitable forging parameters were determined using Finite Element Analysis (FEA) before forming the INC 718 alloy with hot forging. Then, the forging process range was determined as 1050 - 1150 ° C and the process was carried out so that the strain rate did not exceed 100 1s<sup>-1</sup>. Counterblow hammer was used and worked at 200 kJ energy and 1100°C forging temperature. In addition, the deformation speed was worked as 1800 mm / sec. Morphology of grains size of INC718 alloy were characterized, grain sizes were obtained according to ASTM 4.

### Özet

Inconel 718 yüksek sıcaklık süper-alaşımı, aero motorda 700°C'de yüksek mukavemet, oksidasyon direnci, iyi yüksek sıcaklık yorgunluğu ve sürtünme özelliklerine sahip bir malzemedir. Türbin diski, bıçak, kasa, şaft, conta ve bağlantı elemanı gibi aero motor bileşenlerinin tümünde Inconel 718 alaşımı kullanılmaktadır. Bu çalışmada ince taneli, dövülmüş Inconel 718 pancake mikroyapısı ve mekanik özellikleri araştırılmıştır. En uygun dövme parametreleri, INC 718 alaşımını sıcak dövme ile şekillendirilmeden önce Sonlu Elemanlar Analizi (FEA) kullanılarak belirlenmiştir. Daha sonra dövme işlemi aralığı 1050- 1150°C olarak belirlendi ve bu işlem, gerilme oranı 100 s<sup>-1</sup>'i aşmayacak şekilde gerçekleştirilmiştir. Ayrıca, deformasyon hızı 1800 mm / sn olarak çalışılmıştır. INC718 alaşımının tane boyutunun morfolojisi karakterize edildi, tane boyutları ASTM 4'e göre elde edilmiştir.

### 1. Giriş

Inconel-718, yüksek sıcaklık mukavemeti ve korozyon direnci özellikleri nedeniyle 700 C'ye kadar servis sıcaklıklarına sahip gaz türbini ve jet motorlarında disk malzemesi olarak yaygın olarak kullanılan; bunun yanında kimyasallarla temas eden parçalarda, denizcilik araçlarında ve parçalarında, nükleer reaktör parçalarında, roket motor parçalarında, çok özel amaçlar için üretilen depo tanklarında, vanalarda, bağlantı elemanlarında ve türbin pervane bıçaklarında kullanılan süperalaşımır.[2-3] Özellikle havacılık uygulamalarında kullanılacak INC718 parçalarının yüksek mukavemet değerine ve sürtünme yüklerine dayanabileceği değerlere sahip olması gerektiği için, simülasyon programları ile yapılacak olan dövme işlem parametrelerinin belirlenmesi ve dövme işleminin kontrollü gerçekleştirilerek ince taneli düzgün mikro yapı elde edilmesi önemlidir. [4] Farklı mikroyapısal özelliklerin güvenilir bir şekilde ortaya konulması, yorulma ve sürtünme ömrü gibi hizmet yeteneklerini öngören malzeme tabanlı sonlu eleman modellerinin süreç optimizasyonu kullanılması ve geliştirilmesi için vazgeçilmez bir unsurdur.[5]

Bu çalışmada INC718 serbest ezme(pancake) modelinin ilk başta sonlu eleman analiz yöntemlerinden (FEA) biri olan TRANSVALOR FORGE® program kullanılarak dövme hızı, şekil değiştirme hızı (strain rate), dövme sıcaklığı, tezgâh enerjisi ve hızı gibi parametreler belirlenmiştir. Simülasyonlar sonucunda dövme sıcaklık aralığının 1050- 1150 ° C ve tezgâh enerjisinin 200 kJ olarak belirlenmesi kararlaştırılıp dövme işlemi gerçekleştirilmiştir. Dövme sonrasında gerekli ısı işlem uygulanmıştır. Bu sayede mikroyapının stabil olması sağlanmıştır. Dövme sonrasında mekanik testler ve taramalı elektron mikroskopu (SEM) ile mikroyapı incelemesi gerçekleştirilmiştir.

### 2. Deneysel Çalışmalar

#### 2.1. Simülasyon Çalışmaları

Inconel dövme prosesi için özet yaparsak parçanın fırın çıkışından, son şekle gelinceye kadar geçen sürede, parçanın talaş payı/boşaltılan delik hariç her yerinde

sıcaklığın 1050 – 1150 °C, gerinme hızının ise 100'ü (1/s) geçmemesi gerekmektedir. Eğer yapılan simülasyonlar sonucunda beklenen değerler yakalanamıyorsa, proses parametreleri ile oynamak gerekmektedir.

Inconel parçası yapılan araştırmalar sonucunda parçanın hızlı şekillendirme ihtiyacından kaynaklı Parsan koşullarında karşıt vuruşlu çekiç tezgahında dövülmesine karar verilmiştir ve bu bağlamda karşıt vuruşlu çekiç tezgâhı için yukarıda belirtilen proses parametreleri ile simülasyon çalışmaları başlatılmıştır.

#### 2.1.1. Şekil Değiştirme Hızı

Yapılan ilk simülasyonlarda parçaların çapaklı olarak dövülmesine, yani kapalı kalıpta, olanak sağlamadığı gözlenmiştir. Bu durumun en büyük sebebi ise “strain rate” değerinin 0-100 1/s aralığında kalmamasıdır. Hammadde şekillenirken görülmüştür ki parçanın önünde bir engel yokken şekillenme hızı yavaş olduğundan “strain rate (şekil değiştirme hızı)” ile ilgili herhangi bir problem yaşanmamıştır; ancak parça, kalıpta bir engel ile karşılaştığında şekillenme hızı arttığından dolayı şekil değiştirme hızı değerinin yükseldiği gözlenmiştir. Özellikle; parçanın kalıbın çapak yoluna açılan bölgesinde büyük kesitten dar kesite girmesinden kaynaklı şekillenme hızı arttığından şekil değiştirme hız değerinin yüksek değerlere ulaştığı gözlenmiştir.

Tezgâh maksimum gücünde yapılan çoklu simülasyonlar sonucunda şekil değiştirme artışı problemi çözülememiştir; bu durumdan kaynaklı olarak kademeli (300,200,100 kJ) olarak tezgâh gücünü azaltarak simülasyon denemeleri yapılmıştır. Tezgâh gücündeki azalma ile şekillenme hızının azaltılması bu bağlamda da şekil değiştirme hız probleminin ortadan kaldırılması amaçlanmıştır.

Tezgâh gücünün kademeli olarak azaltıldığı çoklu simülasyon denemeleri sonucunda şekil değiştirme hızı değerinde bir miktar iyileşme gözlenmiş ancak yine malzemenin kalıbın çapak yolu bölgesine ulaştığı andan itibaren şekil değiştirme hızı değerlerinin çok yüksek değerlere ulaştığı gözlenmiştir.

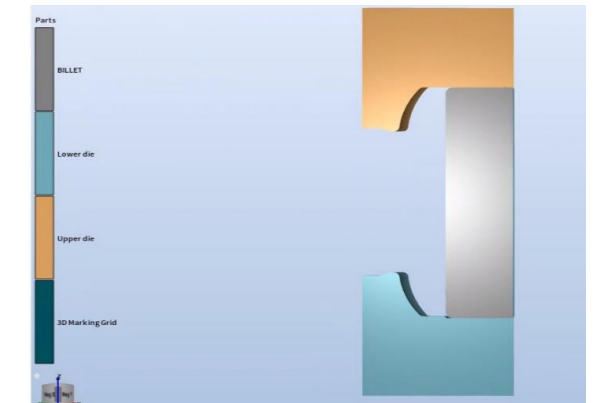
#### 2.1.2. Proses Sıcaklığı Durumu

1100 °C tav sıcaklığı ile 400,300,200 ve 100 kJ lük tezgâh enerjisi kullanılarak simülasyonlar gerçekleştirilmiştir. INC718 malzemesinde sıcaklık ile ilgili görülen problemlerden birisi de çekirdek sıcaklığının istenilen aralıkta (1000-1050 °C) tutulmamasıdır. Bu bağlamda farklı enerji değerleri ile simülasyon yapılarak çekirdek sıcaklığındaki yüksek orandaki artmaların azaltılması amaçlanmış ve çekirdek sıcaklığının istenilen aralıkta tutulması sağlanmaya çalışılmıştır.

Yapılan çoklu simülasyon denemelerinde görülmüştür ki tezgâhın enerjisi azaldıkça parçanın iç bölgesindeki sıcaklık artma oranı azalmış ve daha bir stabil proses elde edilmiştir. Tezgâh gücünün kademeli olarak azaltıldığı simülasyon denemelerinde görülmüştür ki 200 kJ üstü değerlerde parçanın iç bölgesi fazla ısınmaktadır. Bu bağlamda 200 kJ ve 100 kJ ile simülasyonlar gerçekleştirilmiştir. 100 kJ enerjisi parçanın iç bölgesindeki ısınmayı minimuma indirdiği ancak fazların (ara tav sayısı) çok olduğu ve pratikte uygulanmasının zor olduğu gözlenmiştir.

GİRDİLER	
Malzeme Türü	INC718
Hammadde Çapı	177,8 mm
Hammadde Boyu	360 mm
Tezgâh tipi	Karşıt Vuruşlu Çekiç
Tezgâh Enerjisi	200 kJ
Darbe Sayısı	4+5+4
Kalıp Sıcaklığı	230 °C
Kalıba Aktarma Sonrası Sıcaklık	1095-1100 °C
Şekillenme Öncesi Sıcaklık	1035-1100 °C
Tav sıcaklığı	1100 °C
Ara Tav Sayısı	2

**Tablo 1:** INC718 Malzemesinin Optimum Değerler için Simülasyon Girdileri



**Şekil 1:** INC718 alaşımının simülasyondaki başlangıç şekli

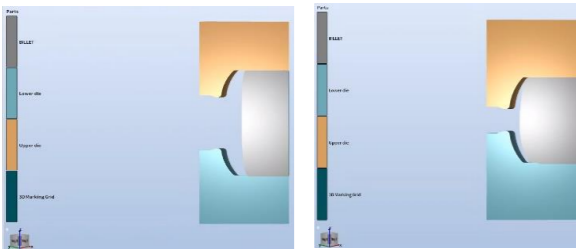
Bütün bu çıkarımların ışığında (şekil değiştirme hızı, proses sıcaklığı, ara tav sayısı) 200 kJ enerji ve 1100°C tav sıcaklığının optimum değerler olduğuna karar verilmiş ve şekil değiştirme probleminin ortadan kaldırılması için tasarım değişikliği yapılmasına karar verilmiştir.

### 2.1.3. Şekil Değişirme Hızının Stabil Etmek için Pancake Geometrisinin İyileştirilmesi

Yukarıda da bahsedildiği gibi yapılan çoklu simülasyon denemelerinde proses sıcaklığı ve tezgâh enerjisi olarak optimum değerler belirlenmiştir. Ancak her simülasyonda görülmüştür ki malzemenin, kalıplar içerisinde herhangi bir engelle karşılaşına kadar, şekil değiştirme değerleri istenilen aralıkta tutulmuştur. Bu bağlamda malzemenin serbest ezme gibi şekillendirilmesine karar verilmiş ve bu yönde tasarım değişikliği yapılmıştır.

Serbest ezme (pancake) geometrisi ile yapılan denemelerde görülmüştür ki malzeme herhangi bir engelle (engel: çapak yolu, küçük radyüsler, açılı yüzeyler, gravür) karşılaşmadığından şekil değiştirme hız (strain rate) aralığının sağlandığı gözlenmiştir. Bu bağlamda parçayı çapaksız olarak pancake geometrisi şeklinde şekillendirme simülasyonu yapılmıştır.

Sonuç olarak; INC718 malzemesi için, strain rate ve proses sıcaklığı (1000-1050 °C) açısından bakıldığında Parsan karşıt vuruşlu çekiç tezgahında 200 kJ 'lük enerji, 1100 °C tav sıcaklığı ve pancake geometrisi ile dövme işlemi gerçekleştirmek bu malzeme için optimum koşullardır.

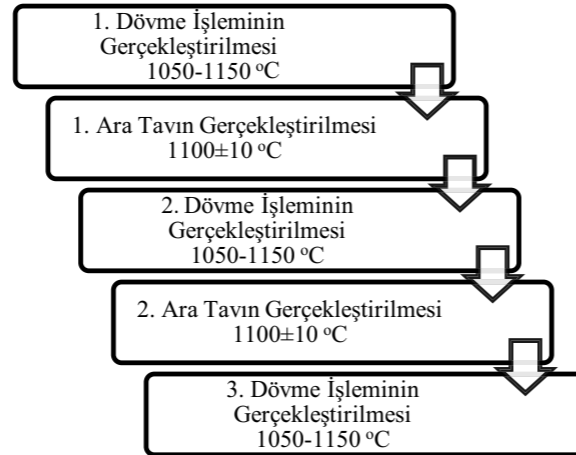


Şekil 2: INC718 alaşımının kademeli olarak dövülmesi (a) 1. dövme işlemi (b) 2. dövme işlemi (c) 3. dövme işlemlerinin simüle edilmesi

## 2.2. Dövme Prosesinin Gerçekleştirilmesi ve Isıl İşlem

### 2.2.1. Dövme Prosesi

INC718 alaşımının dövülmesi 3 ana fazdan 2 ara tavadan oluşmaktadır. Süper alaşımların dövülmesi, diğer alaşımların dövülmesine göre zor olduğu için aşamalı olarak dövülmeli ve sıcaklık dağılımının her bölgede aynı olması gerekmektedir. Yapılan çalışmada karşıt vuruşlu çekiç tezgahında dövme işlemi gerçekleştirilip ardından elektrikli fırında malzemenin tavlama işlemi gerçekleştirilmiştir. Şekil 3'te yapılan çalışma şema halinde gösterilmektedir.



Şekil 3: INC718 alaşımının dövme işlem şeması

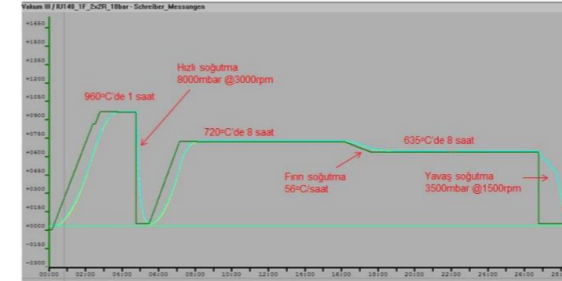
360 mm boyundaki numune 3 aşamalı olarak dövülmüştür. Dövme işlemi öncesinde numune 1100 °C'de 140 dakika boyunca tavlanaarak ilk dövme işlemine hazır hale getirilir. Ardından 1050-1150 °C arasında dövülür. Deformasyon sonucunda oluşan malzemenin iç bölgesindeki sıcaklık ve şekil değiştirme hızının artmasını engellemek ve malzemenin her bölgesinde stabilizeyi sağlamak için 45 dakika boyunca elektrikli fırında 1100 ±10 °C 'de tavlanaır. 2 kez dövme işlemi uygulandıktan sonra yine aynı şartlarda tavlama işlemleri gerçekleştirilir.

Dövme işleminden önce numunenin boyu 360mm'dir; 1. dövme işlemi sonrası 274 mm; 2. dövme işlemi sonrasında 190 mm; 3. dövme işleminden sonra nihai kalınlık 152 mm boyuna ulaşmıştır.

### 2.2.2. Isıl İşlem Parametrelerinin Belirlenmesi ve Uygulanması

Isıl işlem, malzemenin sertliği, tane yapısı ve mekanik özelliklerinin istenen değerlerde olmasını sağlamak amacıyla, malzemeye uygulanan bir dizi ısıtma ve soğutma işlemidir.[5] Dövme prosesinden sonra gerekli analizler yapılarak vakum fırınlarında yapılacak ısıl işlem parametreleri belirlenmiştir. Şekil 4'te ısıl işlem prosesi

şematik olarak gösterilmiştir.



Şekil 4: INC718 alaşımının ısıl işlem prosesi

Uygulanacak olan ısıl işlem çözeltiye alma ısıl işlemi ve çökeltme sertleşmesi ısıl işlemi (yaşlandırma) olmak üzere 2 ana processten oluşmaktadır. Çözeltiye alma ısıl işlemi; malzeme içerisinde bulunan karbür ve intermetalik bileşiklerin katı çözeltiye alınması için yapılan yüksek sıcaklık işlemidir. AMS 5662 ve 5663'e göre sonrasında hava veya daha hızlı bir şekilde oda sıcaklığına soğutulması gerekir. Çökeltme sertleşmesi ısıl işlemi (yaşlandırma) ise malzemenin sertleşmesini ve mukavemetinin artmasını sağlayan ara sıcaklık ısıl işlemidir. Çözeltiye alınmış intermetalik ve bazen karbür bileşiklerin çökmesi ile sertlik artışı sağlanır. İki kademe olarak uygulanır. İşlemin yapılacağı vakum fırını AMS 2750'ye uygun olmalıdır. Çözeltiye alma işlemi için Class 5 (±14°C) yaşlandırma için ise Class 3 (±8°C) TUS homojenliğini sağlamalıdır. İşlemler sırasıyla Şekil 5'te gösterilmiştir.

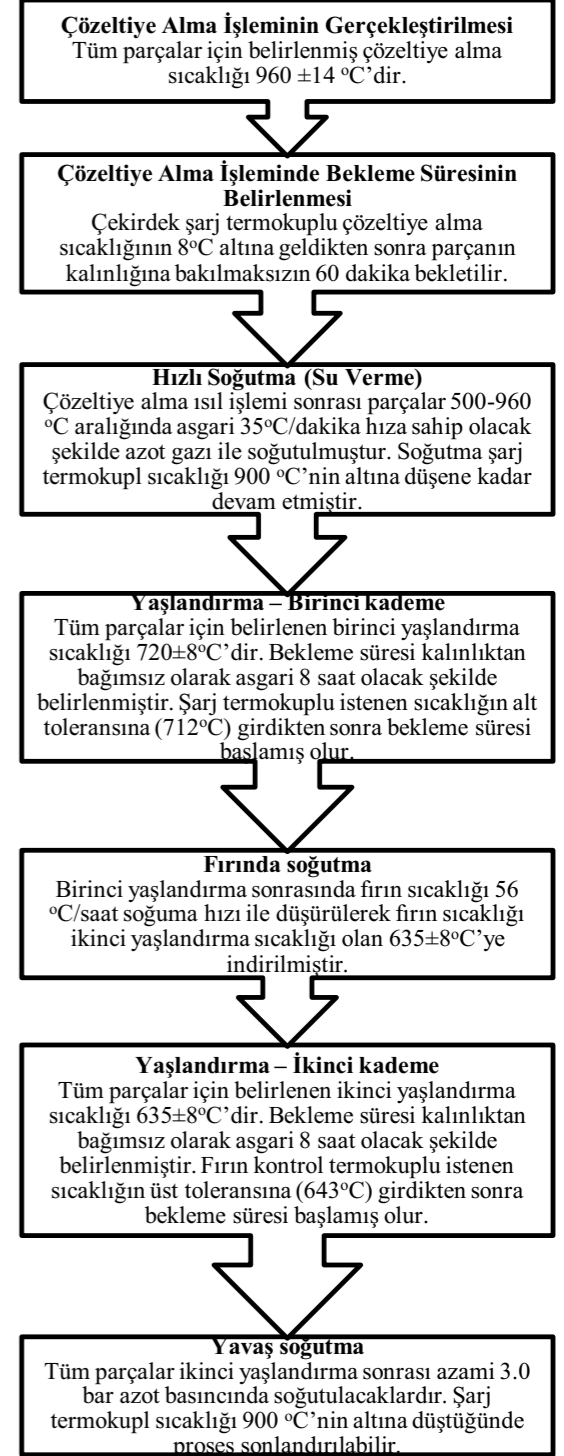
## 3. Sonuçlar ve Tartışma

### 3.1. Mekanik Testler

Çalışılan parçaların mekanik özelliklerini belirlemek için sertlik testi, çekme testi ve stres kopma testleri gerçekleştirilmiştir. Bu testler hem enden hem de boydan yapılmıştır.

#### 3.1.1. Sertlik Testi (Hardness)

2 adet en ve boy numunesi AMS 5663 spesifikasyonuna göre EMCO TEST MSC030 cihazında HB2.5/187.5 altında yapılmıştır. Sertlik testlerinden elde edilen sonuçlar Tablo 3'te verilmiştir.



Şekil 5: INC718 alaşımına uygulanacak ısıl işlem prosedürü



Numune Adı	Brinell Sertlik
	2,5/187,5
Numune 1-Boy	413,8
Numune 2- Boy	412,2

(a)

Numune Adı	Brinell Sertlik
	2,5/187,5
Numune 1-EN	417,4
Numune 2-EN	417,4

(b)

**Tablo 2:** INC718 Numune 1-2'in sertlik test sonuçları a) boydan b) enden sonuçları

### 3.1.2. Çekme Testi (Tensile Test)

Çekme testi ise 4 adet oda sıcaklığı (25 °C) ve 4 adet 650 °C'de yüksek sıcaklık çekme testleri Zwick Z600 Universal test cihazında ASTM E8 ve ASTM E21 standardına göre 0,005mm/mm/dk hızında yapılmıştır. Çekme testlerinden elde edilen detaylı mekanik test sonuçları Tablo 4 ve Tablo 5'te verilmiştir.

Sample No:	Test Temp (°C)	UTS (MPa)	Yield (MPa)	Elongation (%)	RA (%)
Numune 1	25	1339	1136	16,3	16,00
Numune 2	25	1333	1161	17,6	16,38
Numune 3	25	1317	1169	15,3	15,80
Numune 4	25	1342	1146	13,7	13,78

**Tablo 3:** Oda Sıcaklığında Gerçekleştirilen Çekme Deneyi Sonuçları

### 3.1.3. Çentikli gerilme kopma Testi (Stress Rupture)

2 farklı numune 650 °C yüksek sıcaklıkta ve 689MPa ölü yük altında ASTM E292 standardına göre çentikli gerilme kopması (Rupture Notch Tension Test) yapılmıştır. Çentikli gerilme kopması testinden elde edilen test sonuçları Tablo 6'te verilmiştir.

Çentikli gerilme kopması (Rupture Notch Tension Test) testleri için ise; Numune 9 hali hazırda devam etmekte (numune kopana kadar teste devam edilmesi istenmektedir) test "rupture" ömrünü tamamlamamıştır. Numune 10'da ise spesifikasyonlarda belirtildiği üzere

25:00 (hh:mm) saat sonunda durdurulmuştur. Durdurulan Numune 10'da herhangi bir çatlak ya da çarpılma gözlemlenmemiştir, numune boyutunda bir değişiklik görülmemiştir.

Sample No:	Test Temp (°C)	UTS (MPa)	Yield (MPa)	Elongation (%)	RA (%)
Numune 5	650	1048	921	17,41	15,01
Numune 6	650	1079	923	20,21	13,47
Numune 7	650	1078	931	20,08	14,87
Numune 8	650	1063	938	17,38	12,87

**Tablo 4:** 650 °C Gerçekleştirilen Çekme Deneyi Sonuçları

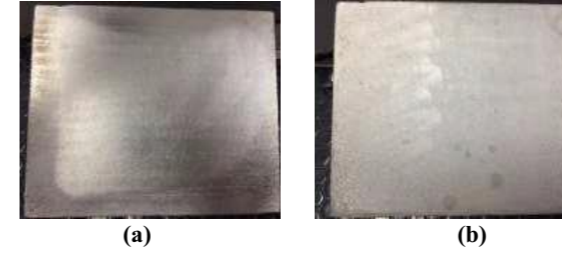
Sample No	Test Temp (°C)	Applied Stress (MPa)	Rupture Life (Hr.)	Elongation (%)
Numune 9	650	689	Devam Etmekte	-
Numune 10	650	689	25	0

**Tablo 5:** 650°C'de Gerçekleştirilen Stress Rupture Deneyi Sonuçları

### 3.2. Metalografik Analizlerinin Yapılması

#### 3.2.1. Makroyapı Analizi

Inconel 718 numunelerin makroyapı analizi gerçekleştirilmiştir. Numuneler metalografik incelemeler için hazırlandıktan sonra daldırma metodu ile dağlanmıştır. Dağlama çözeltisi olarak H<sub>2</sub>O<sub>2</sub> takviyeli Marble's Reagent (10 gr CuSO<sub>4</sub> + 50 ml HCl + 50 ml H<sub>2</sub>O) kullanılmıştır. Dağlama işlemi sonrasında numunelerin makro fotoğrafları kaydedilmiştir. Makroyapı incelemeleri Nikon AZ100 marka Stereo mikroskopu kullanılarak 0,5\*x büyütmede tamamlanmıştır. Makroyapısal bir kusur gözlenmemiştir.



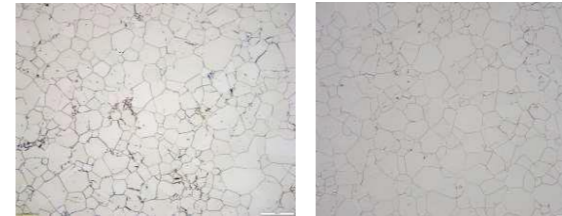
**Şekil 6:** Numunelerden farklı kesitler

#### 3.2.2. Mikroyapı Analizi

Inconel 718 alaşımı malzemenin mikroyapı ve tane boyutu değerlendirmesi için enine ve boyuna kesitleri alınarak 4 adet numune hazırlanmıştır. Uygun parlatma prosedürü gerçekleştirildikten sonra numunelere elektrolitik dağlama işlemi uygulanmış ve mikroyapı görüntüleri kaydedilmiştir. Elektrolitik dağlama işleminde susuz Kalling's Reagent (2 gr CuCl<sub>2</sub> + 40 ml HCl + 80 ml Alkol) çözeltisi kullanılmış olup, numunelere 7 saniye boyunca 10 VA'lık gerilim uygulanmıştır. Dağlama sonrasındaki mikroyapı incelemelerinde, dijital optik mikroskopu kullanılmış olup görüntüler 20x objektif büyüklüğünde kaydedilmiştir. Numunelere ait mikroyapı görüntüleri aşağıda gösterilmektedir.

Boy Kesit

En Kesit



(a)

(b)

(c)

(d)

**Şekil 7:** Farklı numunelerin boydan ve enden mikroyapı görüntüleri a) Numune 11 boyuna kesit b) Numune 11 enine kesit c) Numune 12 boyuna kesit d) Numune 12 enine kesit

Mikroyapı görüntüleri elde edildikten sonra, numunelerin ortalama tane boyutu hesabı, "Cross and Circles Grains

Intercept" metodu kullanılarak gerçekleştirilmiştir. ASTM E1382-97 standardına göre dijital görüntü analizöründe yapılan hesaplamalarda numunelerin; tane büyüklüğü numarası (G), ortalama intersept uzunluğu [ $\mu$ m], ortalama intersept sayısı, birim uzunluktaki intersept sayısı [1/mm] değerleri çıktı sonuçları olarak kaydedilmiştir.

Numune No	Grain Size Number G	Mean Intercept Length ( $\mu$ m)	Average Number of Intercepts	Number of Intercepts per Unit Length [1/mm]
Numune 11	4.30	72.14	147.00	13.86
Numune 12	5.30	50.99	104.00	19.61

**Tablo 6:** Boyuna Kesit Numune Analizleri

Numune No	Grain Size Number G	Mean Intercept Length ( $\mu$ m)	Average Number of Intercepts	Number of Intercepts per Unit Length [1/mm]
Numune 11	4.24	73.65	72.00	13.58
Numune 12	5.30	50.99	104.00	19.61

**Tablo 7:** Enine Kesit Numune Analizleri

### 4. Sonuç

Bu çalışmada, INC718 alaşımının dövülebilirliği çalışılmış, bunun sonucunda da istenilen mekanik ve metalografik özellikleri karşılandığı gözlemlenmiştir. Dövme işlemi karşıt vuruşlu çekiç tezgahında 3 ana faz, 2 ara tavadan oluşan bir prosesle gerçekleştirilmiştir. Isıl işlem uygulandıktan sonra mekanik ve metalografik testler yapılarak istenilen özellikleri karşılandığı belirlenmiştir.

Çekme dayanımı ve akma mukavemeti ortalama değerlerinin oda sıcaklığında sırasıyla 1332 MPa ve 1153 MPa, 650 °C'de ise 1067 MPa ve 928 MPa olduğu belirlenmiştir. Bu değerlerin istenilen standartlara uyduğu görülmüştür. Çentikli gerilme kopması testleri için ise; Numune 9 hali hazırda devam etmekte test "rupture" ömrünü tamamlanmadığı görülmüştür. Numune 10'da herhangi bir çatlak ya da çarpılma gözlemlenmemiştir, numune boyutunda bir değişiklik görülmemiştir.

Metalografik test sonuçlarında ise numunelerin ASTM E112 standardına göre 4 veya daha yüksek değerde tane büyüklüğü numarasına (G) sahip olduğu tespit edilmiştir. Bütün test sonuçları; istenilen özellikleri sağlamaktadır.

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## Ti-6Al-4V Alaşımının Sıcak Dövme Prosesinin İncelenmesi

Investigation of Hot Forging Process of Ti-6Al-4V

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#### Abstract

Ti-6Al-4V alloy is the most widely used titanium grade. Ti-6Al-4V alloy as a kind of  $\alpha + \beta$  type titanium alloy has good formability, weldability and properties against corrosion, which makes it an ideal material in aviation and aerospace industries [1]. In this study, the microstructure, and mechanical properties of Ti-6Al-4V pancake forging were investigated. Before conducting experimental studies of the Ti-6Al-4V alloy with hot forging, the most proper forging parameters such as optimal geometric factors, ideal deformation speed and strain rate at suitable forging temperature were determined by using TRANSVALOR FORGE® Finite Element Analysis (FEA). After simulation, the forging process range was determined between 940-970 °C and the process was carried out so that the strain rate was not more than 10 (1 / s). Hydraulic Press was used and worked at 960°C forging temperature. In addition, the deformation speed was worked as 30 mm / sec. Morphology of grains size of Ti-6Al-4V alloy were characterized and mechanical tests were applied to determine properties.

#### Özet

Ti-6Al-4V alaşımı en yaygın kullanılan titanyum sınıfıdır. Bir tür  $\alpha + \beta$  tipi titanyum alaşımı olarak Ti - 6Al - 4V alaşımı iyi şekillendirilebilirliğe, kaynaklanabilirliğe ve korozyona karşı özelliklere sahiptir, bu da havacılık ve uzay endüstrilerinde ideal bir malzeme olmasını sağlar [1]. Bu çalışmada Ti - 6Al - 4V pancake dövme işleminin mikroyapısı ve mekanik özellikleri araştırılmıştır. Sıcak dövme ile Ti - 6Al-4V alaşımının deneysel çalışmalarını gerçekleştirmeden önce, en uygun geometrik faktörler, ideal deformasyon hızı ve uygun dövme sıcaklığındaki şekil değiştirme oranı gibi en uygun dövme parametreleri TRANSVALOR FORGE® Sonlu Elemanlar Analizi (FEA) kullanılarak belirlenmiştir. Simülasyondan sonra dövme işlemi aralığı 940-970 ° C arasında belirlenmiş ve işlem, gerilme oranı 10'dan (1 / s) fazla olmayacak şekilde gerçekleştirilmiştir. Hidrolik Pres kullanılarak 960 ° C dövme sıcaklığında çalışılmıştır. Ayrıca, deformasyon hızı 30 mm / sn olarak çalışıldı. Ti - 6Al-4V alaşımının tane boyutunun morfolojisi karakterize edilmiş ve özellikleri

belirlemek için mekanik testler yapılmıştır.

#### 1. Giriş

Ti-6Al-4V alaşımı, mukavemet, süneklik, kırılma tokluğu, yüksek sıcaklık mukavemeti, sürünme özellikleri, kaynaklanabilirlik, işlenebilirlik ve termal işlenebilirlik dahil olmak üzere iyi bir özellik dengesi için tasarlanan bir alaşımdır [2]. Yaygın olarak kullanılan iki fazlı [ $\alpha + \beta$ ] titanyum alaşımıdır. Alüminyum alfa, vanadyum ise beta fazı dengeleyici (stabilizer) olarak ilave edilir. Kriyojenik sıcaklıklardan yüksek sıcaklıklara (~450oC) kadar kullanılabilir. Titanyum (Ti) çeliğe göre yaklaşık %56 düşük yoğunluğa sahip olmasına rağmen yüksek özgül dayanıma (çekme mukavemeti/yoğunluk) sahip bir malzemedir. Ti alaşımlarının özellikleri fazların dönüşümü ile karakterize edilir. Endüstriyel uygulamalarda Ti alaşımları fazların dönüşümlerine göre seçilmekte olup biyomalzeme imalatında sıklıkla  $\alpha/\beta$  ve  $\beta'$  ya yakın fazlar önerilmektedir. Ti-6Al-4V ve Ti-5Al-2.5Fe alaşımları  $\alpha/\beta$  alaşımlardır ve sıklıkla uçak iniş takımları, gaz türbin çarkları ve kalça implant imalatı için tercih edilen malzeme olarak kullanılmaktadır.[3]

Bu çalışmada Ti-6Al-4V pancake modelinin ilk başta sonlu eleman analiz yöntemlerinden (FEA) biri olan TRANSVALOR FORGE® program kullanılarak dövme hızı, şekil değiştirme hızı (strain rate), dövme sıcaklığı, tezgâh enerjisi ve hızı gibi parametreler belirlenmiştir. Simülasyonlar sonucunda dövme sıcaklık aralığının 940-970 °C'de dövme işlemi gerçekleştirilmiştir. Dövme sonrasında gerekli ısıl işlem uygulanmıştır. Bu sayede mikroyapının stabil olması sağlanmıştır. Dövme sonrasında mekanik testler ve optik mikroskop ile mikroyapı incelemesi gerçekleştirilmiştir.

#### 2. Deneysel Çalışmalar

##### 2.1. Simülasyon Çalışmaları

Titanyum dövme prosesi için genel olarak bir özet yapılması gerekirse, parçanın fırın çıkışından, son şekle gelinceye kadar geçen sürede, parçanın talaş payı/boşaltılan delik hariç her yerinde sıcaklığın 940 – 970 °C, gerilme hızının ise 10'u (1/s) geçmemesi gerekmektedir. Eğer



yapılan simülasyonlar sonucunda beklenen değerler yakalanamıyorsa, proses parametreleri ile oynamak gerekmektedir.

Ti-6Al-4V parçası yapılan araştırmalar sonucunda parçanın hızlı şekillendirme ihtiyacından kaynaklı Parsan koşullarında Hidrolik Pres tezgahında dövülmesine karar verilmiştir ve bu bağlamda Hidrolik Pres tezgahı için yukarıda belirtilen proses parametreleri ile simülasyon çalışmaları başlatılmıştır.

### 2.1.1. Şekil Değişirme Hızı

Yapılan ilk simülasyonlarda parçaların çapaklı olarak dövülmesine, yani kapalı kalıpta, olanak sağladığı gözlemlenmiştir. Parça hidrolik preste şekillendiğinden talaş bölgesi içerisinde kalan bölümlerin şekil değiştirme hızı değerinin 0-10 1/s değerini geçmediği gözlemlenmiştir. Hidrolik pres koçunun yavaş ve sabit bir hızla hareket etmesinden kaynaklı "şekil değiştirme" açısından herhangi bir sorun teşkil etmemektedir.

### 2.1.2. Proses Sıcaklığı Durumu

960 °C tav sıcaklığı ile yapılan ilk simülasyonlarda parçanın tezgaha aktarılırken ve şekillendirme başlamadan önce kalıp üzerinde beklemesinden dolayı parçada soğumalar meydana gelmektedir. Bu durumdan kaynaklı talaş payı içerisinde kalan bölgelerin 940-970 °C arasında kalmadığı gözlemlenmiştir. Yine Inconel örneğinde olduğu gibi parça şekillendikçe çekirdek bölgesindeki sıcaklığın arttığı gözlemlenmiştir. Bu durumdan kaynaklı prosese ara tav operasyonları eklenmek zorunda kalmıştır. Yapılan çoklu simülasyonlardan sonra parçanın toplamda 3 fazda (1 ana tav, 2 ara tav) dövülmesi gerektiği ortaya çıkmıştır.

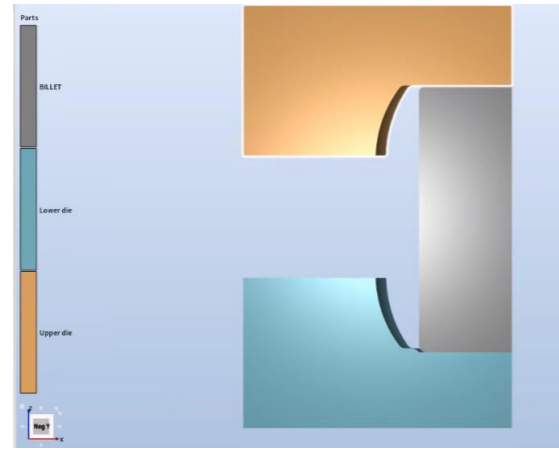
Parçanın gerek yüzey alanı büyüklüğü gerekse üretim esnasında aktarım ve kalıp üzerindeki bekleme süresinden kaynaklı özellikle alt bölgesinde büyük miktarda soğumalar gözlemlenmiştir. Bu soğumalar parçanın talaş payı içerisinde kalan bölgelerine etki etmektedir. Bu durum da talaş payı içerisinde kalan bölgelerin 940-970 °C sıcaklık aralığında kalmaması şeklinde bir problem ortaya çıkarmaktadır. Bu problemden kaynaklı parçada dizayn değişikliği uygulanmış ve talaş payları artırılmıştır. Bu sayede parçanın talaş payı içerisinde kalan bölgelerinde proses sıcaklık aralığı sağlanmış ve onaylanmıştır.

### 2.1.3. Tezgâh Gücü Yetersizliğinden Kaynaklı Pancake Geometrisi

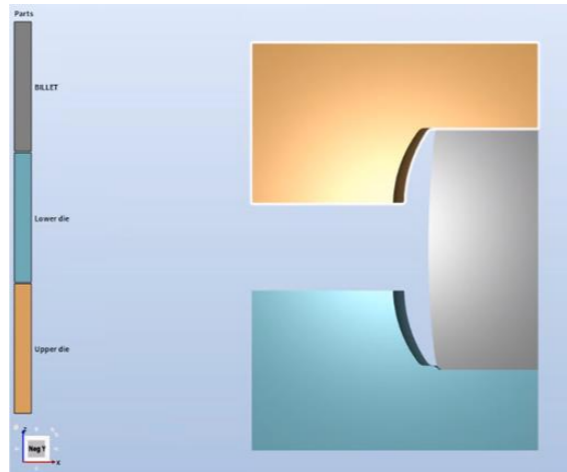
Parsan koşullarında üretimi gerçekleştirmek için kullanılan tezgâh 2500 Tonluk bir hidrolik prestir. Şekil değiştirme hızı ve proses sıcaklığı anlamında parçanın kapalı kalıpta dövülmesi için herhangi bir engel yok iken parçayı kapalı kalıpta şekillendirmek için gereken gücün 2500 Tondan

fazla olduğu görülmüştür. Bu durumdan kaynaklı tezgâh gücünü optimize etmek için parçada pancake geometrisi kullanılmaya karar verilmiştir. Yapılan simülasyonlarda, pancake geometrisi ile, tezgâh gücünün 2500 Tondan az olduğu görülmüş ve onaylanmıştır.

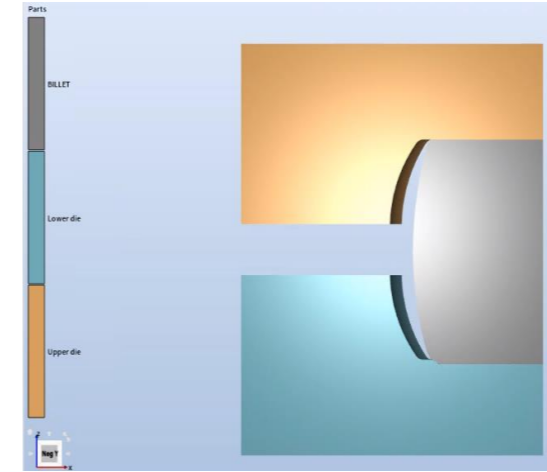
Sonuç olarak parsan koşullarında Ti64 malzemesi için şekil değiştirme hızı, proses sıcaklığı ve tezgâh gücü açısından bakıldığında 2500tonluk hidrolik pres ile 3 fazda dövme işleminin gerçekleştirilmesi bu malzeme için optimum koşullardır.



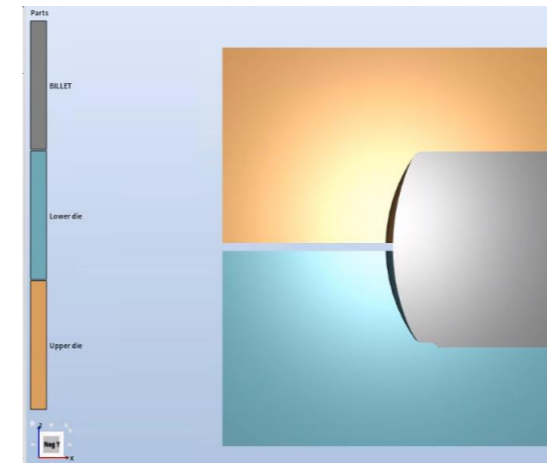
Şekil 1: Ti-6Al-4V alaşımının simülasyondaki başlangıç şekli



(a)



(b)



(c)

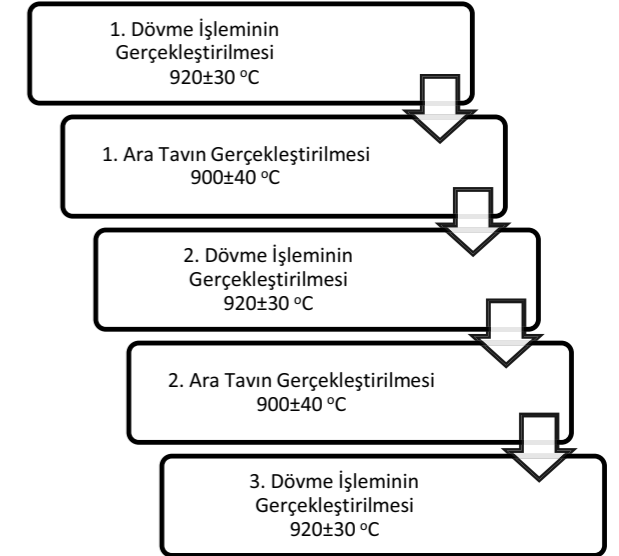
Şekil 2: Ti-6Al-4V alaşımının kademeli olarak dövülmesi (a) 1. dövme işlemi (b) 2. dövme işlemi (c) 3. dövme işlemlerinin simüle edilmesi

## 2.2. Dövme Prosesinin Gerçekleştirilmesi ve Isıl İşlem

### 2.2.1. Dövme Prosesi

Ti-6Al-4V alaşımının dövülmesi 3 fazda (1 ana tav, 2 ara tav) oluşmaktadır. Süper alaşımların dövülmesi, diğer alaşımların dövülmesine göre zor olduğu için aşamalı olarak dövülmeli ve sıcaklık dağılımının her bölgede aynı olması gerekmektedir. Yapılan çalışmada hidrolik pres tezgahında dövme işlemi gerçekleştirilip ardından elektrikli fırında malzemenin tavlama işlemi gerçekleştirilmiştir. Şekil 3'te

yapılan çalışma şema halinde gösterilmektedir.



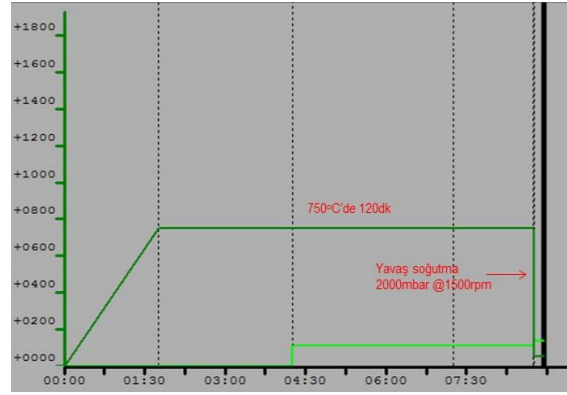
Şekil 3: Ti-6Al-4V alaşımının dövme işlem şeması

345 mm boyundaki numune 3 aşamalı olarak dövülmüştür. Dövme işlemi öncesinde numune 960 °C' de 145 dakika boyunca tavlansak ilk dövme işlemine hazır hale getirilir. Ardından 940-970 °C arasında dövülür. Deformasyon sonucunda oluşan malzemenin iç bölgesindeki sıcaklık ve şekil değiştirme hızının artmasını engellemek ve malzemenin her bölgesinde stabilizeyi sağlamak için 45 dakika boyunca elektrikli fırında 900 ±40 oC 'de tavlansak. 2 kez dövme işlemi uygulandıktan sonra yine aynı şartlarda tavlama işlemleri gerçekleştirilir.

Dövme işleminden önce numunenin boyu 345mm'dir; 1. dövme işlemi sonrası 296 mm; 2. dövme işlemi sonrasında 244 mm; 3. dövme işleminden sonra nihai kalınlık 195 mm boyuna ulaşmıştır.

### 2.2.2. Isıl İşlem Parametrelerinin Belirlenmesi ve Uygulanması

Isıl işlem, malzemenin sertliği, tane yapısı ve mekanik özelliklerinin istenen değerlerde olmasını sağlamak amacıyla, malzemeye uygulanan bir dizi ısıtma ve soğutma işlemidir.[5] Dövme prosesinden sonra gerekli analizler yapılarak vakum fırınlarında yapılacak ısıl işlem parametreleri belirlenmiştir. Şekil 4'te ısıl işlem prosesi şematik olarak gösterilmiştir.



Şekil 4: Ti64 alaşımının ısı işlem prosesi

Isıl işlem prosesinde ilk başta tavlama işlemi ile başlanmaktadır. Titanyum ve titanyum alaşımlarının tavlama, kırılma tokluğu, oda sıcaklığında süneklik, boyutsal kararlılık ve sürünme direncini arttırmak için yapılır. Birçok titanyum alaşımı servis koşullarında tavlama işlemi kullanılır. 704 ile 788 °C arasında bir saatten az olmamak koşulu ile yapılmalıdır. Tavlama işlemi sonrasında havada veya fırında soğutma yapılabilir. İşlemin yapılacağı vakum fırını AMS 2750'ye uygun olmalıdır. Tavlama ısı işlemi için Class 5 ( $\pm 14^\circ\text{C}$ ) TUS homojenliğini sağlamalıdır.

Parçalar fırın içerisinde ısınırken homojen sıcaklık dağılımını engellemeyecek ve parçaların birbirine değmeyeceği şekilde yerleştirilmelidir. Doğru bekleme sürelerini elde edebilmek için parçaların üzerine veya bir şahit parçanın (dummy block) en kalın yerinin çekirdeğine iki ayrı noktada şarj termokuplu yerleştirilmelidir. Şarj termokupl delikleri  $\varnothing 4-6\text{mm}$  olabilir.

Termokupl yerleştirildikten sonra işlem esnasında yerinden çıkmaması için sabitlenmelidir. Bu işlemler başladıktan tavlama işlemine geçilir. Tüm parçalar için belirlenmiş tavlama sıcaklığı  $750^\circ\text{C}$  olarak belirlenmiştir. Çekirdek şarj termokuplu tavlama sıcaklığının  $8^\circ\text{C}$  altına geldikten sonra parçanın kalınlığına bakılmaksızın 120 dakika boyunca işlem gerçekleştirilmiştir. Parçalar tavlama süresinin sonunda 2.0 bar azot basıncında soğutulur. Şarj termokupl sıcaklığı  $900^\circ\text{C}$ 'nin altına düştüğünde proses sonlandırılır.

### 3. Sonuçlar ve Tartışma

#### 3.1. Mekanik Testler

Çalışılan parçaların mekanik özelliklerini belirlemek için çekme testi ve sertlik testleri gerçekleştirilmiştir. Bu testler hem enden hem de boydan yapılmıştır.

#### 3.1.1. Çekme Testi (Tensile Test)

Çekme testi ise 4 adet oda sıcaklığı ( $20^\circ\text{C}$ ) Zwick Z600 Universal test cihazında ASTM E8 standardına göre  $0,005\text{mm/mm/dk}$  hızında yapılmıştır. Çekme testlerinden elde edilen detaylı mekanik test sonuçları Tablo 4'te verilmiştir.

Sample No:	Test Temp ( $^\circ\text{C}$ )	UTS (MPA)	Yield (MPA)	Elongation (%)	RA (%)
Numune 1	20	956	887	14,6	43,25
Numune 2	20	969	895	17,3	44,12
Numune 3	20	975	896	18,2	43,75
Numune 4	20	965	885	16,7	40,53

Tablo 1: Oda Sıcaklığında Gerçekleştirilen

#### Çekme Deneyi Sonuçları

#### 3.1.2. Sertlik Testi (Hardness)

Isıl işlem prosesinde sonra sertlik testi yapılmıştır.

Numune Adı	Rockwell Sertlik (HRC)
Numune 1	36
Numune 2	33
Numune 3	33,5
Numune 4	35

Tablo 2: Sertlik Test Sonuçları

### 3.2. Mikroyapı Analizlerinin Yapılması

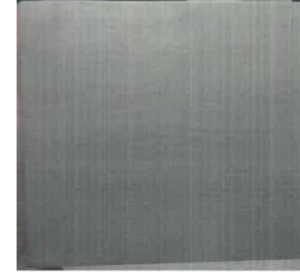
#### 3.2.1. Makroyapı Analizi

Ti64 numunelerin makroyapı analizi gerçekleştirilmiştir. Numuneler metalografik incelemeler için hazırlandıktan sonra daldırma metodu ile dağlanmıştır. Dağlama çözeltisi olarak  $10\text{ml HNO}_3 + 30\text{ml HF} + 300\text{ml H}_2\text{O}$  kullanılmıştır. Dağlama işlemi sonrasında numunelerin makro fotoğrafları kaydedilmiştir. Makroyapı incelemeleri Nikon AZ100 marka Stereo mikroskobu kullanılarak  $0,5\times$  büyütmede tamamlanmıştır. Makroyapısal bir kusur gözlenmemiştir.

#### 3.2.2. Mikroyapı Analizi

Ti64 alaşımı malzemenin mikroyapı ve tane boyutu değerlendirmesi için enine ve boyuna kesitleri alınarak 2 adet numune hazırlanmıştır. Uygun parlatma prosedürü gerçekleştirildikten sonra numunelere daldırma ile dağlama işlemi 7 saniye boyunca uygulanmış ve mikroyapı

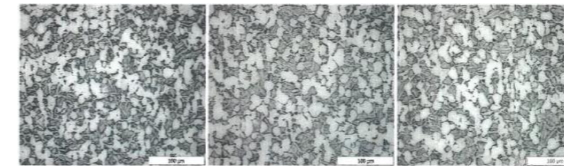
görüntüleri kaydedilmiştir. Mikro dağlama işleminde Kroll's Reagent ( $10\text{ml HF} + 30\text{ml HNO}_3 + 50\text{ml H}_2\text{O}$ ) çözeltisi kullanılmıştır. Ardından optik mikroskop ile incelenmiştir.



Şekil 5: Ti64 makroyapısal olarak görüntüsü

Mikroyapı görüntüleri elde edildikten sonra, numunelerin ortalama tane boyutu hesabı, "Cross and Circles Grains Intercept" metodu kullanılarak gerçekleştirilmiştir. ASTM E1382-97 standardına göre dijital görüntü analizöründe yapılan hesaplamalarda numunelerin; tane büyüklüğü numarası (G), ortalama intersept uzunluğu [ $\mu\text{m}$ ], ortalama intersept sayısı, birim uzunluktaki intersept sayısı [ $1/\text{mm}$ ] değerleri çıktı sonuçları olarak kaydedilmiştir.

Numunelerin "ALA grain size" hesaplaması planimetrik tane boyutu ölçümü metodu kullanılarak gerçekleştirilmiştir. Kaba tane "smoothness" ve "treshold" değerleri ayarlanarak manuel olarak seçilmiş ardından ortalama tane alanları  $\text{mm}^2$  cinsinden belirlenmiştir. Son aşamada ise bu değerlerin ortalaması alınmış ve elde edilen ortalama tane alanı ASTM E930 standardına göre incelenerek numunelerin ALA tane boyutu hesaplanmıştır.



Şekil 6: Numune 5'in boy kesit görüntüleri

Numune No	Grain Size Number G	Mean Intercept Length [ $\mu\text{m}$ ]	Average Number of Intercepts	Number of Intercepts per Unit Length [ $1/\text{mm}$ ]
Numune 5-1	8,90	14,63	145,00	68,36
Numune 5-2	8,43	17,25	123,00	57,99
Numune 5-3	8,38	17,53	121,00	57,04

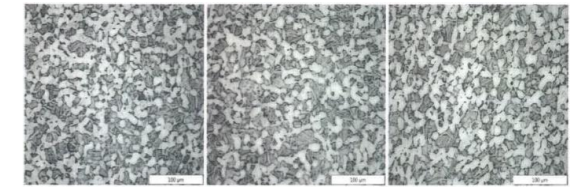
Tablo 3: Ortalama Tane Boyutu Analizleri

Numune No	Mean Grain Area [ $\mu\text{m}^2$ ]	Mean Grain Area [ $\text{mm}^2$ ]	Average [ $\text{mm}^2$ ]	ALA Size
Numune 5-1	640,79	0,00064079	0,00079332	7.0 Üzeri
Numune 5-2	861,50	0,00086150		
Numune 5-3	877,67	0,00087767		

Tablo 4: ALA Tane Boyutu

Numune No	$\alpha$ Fazı	$\beta$ Fazı
Numune 5-1	48,13	51,87
Numune 5-2	51,97	48,03
Numune 5-3	50,02	49,98

Tablo 5: Faz Dağılımı



Şekil 7: Numune 5'in en kesit görüntüleri

Numune No	Grain Size Number G	Mean Intercept Length [ $\mu\text{m}$ ]	Average Number of Intercepts	Number of Intercepts per Unit Length [ $1/\text{mm}$ ]
Numune 5-1	8,03	19,82	107,00	50,44
Numune 5-2	9,11	13,60	156,00	73,54
Numune 5-3	9,40	12,33	172,00	81,09

Tablo 6: Ortalama Tane Boyutu Analizleri



Numune No	Mean Grain Area [ $\mu\text{m}^2$ ]	Mean Grain Area [ $\text{mm}^2$ ]	Average [ $\text{mm}^2$ ]	ALA Size
Numune 5-1	894,67	0,000894667	0,00077244	7.0 Üzeri
Numune 5-2	819,04	0,00081904		
Numune 5-3	603,61	0,00060361		

Tablo 7: ALA Tane Boyutu

Numune No	$\alpha$ Fazı	$\beta$ Fazı
Numune 5-1	50,17	49,83
Numune 5-2	57,65	42,35
Numune 5-3	53,59	46,31

Tablo 8: Faz Dağılımı

#### 4. Sonuç

Bu çalışmada, Ti-6Al-4V alaşımının dövülebilirliği çalışılmış, bunun sonucunda da istenilen mekanik ve metalografik özellikleri karşılandığı gözlemlenmiştir. Dövme işlemi karşıt vuruşlu çekiç tezgahında 3 ana faz, (1 ana 2 ara tav) dan oluşan bir prosesle gerçekleştirilmiştir. Isıl işlem uygulandıktan sonra mekanik ve metalografik testler yapılarak istenilen özellikleri karşıladığı belirlenmiştir. Çekme dayanım ve akma mukavemeti ortalama değerlerinin oda sıcaklığında sırasıyla 966 MPa ve 890 MPa'dır. Bu değerlerin istenilen standartlara uyduğu görülmüştür.

Metalografik analizler sonucunda titanyum alaşımı numunelerin alfa ve beta faz dağılımı görüntü analiz yöntemi yardımıyla yüzdesel olarak hesaplanmıştır. Mikroyapı morfolojisinde alfa ve beta fazlarının homojen dağılım sergilediği gözlemlenmiştir.

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## ISRA VISION - Parsytec Inspection Systems

ISRA VISION - Parsytec Yüzey Muayene Sistemleri

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#### Abstract

Evaluating surface inspection results in one step of the production, e.g. after casting or hot rolling, offers the potential to improve the complete production chain. Surface defects may be a result of suboptimal process parameters during the rolling process itself or may be caused by process faults or wrong parameters in steel making or casting. Moreover information about the defect position offers the opportunity for an optimized process in the next production step, e.g. optimizing the pickling speed based on scale detected at the hot mill. Wherefore information will be forwarded to previous and next production steps. (Figure 1).

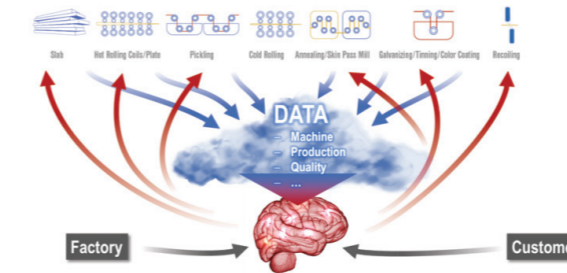


Figure 1. Using the data delivered by the surface inspection system for upstream and downstream decisions

### 1. High-End Surface Inspection along the entire production chain (from Steel Making to Delivering Line)

#### 1.1. Steel Making

The quality of the end product is influenced by each step of the production chain. Even in the very beginning, during the steel making, the reached quality may not be sufficient for the target product quality of the end product. Finding out process faults which will lead to minor steel quality allow assigning the material to the fitting customer orders and avoiding the downgrading of coils in later stages of the production. Examples for process faults are high number of blowing times of oxygen at BOF, long steel holding time of LF, tundish temperature exceeding upper limit, or liquid level fluctuation of the crystallizer.

These process faults can be taken into account evaluating the slab quality and may trigger a downgrade of the slab.

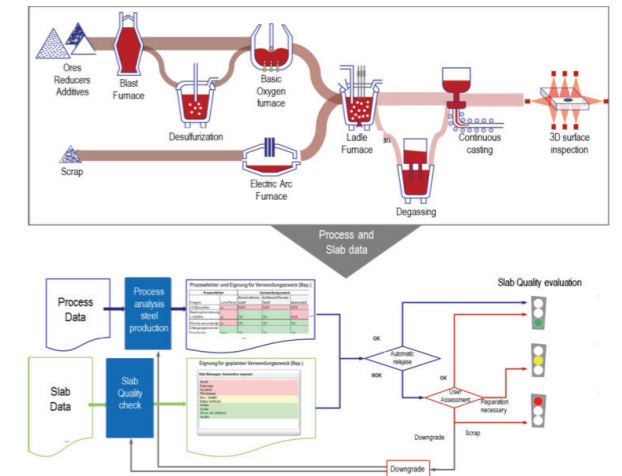


Figure 2. Steel Making faults are taken into account in slab quality decision

#### 1.2. Slab Casting

The optical, two dimensional (2D) inspection of (rolled) steel surfaces is state of the art and well established today. However, during continuous casting of steel slabs the application of 2D inspection is very limited due to the heavy structure at the hot, cast surfaces. Defect detection and depth is critical in grading the cast slab. Defect size and depth plays a crucial part for the decision if a slab is released for the hot strip or plate mill, or if it is sent to grinding. In contrast to conventional 2D inspection, inspection of the cast slab surface by laser triangulation (3D) inspection offers a fast and reliable detection and classification of surface defects, including depth, even during or right after continuous casting. Beside the inspection of four slab sides for defects, the 3D inspection system also generates a complete 3D scan of the slab geometry which opens up the possibility to measure thickness, width and length of the slab as well as it can be assessed for geometrical flaws like ski, camber or the shape of the side faces.

Together with the information about the steel making and casting process this allows blocking and reassigning slabs in the earliest production stages.

### 1.3. Hot Rolling

ISRA Parsytec offers the longest experience in Hot Mill inspection. The unique blue LED illumination allows best image quality being far away from the IR radiation of the hot band in the light spectrum. The proven camera technology allows sharp images even under high pass line deviations.

Feeding forward the information about position and density of scale detected on the surface, together with the downcoiler temperature which may lead the additional scale during cooling, allows the optimization of the pickling process.

### 1.4. Pickling

Using the information about scale occurrence enables a pickling speed optimization for highest speed without over or under pickling. This ensures highest throughput at the pickling line.

Surface inspection at the exit of the pickling line, detecting all remaining scale or pickling pits, gives reliable feedback about the performance of optimization formula.

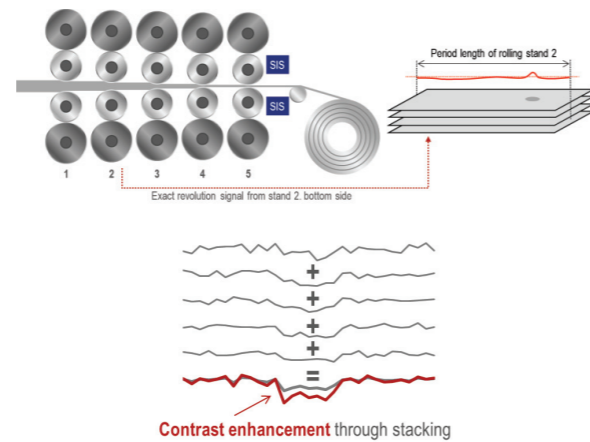
The information about all tandem-critical defects like edge damages, shells or holes near the coil edge can be feed forward to the tandem mill to avoid strip breaks. Using this information leads to a reduction of surface defect related strip breaks of about 60% by slowing down or opening the rolling gap on these defects.

### 1.5. Cold Rolling

Roll marks are a big issue for every steel strip producer. They are usually induced by a defective work roll of (cold) rolling or temper mills. With every revolution, the damaged work roll prints a small mark into the strip surface, creating a periodically occurring surface defect. In tandem mills, the roll mark is usually elongated and over-rolled by subsequent roll stands. This leaves the defect with a very low visual footprint so that it is not detectable by standard SIS nor by a human inspector. For exposed steel grades, the detection of roll marks is crucial as those defects will leave a very visual aspect after coating operations like e.g. galvanizing. It is an essential to identify this type of defect during rolling operation as soon as possible in order to avoid production of tons of material that turn out defective at a later processing stage.

A new approach for detection of extreme low contrast periodic defects lays in increasing the defect signal contrast by overlaying images of numerous roll revolutions. However, current systems using this approach usually have the disadvantage of long processing times or limited inspection time for each coil [1]. ISRA Parsytec's approach

uses hardware signals of each work roll for reliable image overlaying. This has the advantage of real-time availability of inspection results and a 100% surface inspection of the entire coil. Additionally, well proven algorithms allow for high contrast defect detection and secure defect classification.



**Figure 3.** Overlaying Defects based on the effective length of rollers enables high contrast images

### 1.6. Galvanizing / Tinning / Coating

Coating lines often have a wide range of surfaces. From dull to shiny material and from homogeneous to structured surfaces. Additionally, topographic defect like dents or scratches are critical for the coil quality.

ISRA Parsytec's Dual Sensor™ is designed to cope with these requirements. The unique combination of diffuse and direct light offers best inspection results for contrast based and topological surface defects on each material mix.

Having the exact information which defects, created during cold rolling, lead to minor product quality allow the feedback to block coils with these defects already after cold rolling and avoid further investments into that material.

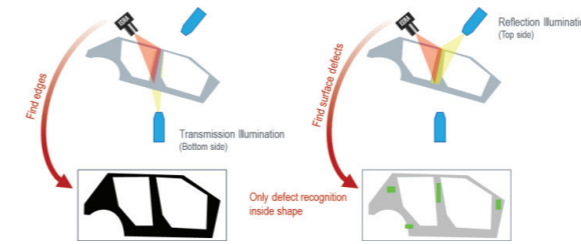
### 1.7. Slitting / Blanking / Lines

At the end of the value chain coils may be cut into smaller bands or into blanks. The quality evaluation of these end products is crucial to avoid customer claims.

The information about surface defects and their (crossweb) position from the last production step can be used to evaluate the quality of the slits.

For blanks it is necessary to exactly determine which part of the strip will be used in the pressing process. With the Blanking Master, ISRA Parsytec offers a solution that gives precise information about the surface defects on blanks. The inspection has two stages (see figure 4):

1. detect the contour of the blank with all its edges
2. detect the defect of the blank



**Figure 4.** The two step inspection of blanks

## 2. (Surface) Quality Management System

The quality of the product is one of the most important control and steering factors in modern metals industry. Customers' specifications and expectations regarding each single order have to be met. With ISRA Parsytec's SQMS (Surface Quality Management System) and the company's deep industry knowledge and experience, the software is able to derive objective decisions out of the huge amount of collected data. Users may conduct a quality forecast of their respective product and identify early on process if the customer's requirements on the end product can be met. Furthermore the software provides a holistic and objective overview about the entire factory and not only about separate lines.

Quality of a product in the metal manufacturing process is, firstly, defined by gauge data, which means thickness, width, flatness and temperatures. Secondly, the correct chemical composition is crucial, as well as, thirdly, mechanical properties like strength and hardness. Those three factors have in common that they are quite easy to evaluate and to handle in quality management. This been said, there is a fourth factor which is much more difficult to evaluate: the surface quality. The number of defects, the defect area, defect density, defect grade and even the handling of defects, which are disrupted by material cuts – all those indicators are not easy to identify and measure.

### 2.1. Quality Definition and Evaluation

ISRA's Surface Quality Management System (SQMS) is a business solution especially designed to face this challenge in the metals industry. The software ties together collected surface data from the whole process, since quality management is a level-crossing function – from order inquiry and order design to planning and product execution, from casting until the last finishing line. In order to efficiently support line managers, SQMS is specialized on the surface quality, and defines the detailed customer specific quality corridors for each production step. Thereby, for example, a coil for a certain automotive manufacturer passes through the line while being inspected continuously following the precise specifications that have

been defined. Those may contain, for example, quality grades from premium to standard to basic.



**Figure 5.** ISRA's Surface Quality Designer allows the definition of standard and customer specific surface quality standards along the complete production chain

The definition of the product quality is done along the complete production chain. Each group of similar production units has a common set of standard products. This secures that the same quality specifications are used in the whole production. Based on these standards, variant customer specific products can be defined by just determining the underlying standard and the deviations from that standard (alpha/beta).

After defining or modifying the rule sets, the Surface Quality Designer allows simulating the rule set result on past production. On the one hand it shows the amount of OK, Block and Recheck coils, on the other hand it also give information which rules are causing the alarms and warning on the coils. This is done in comparison with a reference rule set, in most cases the rule set that is used in SQMS in production.



**Figure 6.** The simulation of the new rule set shows the percentage OK material and the rule(s) causing blocking

### 2.2. Securing Surface Inspection System Reliability

Since surface inspection results are one important base of the quality decisions, it is necessary to make sure that the surface inspections systems (SIS) are in a good condition



and producing reliable inspection results. Therefore each ISRA Parsytec SIS can be equipped with a Performance Monitor. It monitors hardware, detection, classification, and defect trends. It calculates a Key Performance Indicator (KPI) for each measured item, e.g. melt, slab, coil. A KPI is a normalized value between 0 and 1, where 1 means everything works perfect and 0 means complete breakdown. These values are aggregated to one single value, characterizing the overall performance of the SIS. This value will be used in the decision modules of SQMS to decide whether the available inspection results are reliable, even for an automatic decision, if intended.

The Central SIS Monitor combines the information from multiple SISs and creates an overview on the condition of all inspection systems with the possibility to drill down from the central SIS Performance KPI to the lowest level raw data of one single production line.



**Figure 7.** Drill-Down from single SIS performance KPI to underlying KPI with its history

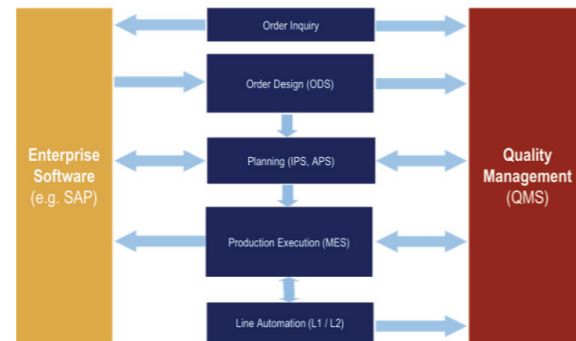
Figure 7 shows the drill down from the overview to #1CRM to the average CPU load of #1CRM's camera PC. The last drill down pages give a history view on the specific KPI as well as the underlying raw data, in this example the CPU load of the camera PC of #1CRM's SIS.

### 2.3. Industry 4.0 Readiness

In a Smart Factory, Quality Management Systems (QMS) interact with Enterprise software, Order Design Systems (ODS), Manufacturing Execution Systems (MES), and Level 1/2 to ensure product quality and optimize the process efficiency. This allows a fast reaction on the actual production situation as well as changes in customer demands.

As most QMS systems do not reflect surface quality in a detailed, customer specific way, SQMS can be an add-on to existing QMS systems, allowing substantial use of the collected surface inspection results.

Alternatively SQMS can be extended to a QMS, covering all aspects of quality like dimensions, mechanical properties, and chemical composition.



**Figure 8.** Quality Management is a level-crossing function

### 4. Conclusion

The best possible surface inspection in each production step, complemented with 3D inspection if the depth of defects is necessary to judge the defect severity, build the foundation for reliable quality decisions. The decisions are based on quality standards and the customer product specific deviations from these standards. Therefore the (Surface) Quality Management System has to define the quality targets along the entire production chain. This helps avoiding customer claims. Blocking defective material as early as possible stops investing into material that has to be downgraded or scrapped later in the production chain.

Feeding forward quality information enables the optimization of the next production steps and a reaction on product quality deviations. The feed backwards helps learning which defects will become critical later in the value chain.

Integrating the (Surface) Quality Management System into the manufacturing IT landscape (ODS, IPS, MES, L1, L2) gives the chance to optimize the production as a whole. Keywords are: planning surplus material, material reassignment, process parameter adaption, planning of repair steps.

ISRA Parsytec is your partner for premium surface inspection and quality management.

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## Imaging-Based Surface Inspection on Continuously Cast and Hot Rolled Products

Sürekli Döküm ve Sıcak Haddelenmiş Ürünlerde Görüntüleme Tabanlı Yüzey Denetimi

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### Abstract

Imaging-based surface inspection is gaining attention. Initiated from the applications in strip mills, imaging-based surface inspection systems are being installed in long product mills for both continuous casting and hot rolling, riding the new trend of digitization. Substantial advancement has been achieved in the bar and rod industry. Not only the finished products, but also the intermediate rolling stocks and the raw materials (the continuously cast products) are being inspected. Merging of different technologies and sensor network is also being practiced. Together, the technology is providing high value to the users as well as leading to the emerging quality-oriented data analytics. This presentation will cover the various imaging-based technologies and their applications, along with the extended use, in long product facilities.

### 1. Introduction

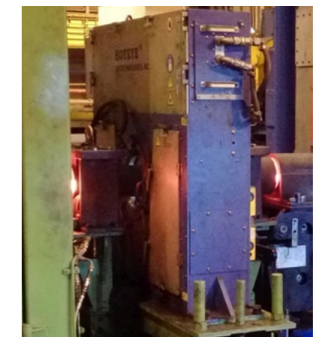
In-line surface inspection equipment for long products have long been dominated by eddy current testing (ECT), as well as some ultrasonic testing (UT). However, these technologies suffer from lack of direct correspondence to the defect appearance. The information generated from such inspection is very limited, and in some cases not user friendly.

The development of imaging-based equipment offers an additional dimension in surface inspection. The data, namely the images, is far more intuitive and corresponding to the actual defect appearance. The images provide surface defect length, width, estimated depth, shape, and so on. Aside from the visible difference, imaging technology can also provide expanded detection due to the use of electro-magnetic radiation with much shorter wavelengths, as well as the ability to detect defects of all shapes and orientations. The factor of Currie temperature transformation of steel would no longer be critical with imaging, and the imaging technology supports thermo-mechanical rolling for fine grain structures.

The application of in-line surface inspection based on imaging was implemented and reported for the bar and rod rolling mills as early as in 2003 [1], followed by additional publications based on image morphology

analysis [2, 3, 4], image difference analysis [5], and 3D scan contour analysis [6]. Image difference analysis [5] is to extract the surface protrusion/indentation based on the differences of the images from at least two substantially different perspectives. The reported trial unit was installed in an intermediate mill. The bar stock is of a relatively constant size, stable motion and slow speed. The 3D scan applications [6] are reported in use with bars moving at 5 m/s or less, and the reported defects are at least millimeter in size. The most popular defect detection approach is to compare two consecutive cross-section profiles and threshold on the difference(s) with a hand-full of parameters. The results from using the morphology analysis [1, 2, 3, 4] could significantly vary due to the use of different image processing algorithms. The development of dedicated detect-search algorithms and the use of generic image processing cores such as machine learning and neural network provide a full range of options. Yet, the performance highly depends on the implementations and experiences.

To date, installations of imaging based surface inspection are getting more popular in long product mills, inspecting continuously cast and hot rolled long products such as wire rods as small as  $\varnothing 4$  mm, bars, rails, shapes, billets, and seamless pipes as large as  $\varnothing 280$  mm. The highest in-service rolling speed on record is 112 m/s. There exist about 10 documented installations with the combination of imaging and ECT [7, 8].



**Figure 1.** An imaging system in a bar mill.

The adoption of in-line surface inspection is riding on the wave of digital manufacturing, and imaging based technology is particularly beneficial. The “visible access”

to the steel product is invaluable to the production lines counting on minimum manpower presence. That is, the images that can be automatically processed and presented when needed to the operators greatly reduce the necessity of keeping workers on site to visually review product surfaces. Information carried in the images could be deciphered for not only quality judgment, but also process control, in which the images are used to guide the operation for equipment/process adjustment and/or fault corrections.

This paper will briefly review the applications of imaging in long product mills, including billet casting and bar/wire rod rolling.

## 2. Imaging, 2D vs 3D

The fundamental of imaging, when used for surface inspection is to design the light path such that optical impingement on the steel surface be reflected into the imaging sensors, typically a CCD or CMOS chip, carries the geometric surface characteristics of the steel product.

Figure 2 shows a typical 2D image of a seam crack on a steel rod. The geometric surface characteristics, such as the parting lines and the defect, are reflected in the form of picture contrast. The high definition image was taken at the rolling temperature, which was around 950°C. It is capable of discerning even a fine seam crack as shown, typically not visible by naked eyes in the mill. Many steel mills adopting the technology have verified this capability by conduction post inspection verification through destructive testing, as illustrated in Figure 3.

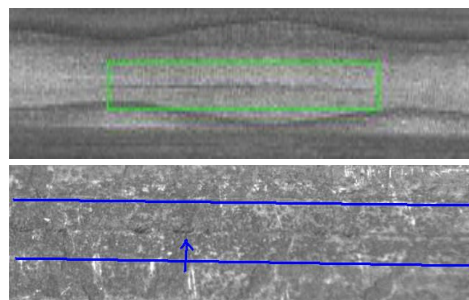


Figure 2. 2D inline image (upper) and the digital photo of the corresponding bar surface (lower).



Figure 3. Destructive verification of very fine seam cracks detected inline by imaging technology.

The 3D imaging, on the other hand, results in a different data format. Figure 4 shows a typical 3D defect rendering. Actual 3D point coordinates are composed to

the cognition of the geometric surface characteristics. It is more informative and intuitive, and could more preferable.

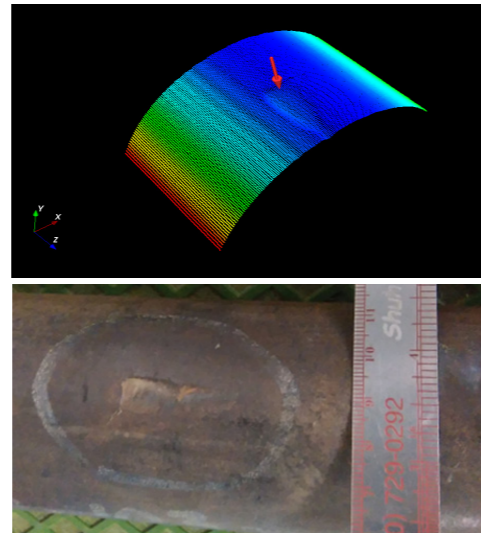


Figure 4. 3D inline image (upper) and the digital photo of the corresponding bar surface (lower).

However, 3D based imaging is still limited by the balance of data quality and scanning rate. More critically, the physics of light scattering when impinging on a sharp edge, such as a narrow crack as well as the combination of line of sight and view angle severely compromised the 3D ability.

The effect of scattering would be hard to predict, particularly with a coherent light beam. Figure 5 displays an example of such effect, which greatly limits the ability of using 3D imaging for fine cracks. As a result, 3D imaging will only be able to detect defects with larger surface openings.

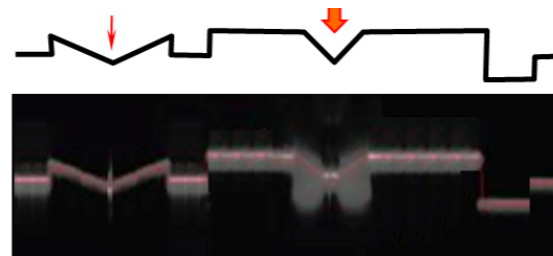


Figure 5. Scattering effect of coherent lighting used in 3D imaging on surface cavities.

As the 3D lighting is typically laser based, the light is emitted from a point, or a handful of points around the steel surface. Light emitted from point sources travels straight and has a viewing angle. If the light cannot impinge the defective surface with a normal viewing angle, it may be at risk of assessing the true geometric surface characteristics. In Figure 6, the two defects on

the round bar surface could be assessed substantially differently due to this effect ( $d'$  vs  $d$ ).

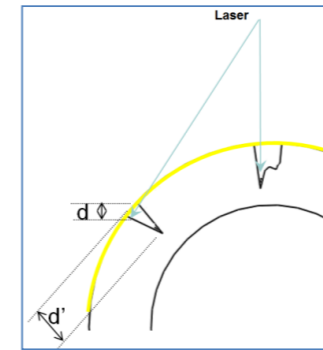


Figure 6. Viewing angle and line of sight limitation.

All things considered, the 2D imaging technology provides the ability of high resolution and suitable for high speed applications. The 3D imaging technology, while being able to measure the steel product dimensions at the same time, is good for presentation, but only limited to relatively large defects.

## 3. Detection Capability

The applications of imaging technologies in long product casting and rolling have unveiled new detection capability in the industry. The nature of imaging allows informatics analysis for at least two dimensions, breaking the limitation of “directional detection” and allowing techniques of high dimension data analytics being applied for advanced processing. As a result, the imaging technologies have demonstrated the detection of various types of defect. Figure 7 documents a summary of such rolling defects, ranging from seams, laps, scratches, cross-rolls, roll marks, inclusions, slivers, scabs, and pits (from left to right, top to bottom).

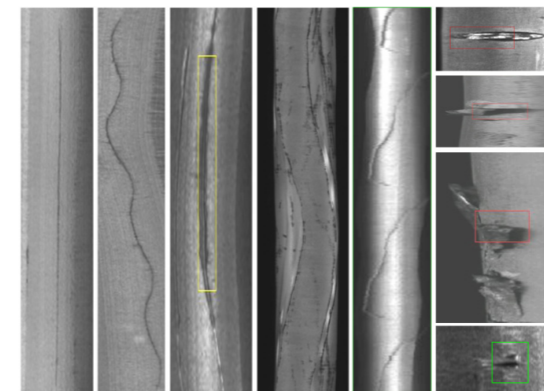


Figure 7. Various types of rolling defects detected by imaging.

Defects on continuously cast billets are also detected by imaging, yet using the 3D technique. The primary

concern is on the surface irregularity, which poses a great challenge to the 2D high definition imaging. As a result, 3D imaging is proven to be more noise resilient, and able to detect key defects on cast billets, examples shown in Figure 8.

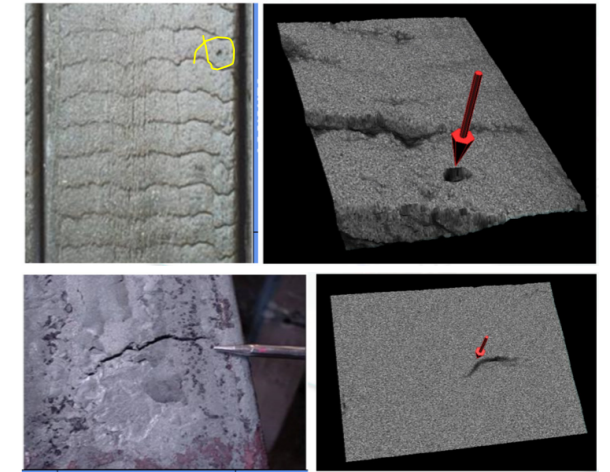


Figure 8. Pin hole and bleeding detected by 3D imaging on continuously cast billets (left: digital photos; right: 3D images of the detections).

## 4. Applications

Inspection is not a value adding process. It does not alter the cast or rolled products. In fact, inspection may have a negative impact to production because it results in scrap, unless the data is used properly. That is, value of inspection shall lie more on preventing defects, instead of weeding out defects. Solving problems is always more valuable than detecting problems.

To maximize the benefit of surface inspection, the imaging technologies come as the best tool to provide visible, intuitive surface information of the cast or rolled products for technical deciphering of the process/equipment issue. The imaging data supports process monitoring and diagnosis, process optimization, as well as mill management and customer interactions.

### 4.1. Process monitoring and diagnosis

In the process of hot rolling of wire, bar or other long products, there exist many different conditions which can upon failure result in poor surface quality. Typical root cause analysis by mill personnel have attributed unacceptable surface conditions due to, as examples, billet defects, reheating practices and mill rolling equipment failure. The goal of any rolling mill management team is to produce defect free material at a low conversion cost, and to achieve this, immediate notification and awareness of those at the rolling mill must be provided so they may react in kind to the conditions of poor surface quality. Containment of a “quality spill” to minimize the amount of product affected is as well of utmost importance. Inline imaging



systems provide pictures of the defects. A picture has been proven to be a better tool for the understanding, identification and training of mill personnel than traditional polygraph-like data. The following are some actual exhibits of defects and resolutions from some rolling mills.

#### Repeating roll marks

Repeating roll marks can be attributed to longitudinal thermal cracks on the roll passes; or cracks, chipping and iron oxide build up on guide rolls and process rolls. Images are not only to show visual pattern of recurring marks, but also to support automatic calculation of repeating pitch.

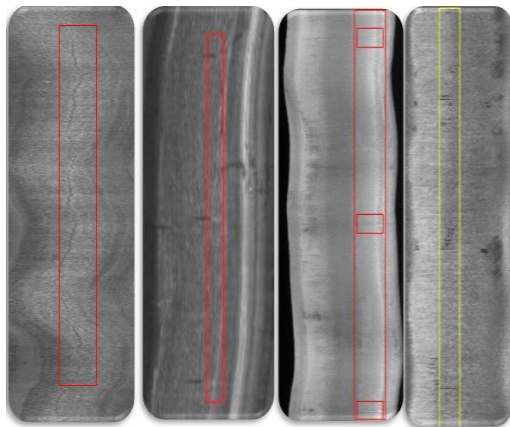


Figure 9. Repeating roll marks.

#### Damaged guide

This is an example about a seized guide occurred in stand #28 (inside a rod block) at the time rolling 5.5 mm wire at > 100 m/s. The incident was contained to one coil due to the monitoring of the defect system HMI screen by the operations crew.

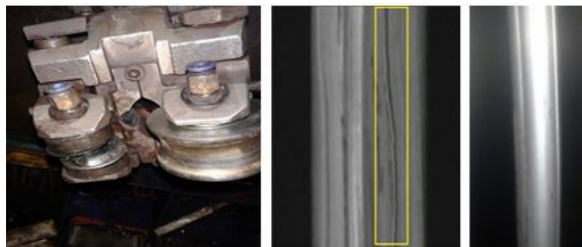


Figure 10. The defect induced by a seized guide (left: damaged guide; middle: inline image; right: actual rod surface).

#### Tension control

In high speed section of a wire rod mill, tensions between the equipment, such as between NTM (No-Twist Mill) and the RSM (Reducing-Sizing Mill), can result in severe

vibration of the wire, as well as Necking of the wire being rolled. An imaging system provides immediate feedback to the mill operators when they make adjustments to the setup to minimize or eliminate the high frequency vibration.

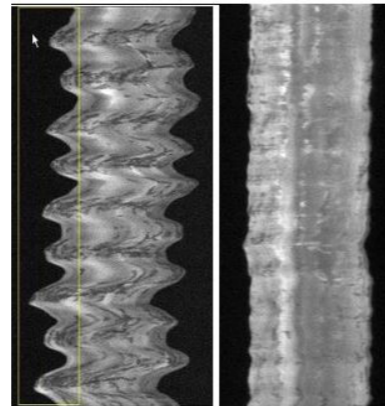


Figure 11. Left: high frequency vibration 6 mm wire @ 106 m/s; Right: mill adjustments to setup @ 100 m/s.



Figure 12. Left: Necking of a 5.5 mm wire at 105 m/s; Right: Wire Break.

#### Rolled in objects / scale

Rolled in object (mostly foreign) and rolled in scale (RIS) can typically be attributed to origins in the billet and to the potential malfunctioning of inline descaler system in the process, respectively. Other potential reasons for RIS could be reheating and cooling practices while the product is being rolled.

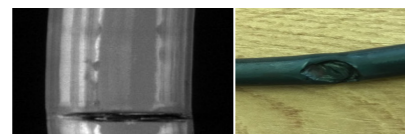


Figure 13. Detection of rolled in object (left: inline image; right: rod Sample).



Figure 14. Rolled in scale (left: inline image; right: rod sample).

#### 4.2. Process optimization

The imaging data can be used to understand the rolling process and optimize the process settings and equipment operation. The following exhibit illustrates a case of process optimization.

##### Billet grinding

Although billet grinding is a practice which many mills utilize to remove known surface defects of a billet that could potential cause rolled defects in the finished product, grinding in itself can be a greater contributor to surface defects in the finished product than the billet defect being removed. The following is an example of the outcome of poor grinding practices using the HotEye® system, an imaging based surface inspection equipment, installed in the bar mill to evaluate the grinding practice:

Figure 15 shows a billet ground with a sharp/ Non-Chamber edge and resulting in longitudinal surface defects. Figure 16 on the other hand documents a billet ground with chamfering (smoothing) the sharp edge, resulting in significant minimization of longitudinal defects.

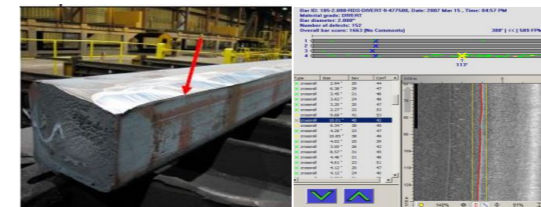


Figure 15. Left: Billet ground (no chamfer edge); Right: Resulted longitudinal defects.

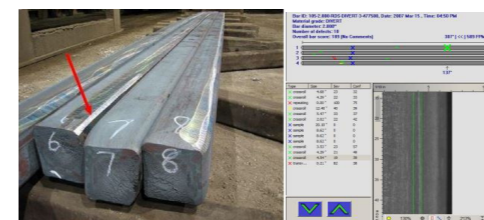


Figure 16. Left: Billet ground (chamfer edge); Right: Resulted minimal longitudinal defects.

#### 4.3. Mill management

The images provided by the imaging system do not only provide the visibility of the surface defects for each

individual product (billet, bar, coiled wire etc.), but also carry a wealth of information on the condition of the rolling equipment in the process (rolls, guides, gear boxes as an example). Each file is time stamped, length of rolled product, location of defect, severity, grade, and other customized information such as caster strand. All this wealth of data can be utilized by mill management to analyze and evaluate the performance of the mill shift to shift, day to day, as well, inclusive the mill setup by the operating crew. This is a tool for continuous improvements which are always an ongoing task in the mill.

A further application and usage of the images of defects provided by an imaging system is in the training of present and new employees to the steel mill on what a surface defect looks like. With the ongoing turnover of employees in most businesses, and the cost incurred by the business in training of employees, the images of the defects provided by an imaging system is a tool to accelerate the time for employees to comprehend what a defect looks like on a product surface, and further, understand if this defect is acceptable or not to a customer. An informed team of employees is a valuable aspect of most successful businesses, and images have been proven a great tool in all education activities.

#### 4.4. Customer interactions

Building the relationships and confidence with customers is always an ongoing challenge for a business. Steel buyers want to ensure that the quality product they are buying will be suitable for them in the consumption in their process to produce finish products for their customers with no defects. All steel buyers have enough issues in their own manufacturing process, without adding further problems due to incoming defects on the material they buy. An imaging system provides a forum from which positive relationships can be built with the mill and those who buy steel, as the steel buyers are aware that the mill has control of the process and is aware of defects that would harm the buyers' process.

Further, the expansion of the customer base of the business may be achieved. New customers once they are made aware of an imaging system in the process of a supplier, react very positively. In their view, the supplier is "serious" about quality and has invested in a tool (imaging system) to ensure the supplied product will have good surface quality.

If in the case of a customer complaint, both the producer and the customer can meet to review. In one case of a present HotEye® user, a customer (steel buyer) complained of a defect on the bar product supplied to him. The customer immediately attributed the surface defect to the incoming product supplied by the mill. The customer supplied a sample of the defect to the supplier (the steel mill) and a meeting and review of the products rolled using the imaging system was done. There was no evidence in the imaging system records (images stored in the database) for the type of defect which the customer claimed. Upon a further investigation by the customer, the customer found that one of the pre-processing stations

prior to making the final component was causing the surface defect and the supplying mill was informed of the finding and the complaint was closed.

## 5. Discussion

To improve the surface quality on a rolling mill, aside from the inspection tool (imaging system), it requires a “buy in” at all levels of management and workers - the same common vision and goal. The intuitive data (images) from imaging based inspection systems will not be a useful tool if the senior management, as well as those at different management levels and disciplines of the business are not committed in using the information.

To improve the quality in a rolling facility (the what), the management of the mill must first know where they are with respect to overall rolled surface quality on the rolling facility (inspection), and the root cause (the why) of the causes from which poor quality occurs in the mill, and the corrective action(s) taken in the process to fix the item that causes the poor quality situation (the how). To be able to perform process control in a rolling mill, the process variables which directly contribute to good surface quality need to be continuously measured - “what you can’t measure, you can’t control it”. It is understood by most businesses, that all improvements in surface quality provide direct financial benefits to the business in the form of improved net yield, lower energy costs, and better ship tonnage to the customer.

An image of a surface defect is more intuitive to an individual than a spike signal. The concept of a “surface defect” can be visually seen (the image) by individuals in the operation (operator/quality personnel), analyzed (why or where it is sourced), and followed by an activity to permanently remedy the source of the problems (e.g. a guide, a roll, etc.). After the activity of fixing the source of the problem in a single quality event, the mill can roll a single billet and see the “live” data to confirm that the surface defect has been resolved. The ease of establishing the correlation between the process adjustments to the finished product surface condition is immediate. There is no lag and no doubt, and the result is visually verifiable on an individual-defect basis. The correlation sets the foundation for getting from seeing (what), to knowing (why) and how to correct. Further, mill managers will have quantifiable and documented data (imaging system files) to hold accountable those individuals who control the process and the quality of the product.

The ability that the imaging system and its data can provide immediate and historical information for the process control/monitoring and that mill operators buy into this tool, provides the basis for the training of present and future employees. As well, it provides upper management the right metric for investment and payback into new equipment upgrades when it deals with quality, customer satisfaction, new product development and cost reduction initiatives.

## 6. Selection of an Imaging System

A potential user seeking an imaging-based inspection system must be well informed on the capabilities of the imaging system and have a clear goal of what they want the imaging system to detect. Prospects as well should discuss potential upgrades in surface detection capabilities of the system they purchase, without having to invest in a new system again in near future.

As such, a potential user of an imaging-based inspection system should have dossier of digital images of the various defects types which they want an imaging system to detect. These images must be provided to the suppliers as a critical part of the original inquiry, and all suppliers should respond in writing with tangible and quantifiable proof that their system is capable of meeting or exciding the detection of those presented defects in actual rolling conditions. Written performance guarantees should be highlighted in the commercial purchase documents, with associated consequences for the lack of performance.

## 7. Conclusion

Imaging systems in the long product mills in general, have advanced tremendously over the last 15 years to satisfy the increasing needs and requirements of “defect free” product. The imaging system presented in this paper has evolved and matured in parallel with these advances, and will continue to improve to satisfy the needs of our present and future customers.

Any production process needs a tool to maintain it in control. Similarly, a process that is inconsistent and not in control needs a tool to bring it into control. The steel rolling process has numerous input variables that need to be maintained stable to achieve consistent and good surface quality. In today’s competitive long steel product market place which steel suppliers face, surface quality which meets or exceed the expectations of the steel buyers is a given, competitive pricing is a must – otherwise the steel buyers will find someone who will provide them both.

## Acknowledgement

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## Through Process Optimization (TPO)

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### INTRODUCTION

A key cornerstone for being successful in Steel and Metals Business is to achieve a highly efficient overall production process enabling the economical successful production of high quality products with high yield at competitive low costs. This can be pushed to higher levels by digitalization and sufficient know-how. Primetals Technologies has developed a pioneering solution for this – TPO, Through-Process Optimization. TPO combines the modern, highly functional digitalization IT System “TPQC – Through-Process Quality Control” with the digitalized know-how and experience of domain experts and AI algorithms.

TPO enables metals producers to control and optimize the production and product quality across the entire process chain, enabling real and seamless “Through-Process Optimization”. By collecting the right data with TPQC out of all automation systems, measurement systems, smart sensors and even from operators, data are transformed into valuable information, KPIs, decisions, advices and actions enabling a higher level of production and product quality. So TPO is a pioneering digitalization solution for making the next big steps towards a fully automated intelligent digital steel production. This paper explains the cornerstones and main elements of TPO, the background of the development, a view and outlook on the further potential and gives some examples of successful customer implementation. Additionally the paper discusses experiences and key success factors for a successful execution of a digitalization project.

### DIGITLIZATION OF OPERATIONAL KNOW-HOW

#### Point of departure

Steel producers globally face increasing technical and economic challenges. While commodity products are coming under pressure, requirements of the premium customers', for example, on the quality of the surface and on the constancy of mechanical-technological properties of complex steel grades increase in all markets simultaneously. This leads to narrower process windows and requires a more rapid reaction to process imperfections. At the same time the number of product variants increases. But even for the so called commodity products the increasing cost pressure requests a fully optimized through-process production in order to stay competitive with these mass products. To succeed in such a challenging context, productivity and efficiency must be increased steadily to meet the requirements of customers. Clearly structured management processes form the indispensable backbone of successful steel companies and are already wide-spread not only in steel industry. The increased necessity of intelligent digital tools is not only encouraged by productivity and efficiency but also by the latest releases of quality management standards like IATF 16949, ISO 9001 etc. These standards demand to regard the actual process and additionally require employment with parties interested in the respective companies and emphasize a risk-based approach. This makes the employment with social and environmental factors even more important and indispensable. Also here algorithm-based analyzing and evaluating methods [7] begin to play an important role. This increases the complexity of the field of action for companies additionally as can be schematically seen in Figure 1. Risks and opportunities are close to each other and digitalization can be used effectively as a tool to lower uncertainty and to unlock additional value [10]. Some of these additional values can be unlocked by Data Analytics. Data analytics techniques can show trends and characteristics that would otherwise be lost in the mass of information. This information can be used to optimize product quality and process efficiency.

#### IT systems start to map complete plants

Over many years, single production units in metals companies were intensively improved and their reliability has been increased. They were upgraded and modernized. Also new production plants and production technologies have been developed, e.g. for the production of new steel grades. Such state-of-the-art plants comprise modern mechanical equipment and advanced automation systems, which nowadays integrate intuitively to-use HMIs, new and more powerful control techniques and modern metallurgical and technological (sub-) process models. Currently, the so called digital twin, which is an integrated cyber physical model of real world processes moves in the focus of attention, cf. [8]. This became possible, because in the last years the performance of computer power and data storage technology has

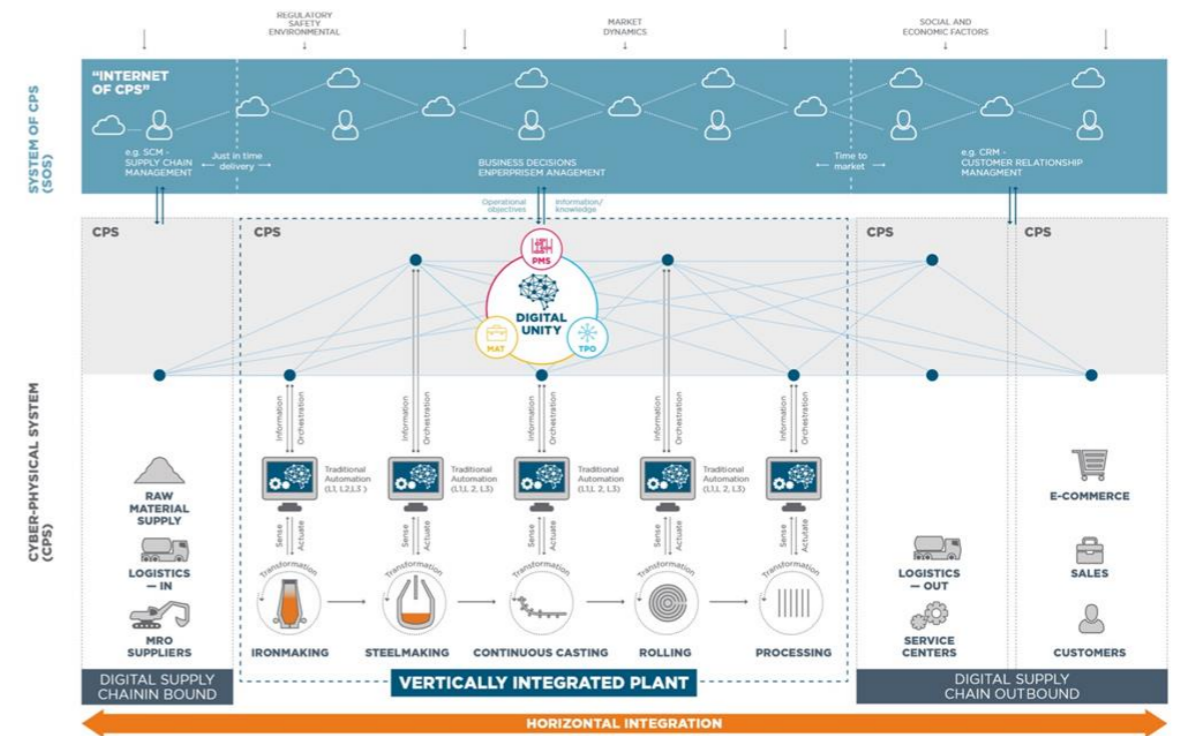


Figure 1 IT systems digitally represent the over-all metal business and influence factors

continued to increase exponentially in accordance with Moor's rule [1]. A weakening of Moor's rule of thumb, although predicted, will be more than offset by recent developments in the area of algorithms which will make future calculations even more successful [6]. So for example physical based metallurgical models which had to be executed “offline” in the past can be executed in real time due to the increased processing power of the CPUs. The basis for all the capability of models is made not only by the mathematical approach that necessarily represents a simplified image of reality, but by data availability and data quality. Sensors and data acquisition are more or less the digital senses of a cyber physical model and therefore determining up to which level of processing and learning a computer model can come. This process is running fast but is still incomplete as Uhlemann et al. [5] note: “[...] the application of fully automated techniques [...] is not yet common practice. Deficits are to be observed in the course of the use of a fully automated data acquisition of the underlying process data, a key element of Industry 4.0, as well as the evaluation and quantification and analysis of the gathered data.”

Therefore and starting from "Veracity", one the "four V's of Big Data", the authors attach not only great importance on the quality of the data itself, but also on increasing the "Volume" by means of advanced sensor systems to make data available which are hardly available today. In a highly digitalized plant it is crucial to be able to predict end-of-process parameters and to detect and explain process anomalies with an intelligent root cause analyzing tool. Based on automatic root-cause analysis compensational actions can be made directly by the IT-system to keep productivity at a high level. These IT systems have to combine expert driven calculation models and data interpretation which satisfy the necessity of logical correction algorithms of industrial data to avoid misleading predictions, cf. [9]. Undoubtedly, optimization of the parts can result in increased efficiency and better quality but there is no guarantee that it optimizes the whole automatically. Thanks to increased computational power the combination of formerly stand-alone simulation models, measured process and product data under the common roof of the so called “Digital Twin” has become possible. The combination of models allows a much better prediction of process behavior and product properties resulting thereof.

#### Digitalized Knowledge and Know-How Rules

W. E. Deming said: “There is no substitute for knowledge.” In general, one can confirm that knowledge (science) always depends on theory and information (data) alone is not knowledge. It is necessary to combine a profound physical background with modelling and simulation as well as with data science and finally with quality oriented, practical procedures and recommendations. The result will be digitalized operational know-how and digitalized practical experience, which can be made available in an intelligent way for a twenty-four-seven use.

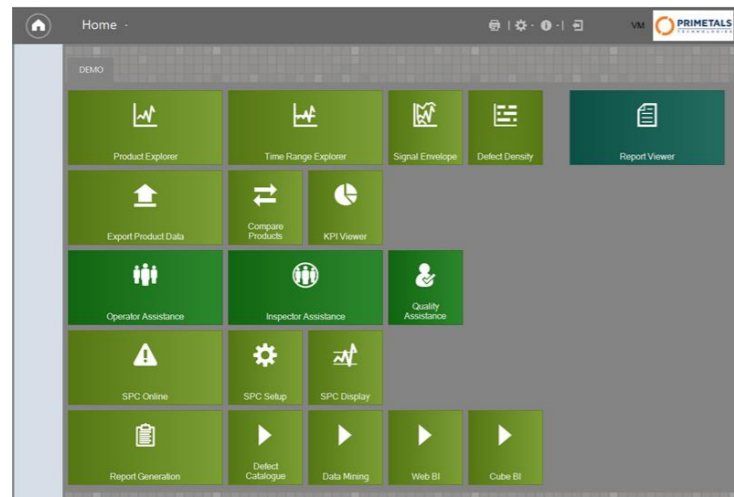


Figure 2 Screenshot of Primetals Technologies' TPQC Through-Process Quality Control IT system

Therefore IT systems, Figure 2, where quality- and process-relevant production data from all production units are not only stored but can be combined, processed and evaluated automatically and where decisions are proposed and actions are triggered, offer great chances of improvement. The knowledge-based algorithm which is behind each proposal or action is called a "Rule". Rules represent well-proven digital procedures and instructions and build a central place of operating know-how. A central rule system is therefore a core element of a Through-Process Know-How system.

**THROUGH-PROCESS OPTIMIZATION (TPO) AND DIGITALIZATION**

One main lever of efficiency and quality is an optimization process which covers a total plant comprehensively. One precondition for a deep and successful understanding of the interdependence of the different process steps following each other is data acquisition and data interpretation. Well beware of the conclusion: „Stored data does not generate business value” [3] the authors want to propose a knowledge based tool-box called Through-Process Optimization (TPO) which consists of two main parts

1. A new, intelligent Through-Process Quality Control (TPQC) IT system and
2. The Through-Process Know-How (TPKH) packages

The reason why two parts were put together is the fact that: “The transformation of data into knowledge is by no means an easy task for high performance large-scale data processing, including exploiting parallelism of current and upcoming computer architectures for data mining. Moreover, these data may involve uncertainty in many different forms.” [2].

TPO assists steel producers to maximize the through-process quality of their products and processes by

- collecting and visualizing seamless quality data in a through-process data warehouse
- using data to evaluate and control product quality and process performance, and
- by assisting your entire organization to continuously grow corporate know-how.

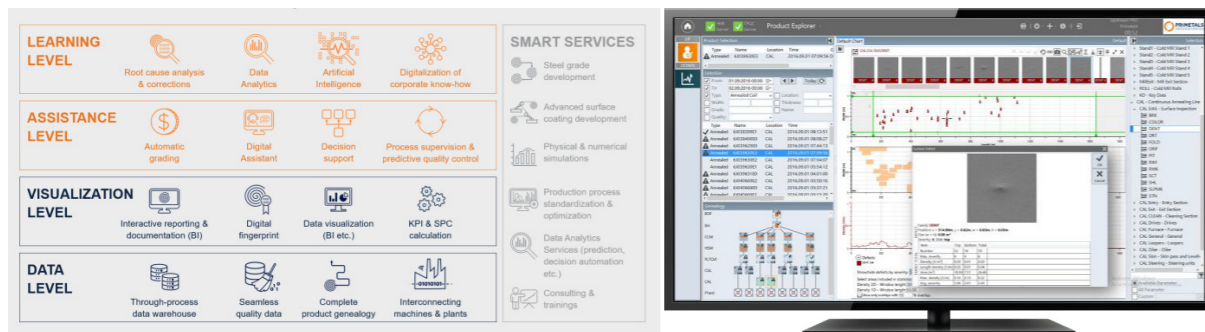


Figure 3 TPO – the four levels of interconnected operational excellence and TPQC's Product Explorer

**Digital Genes - Human Brains: The expert's role in TPO**

Experienced experts in metals industry are a key success factor for successful metals producers. Already today these specialists are able to highlight, to discuss and to interpret even the most complex interconnections which are decisive to competitiveness and success. In future additional qualification will be needed to transform human knowledge into computable algorithms and formula. Human expertise which turns knowledge into useful, permanently available and digitalized know-how is the basis for enabling next generation intelligent digitalization systems. For the implementation of such IT-systems and in order to resolve specific problems, additional support by domain experts can contribute to fast acceptance and pay off.

In exactly this well balanced combination of modern machinery, high end computerized data processing, artificial intelligence and internal and external experts, like operators, quality engineers, product development scientists there the authors look for the reason why a handful of leading steel producers are able to sail nearer the wind.

Expert services and IT-solutions have to work closely related to the PDCA (PDSA) cycle, Figure 4. While TPO creates something to the effect of a larger outer cycle or of a superordinate optimization process, it is the easiness of data access within the IT-solution in combination with human expertise which enables target-oriented and efficient working. Of course, there can be several optimization cycles running simultaneously or sequentially.

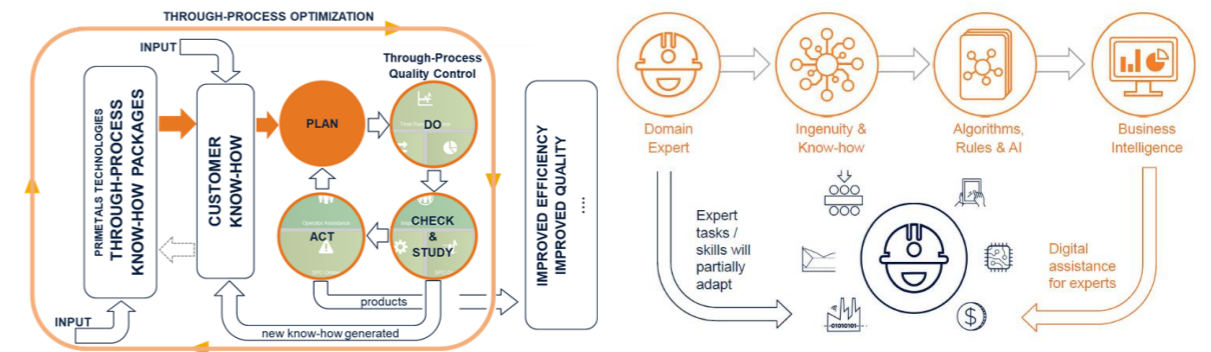


Figure 4 Through-Process Optimization and the PDCA-Cycle

In accordance with QM-standards unusual process or quality deviations or alarms will trigger a so called root cause analysis. Following the classical approach a team of experts will gather information and combine their knowledge in a structured way using methods like 5W or Ishikawa-diagrams. These very useful but more or less still paper based methods can be very time consuming and every team of experts occupied with these tasks will highly appreciate support.

Thanks to comprehensive data and digitalized procedures mapped within TPQC's rule editor the modern approach allows to analyze a situation automatically and to deliver relevant information. The result is a fast and highly computerized root-cause analysis of high quality which additionally proposes or even activates model based corrective or compensational actions to counteract the deviation.

**Key aspects of implementing know-how based digitalization systems**

In the case of implementing know-how based digitalization systems one has to consider not only technical issues but also cultural and human factors. Digitalization can cause disturbance and unsettledness. It is especially the group of mill experts, quality engineers and technicians whose role might change in the socio-cultural environment of a production team. First of all, digitalized systems will increase transparency tremendously and the felt or real competition among persons, teams, shifts etc. becomes obvious. Automatically and permanently updated, real-time KPIs and SPCs and other forms of compressed information can raise a human's stress level if this information is used as a human's performance indicator solely. This might lead to a situation of non-usage or of non-accepting where people magnify even the smallest shortcomings of a new system. If such a situation occurs or to which kind of degree it will occur mainly depends on the quality of working culture and on the personal attitude to innovation. The supportive mill management's paradigm for digitalization plays a vital role how well digitalized systems contribute to the success of a company.

Secondly, the implementation of an intelligent system might in some cases create a kind of aloofness or unwillingness among mill experts who fear to render their knowledge to a computerized system because it is regarded as a decrease of the expert's standing within the team. In contradiction, these systems are a personal enrichment because digitalized systems can help experts to be more informed and offer a good chance to increase the probability of making correct decisions. Thus, the role of an expert who transparently leans on reliable data, methods and mathematical algorithms and whose analyses and decisions are highly correct is strengthened.



### Through-Process Quality Control

Within the system an information-rich genealogy of each individual product that is processed [cf 11], and makes it possible to retrieve process data of all production steps for every part of the product. This allows users to track quality issues in very little time and analyze them by reviewing process data for all relevant production steps, which is the key for fast troubleshooting and claim management. Figure 5 shows the TPQC System embedded into the automation and IT-environment and can cover the whole process chain; Figure 6.

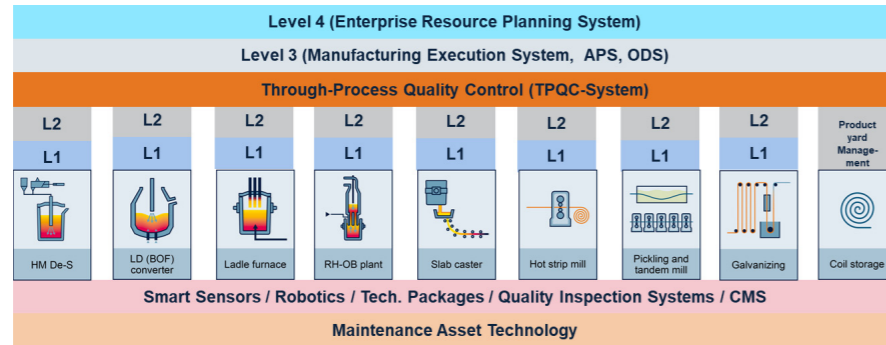


Figure 5 Integration of TPQC with Automation and IT-Systems

The essential functionality is to ensure desired product properties and increase quality levels by monitoring all quality-relevant process parameters along the full production route at defined quality gates. In addition to pure process data, which is collected from various processing unit, the genealogy information interconnects this data across all involved processing unit. I.e., the genealogy, Figure 6, keeps track about elongation factors, head/tail changes, upside/down-changes as well as cutting and welding operations that are possible between different processing units of the production chain.

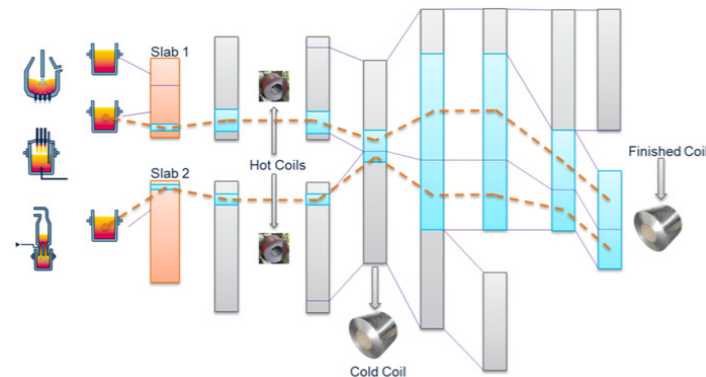


Figure 6 Genealogy based data tracking across multiple processing units

### Quality Control System Functionality

Quality conformance checks are carried out by means of a specific rule system using production data. The results will be shown to operators and quality engineers, respectively, depending on the kind of quality issue and location in the plant. By means of the rule editor TPQC offers a flexible way for quality checks, which paves the way for future adaptations and extensions without having to change any part of the system's source code. Figure 7 shows the principle of this process / quality checking. A green traffic light indicates all values (of a production unit) are inside the specified bounds. A yellow light expresses the presence of minor problems, requiring some further checks. A red light indicates more serious issues which in most cases need a more complex remedial action and a final decision plan. What can be defined as minor and major has to be developed from the process experience and must be finally specified as expert rules, again an example of digitalization of know-how.

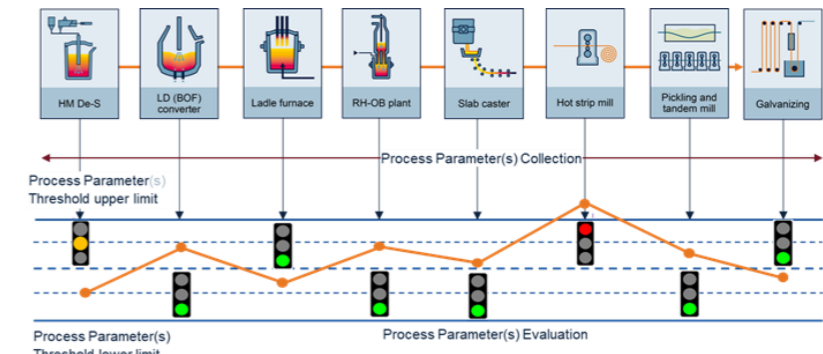


Figure 7 Quality-control functions along the production route.  
Red lights will trigger corrective or compensational actions.

### Deviation and Root-cause analysis

Root-cause analysis (RCA) is a mandatory, method-based and structured way of problem solving used for identifying the real causes of faults or problems. TPQC provides a dynamic root cause approach, Figure 8:

1. In case of a detected deviation, a list of highly probable root-causes is shown to the operators or quality engineers depending on the plant location and organizational responsibility. People who are in charge of deviation management can be informed automatically which possible root causes can be excluded because of non-anomalous measurements.
2. Each root-cause comes with a specific description for root-cause verification, in order to eventually remove any doubt in cases in which more than just one root-cause might be possible.
3. After identification of the actual root-cause, the responsible person places a check-mark and thereby confirms the root-cause for the given quality deviation.
4. The system keeps track of the root-causes for any detected quality deviation and calculates a root-cause statistic.

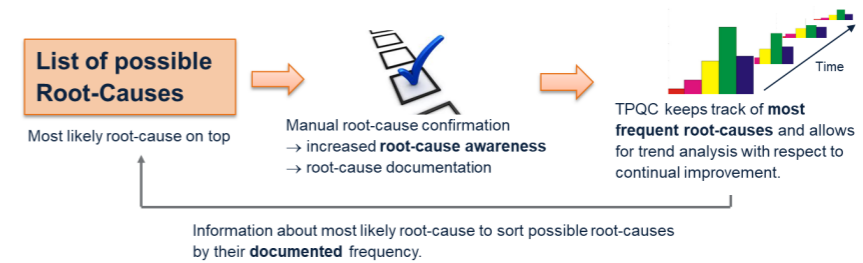


Figure 8 Dynamic Root-Cause Analysis Support

In addition, a root-cause statistic can be calculated for an arbitrary time period and thereby enables the calculation of trends over time. Hence, the root-cause statistic feature is a valuable aid to provide convincing evidence on the effectiveness of the quality management with respect to continual improvements. In particular, it is a useful tool for the plant manager, enabling a strict monitoring of deviation frequencies, in order to identify the most frequent and most costly deviations. These identified deviations may then be addressed by additional problem solving methods and corrective actions, if adequate.

### Corrective and compensational actions

A corrective action can be defined as a set of actions to eliminate the cause of a quality deviation under specific conditions. Unfortunately, the production environment is subject to a large number of influences like any kind of external disturbances, raw material unknowns as well as the human factor and other non-deterministic events. Hence, it is seldom possible to eliminate the cause of a quality issue permanently. For this reason, the definition of corrective action has to be broadened in so far as a certain corrective action for a given root-cause may eliminate a quality deviation absolutely and permanently only under the specific condition that applied previously, although not all of them can be determined or measured and archived. A compensational action is defined as an action to repair an already affected semi-finished product, e.g. by cutting out defective sections from a strip or by means of surface scarifying of a slab as indicated in the example below etc. Because of the fact that the system provides guidance to operators and quality engineers, the tool can also be seen as a learning tool in that regard. It is a fact that people who are actively involved in root-cause analysis for some time will become more aware

regarding quality related influences, which allow them to take preventive measures even before a quality related incident happens, that is without having to wait for root-cause suggestions at any rate and for any incident, respectively. Thus, TPQC can be used as a pure conformance tool for quality checks and root-cause analysis support, but the real benefit of this system is realized when it is also used as a continual learning tool in order to improve the skill level of operators and quality engineers. The next easy example in Figure 9 deals with quality issues in the melt-shop.

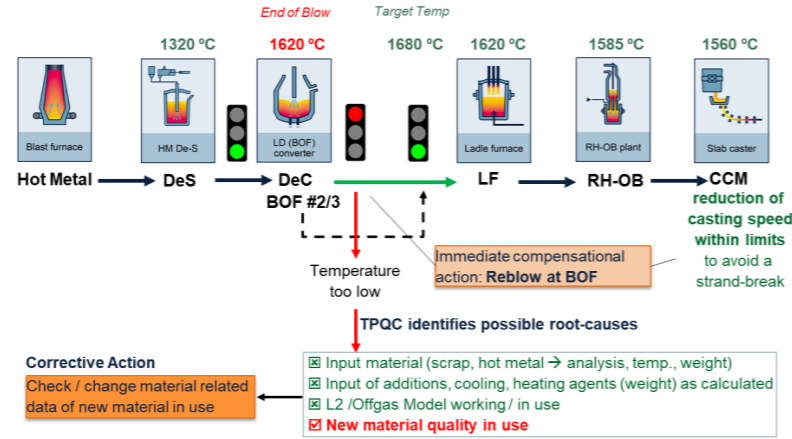


Figure 9 Root-cause analysis within the melt-shop

Figure 9 illustrates the example of a produced heat, which is planned to arrive subsequently at a continuous casting machine. At the end of the BOF process, the L2 system indicates a temperature of the liquid steel that violates the grade specific requirements. In this case, TPQC evaluates the temperature by means of process specific rules and records a quality issue. In addition, the TPQC system immediately suggests a re-blow at the BOF and if this is confirmed by the operator, a message is sent to the operator at the continuous casting machine to reduce the casting speed. By reducing the casting speed, TPQC tries to compensate for the additional processing time caused by the re-blow at the BOF, which otherwise would increase the risk of a sequence break or slab quality issues.

In addition, the system indicates again a list of likely root causes for this problem. In the example case, a new material had been used for the material additions. I.e., the operators had not managed to update the L2 data base with the new material data in time, which led to an inaccurate calculation of the L2 model for the BOF process and finally caused the temperature deviation.

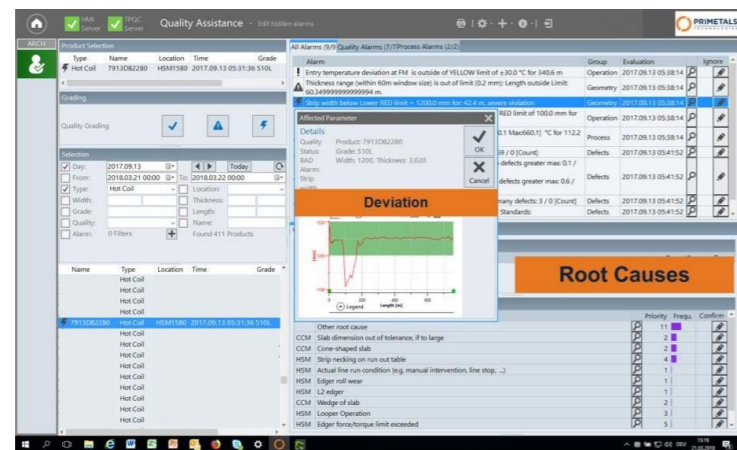


Figure 10 Root-cause analysis support as part of quality assistance

Figure 10 shows a screenshot of how TPQC indicates root-causes for recorded quality issues to quality engineers. The list on the left hand side of the screen shows all semi-finished products for a given day (in this case filtered for heats). The selection of a heat with recorded quality issues (indicated by the call sign) shows all recorded quality alarms/issues. In this case there

are two quality alarms. By selecting a quality alarm, the instructions for verification as well as root causes are shown in the text window at the bottom of the screen.

Even though the given example shows a root-cause analysis for a single process unit, this kind of root-cause analysis is not restricted to single processes or plant areas (melt-shop, hot strip mill, cold mill etc.). By means of carefully specified rules for root-cause analysis, TPQC can also indicate root-causes across process or plant boundaries. In this way, the system supports through-process root-cause analysis, which is especially useful in case of certain surface defects that can be tracked back to the liquid phase. Surface defect rules as well as surface grading will be treated below.

**Automatic product grading**

TPQC incorporates a rule-based module for coil-grading. The coil-grading module pre-processes e.g. surface defect maps, Figure 11. Afterwards, the grading-module performs an in-depth evaluation of the defect map, in order to determine instantly whether a coil surface quality matches the pre-defined requirements of the end-customer, and what action to take if this is not the case.

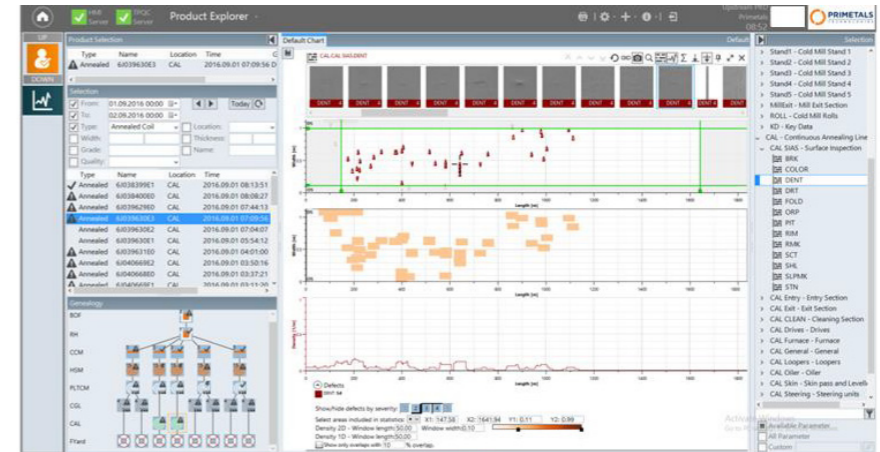


Figure 11 Various surface defects scattered across a hot rolled coil

**Key Performance Indicator evaluation and visualization**

The centralized collection of data enables the generation of key performance indicators (KPIs), which convey information about technical and business-related achievements and illustrate what progress has been made, Figure 12. TPQC implements various types of graphical human-machine interfaces to support staff members from the quality and production departments, as well as top-management executives, in monitoring and benchmarking production conditions with respect to specific targets that are in alignment with the KPIs.

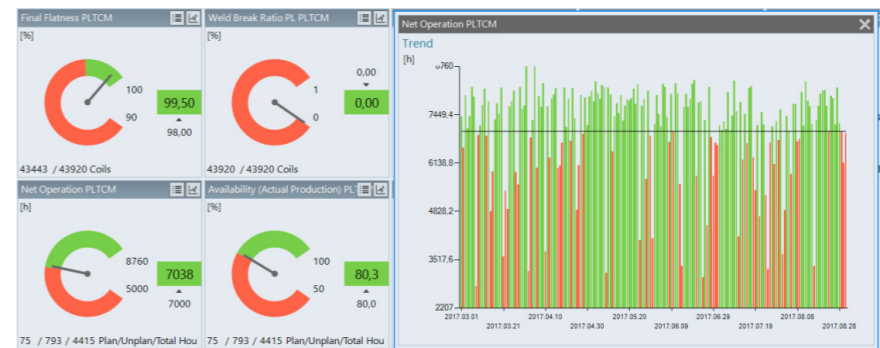


Figure 12 KPI Visualization



### Statistic-process control (SPC)

SPC is a reliable and proven tool to provide statistical evidence that a production process stays within its predefined operational range and therefore behaves in a controlled way, Figure 12. There are significant advantages of having this statistical process control applied to quality assurance processes, since sooner or later statistical significant deviations of process values will have an impact on the product quality. In general, SPC aims on sampling data which is meant to be stable over a long period of time in order to allow for a reliable detection of undesired process dynamic. TPQC can follow up single process criteria but also combined calculated performance indicators and KPIs, and offers SPC charts for selectable material/product related measurements or process data.

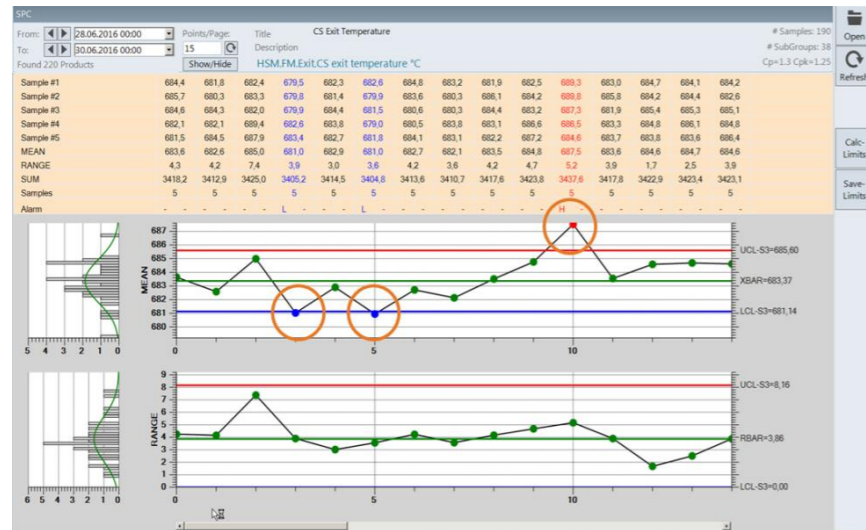


Figure 13 Typical SPC Diagram

### Machine learning capabilities

The extraordinary large amount of structured data in the TPQC system is perfectly suited for analysis with data mining and machine learning algorithms. A direct interface is offered to transfer data to state of the art data mining platforms. All acquired data is automatically assigned to the correct products along the process chain (steel making heat, slab, hot rolled strip, cold rolled strip, galvanized strip) by the genealogy function in the TPQC. Data mining and machine learning in combination with TPQC have following benefits:

1. Fast analysis for data quality and potential problems of measurements, manual inputs, etc.
2. Quick analysis of multi-variate problems e.g. variation of mechanical properties by visualizing the raw data from TPQC
3. Root cause analysis of problems using through-process data and applying advanced data mining methods
4. Predictions using machine learning methods for end of line properties of products or process stability
5. Customized data-based models for quality and process optimization

Closing the loop by creating new rules, KPIs or SPC charts in TPQC can be based on the data mining results, Figure 14. The data mining functionality of TPQC supports quality and process engineers in optimizing the product quality and stabilizing the production process. It is an extremely useful tool to increase the productivity of technologists and engineers throughout the process chain.

Different steps at Data Analytic Services based on Big Data and Machine Learning:

- Data selection and data fusion: Integration of separate but related data from all relevant data sources (L1, L2, L3, MES, TPQC, SIS, CMS, ODS, ERP, etc.) selected by experienced domain experts. Installation of interfaces between different systems by automation experts.
- Data Mining: Data analysis and pre-processing, including clustering, feature selection and reduction, anomaly detection, data visualization, filter, outlier detection, missing data, feature reduction, etc.
- Modeling: Split into train and test data set, choice of model type, validation and optimization, hyper-parameter tuning.

- Evaluation and optimization: Model accuracy, domain knowledge, model update, optimization based on real-time results, and customization of model behavior, combination of multiple models, and integration of calculated values.
- Deployment of software solution and user interface: Software that enables virtual optimization of production parameters as well as reduction of production costs and increase in quality based on prediction models showing the influence of each prediction parameter on target parameters, e.g. optimization of mechanical properties.
- Implementation of deployed models and integration within line automation and IT infrastructure. Transformation of data analytic results into optimized production parameters, production windows (optimized limits), KPI and Rule definition.

Figure 14 is showing the specific know-how demand at different steps of data mining projects.

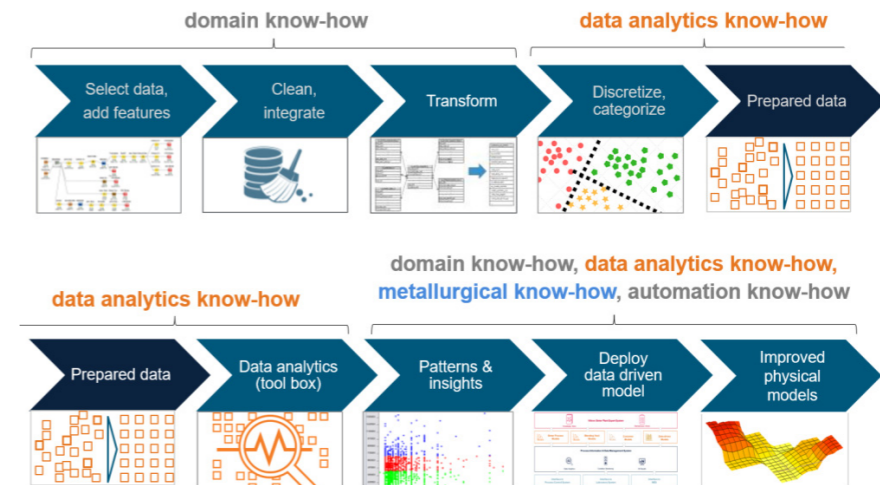


Figure 14 Example for data mining project and definition of actions

## CONCLUSIONS

This paper presents how the coaction of digitalization and human expertise results in a deeper overall process understanding and how this coaction can be supported by a “Through-Process Optimization” digital solution. The holistic approach, considering technical as well as socio-cultural aspects and the combination of metallurgical and operational know-how with an intelligent IT-system allows steel producers to improve their overall efficiency, achieving higher levels of quality and developing and maintain their know-how basis. Particular attention is drawn to the method of generating knowledge from the analysis of production data through on-click access to all quality and process-related production data across the value chain realized by Through-Process Quality Control systems such as TPQC.

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## Haddehane Uçar Makas Uygulamalarında Kullanılan 1.2344, 1.2367 ve 1.2367VAR Takım Çeliklerinin Darbe Dayanımlarının İncelenmesi

Investigation of Impact Resistances of DIN 1.2344, DIN 1.2367 and DIN 1.2367VAR Tool Steels Used in Rolling Mill Flying Shear Applications

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### Abstract

Blades play an important role for keeping weekly stops down to a minimum related to the intention of plants to increase their production rate and capacity. Substitution of a blade or re-welding and grinding operations of a fractured blade takes a significant time during a production route.

In this study, mechanical properties of 1.2367 and 1.2367var steels, both of which are offered as an alternative to 1.2344 steel that is used in flying shear blades for cutting hot rolled semi-finished products (bloom, sheet, plate, bar, etc.), and are produced by the conventional method and vacuum arc remelting method respectively, were evaluated in laboratory conditions. For characterisation, the materials were machined into 20 samples half of which had dimensions of 10x10x55 mm and the rest having dimensions of 14x19x50 mm by the method of wire erosion. The change of hardness with tempering temperature was derived for the investigated steel grades and analyses of Scanning Electron Microscopy (SEM) were performed before the mechanical tests. Cold-environment and hot-environment impact resistance tests were conducted at 25 and 400 °C in order to determine the behaviour of the related materials in case of being subjected to an immediate load.

1.2367var was the most resistant steel against tempering. At both room temperature and 400 °C, the highest impact resistance determined by the impact resistance tests was exhibited by 1.2367var. Finally, real service performances of the samples were measured in a rolling mill facility. Exhibiting the best resistance to tempering, the rolling service performance of 1.2367var steel was higher than the other two materials.

### Özet

İşletmelerin sürekli olarak üretim hızını ve üretim kapasitelerini arttırmak istemesi ve haftalık duruşların minimuma çekilmesini hedeflemeleri sebebiyle bıçaklar önemli bir rol oynamaktadır. Üretim esnasında bir bıçağın değiştirilmesi ya da hasara uğrayan bıçağın yeniden kaynak ve taşlama işlemleri oldukça uzun sürmektedir.

Bu çalışmada haddehanelerde sıcak hadde yarı ürünlerini (kütük, lama, yuvarlak vb.) kesmek için kullanılan DIN 1.2344 kalite uçar makas bıçağına alternatif olarak önerilen: konvansiyonel yöntemle üretilmiş olan 1.2367 ve VAR (Vakum Ark Yeniden Ergitme) yöntemi ile üretilmiş olan 1.2367var kalite çeliklerin laboratuvarında mekanik özellikleri test edilmiştir. Karakterizasyon testleri için malzemelerden, tel erozyon yöntemi ile 10'ar adet 10x10x55mm ve 14x19x50mm ebatlarında numuneler çıkarılmıştır. İncelenen çelik kalitelerinin öncelikle sertlik değerinin menevişleme sıcaklığına göre değişimi ortaya çıkarılmış ve SEM (Taramalı Elektron Mikroskop) analizleri yapılmıştır. Malzemenin ani bir yüke maruz kaldığında nasıl davranacağını tespit edebilmek amacı ile oda sıcaklığında soğuk ortam ve 400 °C'de sıcak ortam darbe deneyleri yapılmıştır.

Menevişlemeye karşı en iyi direnci 1.2367var göstermiştir. Hem oda sıcaklığında hem de 400 °C'de yapılan darbe deneyinde darbeye karşı en yüksek direnci 1.2367var sergilemiştir. Son olarak numunelerin haddehanede gerçek çalışma şartlarında performansları ölçülmüştür. 1.2367var malzemesi menevişlemeye karşı en iyi direnci gösterdiği gibi bu çeliğin haddehane şartlarındaki aşınma direncinin diğer iki malzemeye göre daha yüksek olduğu anlaşılmıştır.

### 1. Giriş

Demir çelik sektöründe, haddehanelerde sıcak haddelenmiş kütük mamullerini kesmek için kullanılan uçar makas bıçakları çeşitli kalite sıcak iş takım çeliklerinden üretilmektedir. Ancak günümüz demir çelik



sektöründe haddehanelerde sıcak haddelenmiş kütük mamullerini kesmek için kullanılan uçar makas bıçakları, maruz kaldıkları yüklerden ve çevresel şartlardan dolayı aşınma, kırılma ve kalıcı deformasyona (ezilme) uğramaktadır. Bu olumsuzluklarla birlikte, bakım-onarım için geçen süre ve bıçağın kırılması veya ezilmesi durumunda gerçekleşen ani duruşlar da göz önüne alındığında, hadde bıçağının düşük kalitede olmasının üretim açısından ciddi aksamalara sebep olup üretimi azalttığı gözlenmektedir.

Haddehanelerde kullanılan uçar makas bıçaklarının darbe dayanımlarını iyileştirmek için DIN 1.2344 takım çeliğine alternatif olarak üretilen 1.2367 ve 1.2367var çeliklerinin ısıtım parametrelerinin belirlenmesi son derece büyük bir önem arz etmektedir. Bıçağın menevişlemeye karşı direncinin de fazla olması ve yüksek sıcaklıkta uzun süre sertliğini yitirmeden tok kalması gerekmektedir. Bu nedenle, bıçak malzemesinin cinsi ve malzemenin ısıtım işlemi geçmişi ile birlikte malzemenin çalışma şartları ve malzemenin deformasyonuna etki eden faktörler hassas bir şekilde incelenmeli ve değerlendirilmelidir.

Bu çalışmada, haddehanelerde sıcak kesim bıçak uygulamalarında kullanılan DIN 1.2344, 1.2367 ve 1.2367var kalite sıcak iş takım çeliklerinin laboratuvar koşullarındaki mekanik özellikleri incelenmiş, mekanik testler olarak sertlik ölçümü ve darbe deneyleri yapılmıştır. Çeliklerin SEM çalışmaları yapılarak mikro yapı bileşenleri belirlenmiştir. Bu testlere ek olarak bu malzemelerden üretilmiş uçar makaslarla haddehanede performans karşılaştırmaları yapılmıştır.

## 2. Deneysel Çalışma

### 2.1. Malzeme

Bıçak malzemelerinin kimyasal bileşimleri, SpektroMax marka spektral analiz cihazında belirlenmiştir. İncelenen takım çeliklerinin kimyasal bileşimleri Çizelge 1'de verilmektedir.

**Çizelge 1.** DIN 1.2344, 1.2367 ve 1.2367var malzemelerin kimyasal bileşim analizi değerleri.

Malzeme	% ağırlıkça bileşim					
	C	Si	Cr	Mo	Mn	V
1.2344	0.40	1.00	5.30	1.40	0.35	1.00
1.2367	0.38	0.40	5.00	3.00	0.40	0.50
1.2367var	0.37	0.40	5.00	3.00	0.50	0.60

### 2.2. Isıl İşlem

Karbürce zengin olan sıcak iş takım çeliklerinin sürtünme ve/veya bıçak uygulamalarında en uygun performansla çalışabilmesi için ısıtım işlemi geçişinin çok iyi olması gerekmektedir. Bu nedenle malzemelerin sertliğinin

menevişleme sıcaklığına göre değişimini gösteren bir diyagram çıkarılmıştır. Östenitleme işlemi vakum fırınında 1050 °C'de yapılarak ardından yağda soğutma ile su verilmiştir. Menevişleme ısıtım işlemi Schmetz marka fırında 250 ve 350 °C'de 2 saat, 450, 550 ve 625 °C'de ise 2 saat 30 dakika süre ile yapılmıştır.

### 2.3. Mikroyapısal İncelemeler

Uygulanan ısıtım işleminden sonra numuneler 200-1200 mesh silisyum karbür zımpara ile zımparalanmış, ardından parlatma işlemi yapılmış ve parlatıldıktan sonra da numunelerin yüzeyleri % 3 Nital ile dağlanmış. Mikro yapı analizi Zeiss Ultra Plus marka SEM cihazında gerçekleştirilmiştir.

### 2.4. Sertlik Ölçümleri

Takım çeliği numuneleri üzerinden gerçekleştirilen sertlik ölçümleri standart Rockwell C esasına göre yapılmıştır.

### 2.5. Darbe Deneyleri

Darbe deneyleri (charpy tipi) TS EN ISO 148-1 standardına göre Zwick marka darbe deneyi cihazında oda sıcaklığında ve 400 °C sıcaklıkta yapılmıştır. Menevişleme ısıtım işleminden sonra standarda göre hazırlanan darbe numunelerinin darbe dayanımı 450 J kapasiteli bu darbe deneyi cihazı ile belirlenmiştir. Darbe deneylerinin oda sıcaklığında yapıldığı ortamın sıcaklığı 25.6 °C, nemi ise %46 olarak ölçülmüştür. Deney cihazından okunan enerji değeri çentikli kısmın altında kalan alana bölünüp malzemelerin darbeye karşı gösterdiği direnç kJ/m<sup>2</sup> cinsinden ölçülmüştür.

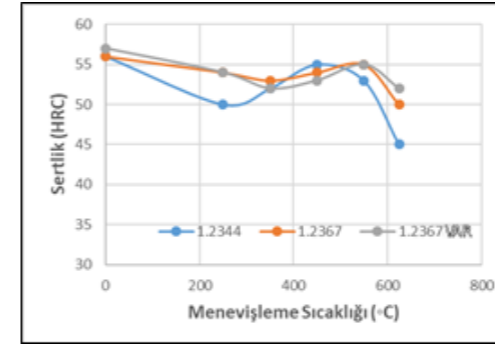
## 3. Bulgular ve İrdeleme

### 3.1. Menevişleme Diyagramının Çıkarılması

Menevişleme ısıtım işlemi uygulanmış malzemelerin farklı meneviş sıcaklıklarına karşı ölçülen sertlik değerleri Çizelge 2'de verilmiştir. Bu ölçümler neticesinde Şekil 1'deki menevişleme diyagramı oluşturulmuştur.

**Çizelge 2.** Farklı sıcaklıklarda menevişlenen takım çeliklerinin sertliklerindeki değişim.

Menevişleme sıcaklığı (°C)	1.2344 (HRC)	1.2367 (HRC)	1.2367var (HRC)
0	56	56	57
250	50	54	54
350	52	53	52
450	55	54	53
550	53	55	55
625	45	50	52

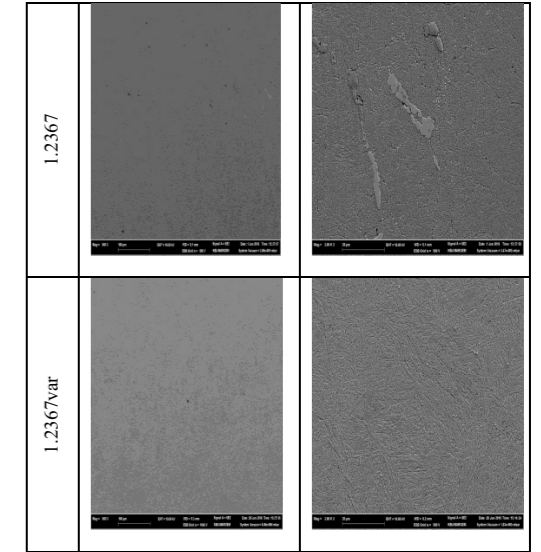


**Şekil 1.** DIN 1.2344, 1.2367 ve 1.2367var takım çeliklerinin menevişleme diyagramı.

### 3.2. Mikroyapısal İncelemeler

İncelenen takım çeliklerinin SEM görüntüleri Şekil 2'de verilmiştir. 1.2344, 1.2367 ve 1.2367var sıcak iş takım çeliklerinin üzerinden edinilen SEM fotoğraflarında matris, tane sınırı boyunca uzanmış küresel açık gri renkli fazlar, noktasal beyaz renkli çökeltiler ve koyu gri renkli küresel parçacıklar görülmektedir. 1.2344 kalite takım çeliğinin mikro yapısına kıyasla 1.2367 kalite çelikte tane sınırlarında oluşan açık gri renkli fazlar kaba ve süreklidir [1, 2]. 1.2344 ve 1.2367 kalite çeliklerin mikro yapısında tane sınırında oluşan fazlar çözünmemiş sert karbürlerdir [2]. 1.2367var malzemede ise tane sınırı boyunca uzanmış küresel açık gri renkli fazlar ve koyu gri renkli küresel parçacık hiç bulunmamakla birlikte noktasal beyaz renkli çökeltiler oldukça ince ve seyrek bir şekilde dağılmıştır [3].

Malzeme	Düşük büyütme (500x)	Yüksek büyütme (3000x)
1.2344		



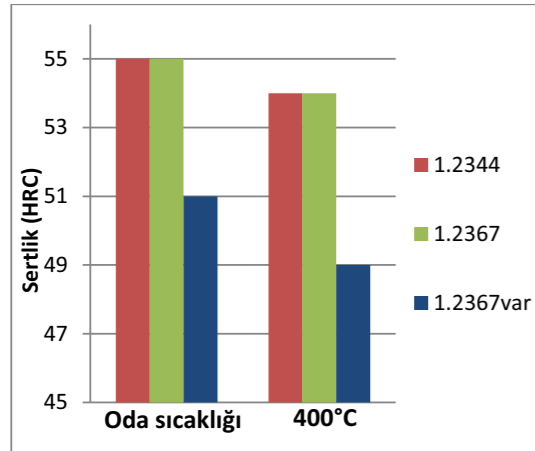
**Şekil 2.** İncelenen DIN 1.2344, 1.2367 ve 1.2367var takım çeliklerinin 500 (solda) ve 3000 (sağda) büyütmede elde edilen SEM görüntüleri.

### 3.3. Darbe Deneyleri

İncelenen numunelerin sertlik değerleri oda sıcaklığında ve 400 °C'de yapılmış darbe deneyleri sonucu ikiye bölünmüş olan numunelerin üzerinden edinilmiş olup Çizelge 3'te ve Şekil 3'te HRC biriminde verilmiştir. Sertlik ölçümünde darbe numunelerinin kullanılmasında ile numunelere uygulanan ısıtım işlemi üzerindeki etkisi belirlenmiştir. Şekil 3 incelendiğinde 1.2344 ile 1.2367 çeliği numunelerinin oda sıcaklığında yapılan darbe deneyi sonrasındaki sertliklerinin aynı ve yüksek (55 HRC) iken 1.2367var çeliği numunesinin sertliğinin bir miktar düşük (51 HRC) olduğu görülmektedir. İncelenen numunelerin sıcaklıkla birlikte sertliklerinin az miktarda düştüğü gözlenmiştir.

**Çizelge 3.** Darbe numunelerinin oda sıcaklığındaki soğuk darbe ve 400 °C'deki sıcak darbe sonrasında HRC biriminde ölçülen sertlik değerleri.

Malzeme ve deney sıcaklığı	Sertlik (HRC)
1.2344 (oda sıcaklığı)	55
1.2344 (400 °C)	54
1.2367 (oda sıcaklığı)	55
1.2367 (400 °C)	54
1.2367var (oda sıcaklığı)	51
1.2367var (400 °C)	49

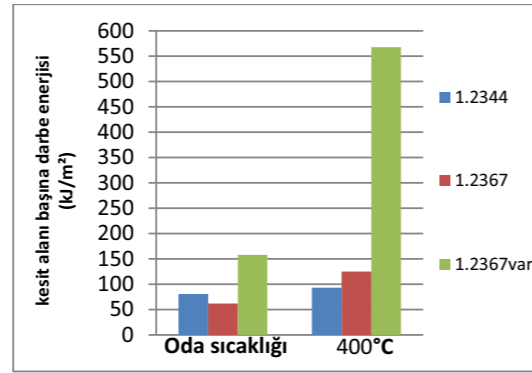


Şekil 3. Darbe numunelerinin oda sıcaklığındaki soğuk darbe ve 400 °C'deki sıcak darbe sonrasında ölçülen sertlik değerlerinin grafik ile gösterimi.

Malzemelerin kesit alanı başına darbe cihazında absorbe ettikleri enerji miktarları Çizelge 4'te verilmiştir. 1.2367 ve 1.2367var malzeme aynı kimyasal bileşime sahip olmasına rağmen ikisinin darbeye karşı gösterdiği dirençte, Şekil 4'te verilen grafikten de anlaşıldığı üzere, çok ciddi bir fark olmuş, bu fark da VAR üretim tekniği ile elde edilen daha homojen bir iç yapıdan (tane boyutu, karbür miktarı ve boyutu vb.) kaynaklanmıştır [1, 4]. Bu farkın sebebi Şekil 2'de verilen SEM görüntülerinde yer alan mikroyapılarda açıkça gözlemlenebilmektedir. Genel olarak, darbe deneyi sıcaklığı yükseldikçe malzemelerin sünekliliği artmaktadır [5]. VAR yöntemiyle üretim kırılma enerjisi ve mikroyapı açısından konvansiyonel üretime göre daha yüksek ve gelişmiş özellikler göstermektedir [4].

Çizelge 4. Malzemelerin kesit alanı başına darbe enerjileri.

	1.2344	1.2367	1.2367var
Oda sıcaklığı	81 kJ/m <sup>2</sup>	62 kJ/m <sup>2</sup>	158 kJ/m <sup>2</sup>
400 °C	93 kJ/m <sup>2</sup>	125 kJ/m <sup>2</sup>	568 kJ/m <sup>2</sup>

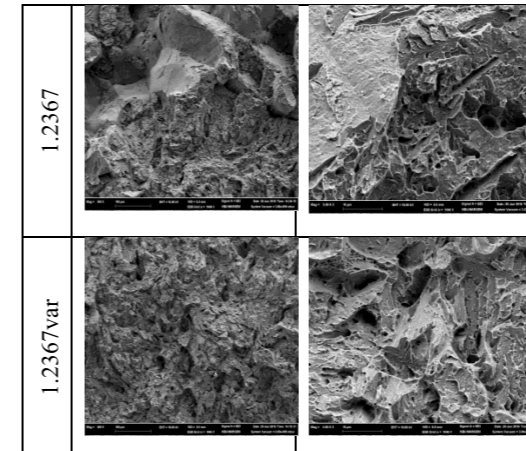
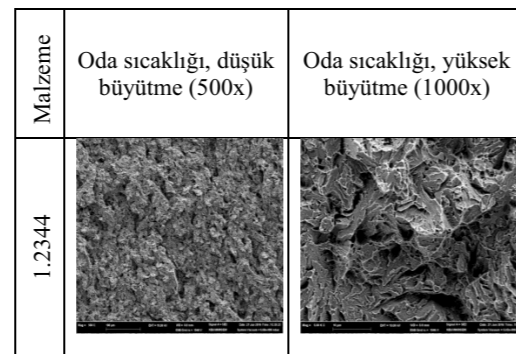


Şekil 4. Malzemelerin kesit alanı başına darbe enerjilerinin grafik ile gösterimi.

Sıcak iş takım çeliği numunelerine oda sıcaklığı ve 400 °C'de uygulanan darbe deneyi sonrasında numunelerin kırık yüzeyinden elde edilen SEM görüntüleri sırasıyla Şekil 5 ve Şekil 6'da verilmiştir.

Şekil 5 incelendiğinde incelenen malzemelerin gevrek karakterde olup düz yüzeyli bir kırılma sergilediği gözlemlenmektedir [1]. 1.2367var kalite takım çeliği oda sıcaklığında diğerlerine kıyasla daha yüksek enerjide kırılmasına rağmen kırık yüzey açısından dikkatli bakılmadıkça bir fark gözlemlenmeyebilir. Fakat kırık yüzeyde yer yer plastik deformasyon izleri taşıyan bölgeler bulunabilmektedir.

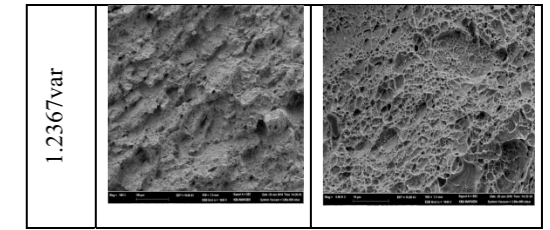
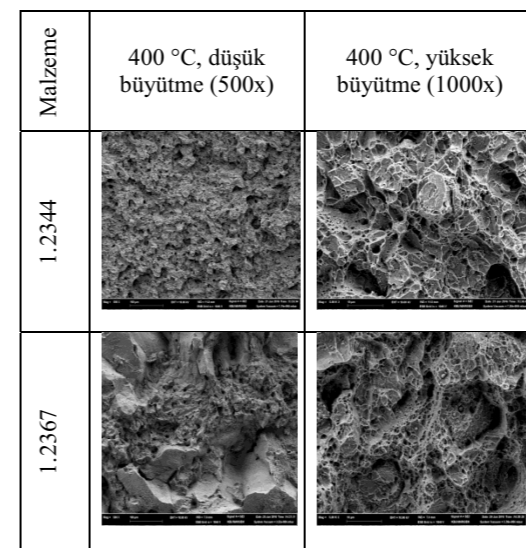
Şekil 6 incelendiğinde 1.2344 ve 1.2367 malzemede çok sayıda dimple karakterinde sünek kırılma gözlenmektedir. 1.2367var malzemede ise diğerlerine kıyasla daha ince ve homojen dağılmış dimple içeren daha sünek bir kırılmanın gerçekleştiği görülmektedir.



Şekil 5. Oda sıcaklığında yapılan darbe deneyi sonrası numunelerin kırık yüzeylerinin 500 (solda) ve 1000 (sağda) büyütmede elde edilen SEM görüntüleri.

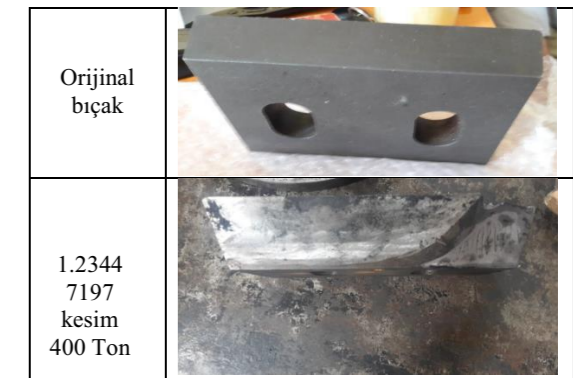
#### 3.4. Haddehane bıçak performansı testleri

Laboratuvar ortamında incelenen bıçak malzemelerinin gerçek koşullardaki performansını incelemek ve laboratuvar ortamındaki sonuçlar ile karşılaştırmak amacıyla haddehane testleri yapılmıştır. Bu test esnasında, haddehanelerde olağan olarak yaşanmakta olan, mal ve çekilen boyuttaki ani değişimler, zamansız duruşlar vb. faktörlerin hiçbirisi minimize edilmeyerek tamamen gerçek koşullardaki çalışma performansı incelenmiştir. 1.2367 malzemeden yapılan bıçak ile st37-2 kalite çubuk ve ağırlıklı olarak da DIN 1.1040 kalite çubuk mamul kesilmiştir. 1.2344 kalite bıçak ile de st37-2 ve DIN 1.1040 kalite mamul kesilirken 1.2367var kalite bıçak ile DIN 1.1040 ve st52-2 kalite mamul kesilmiştir.

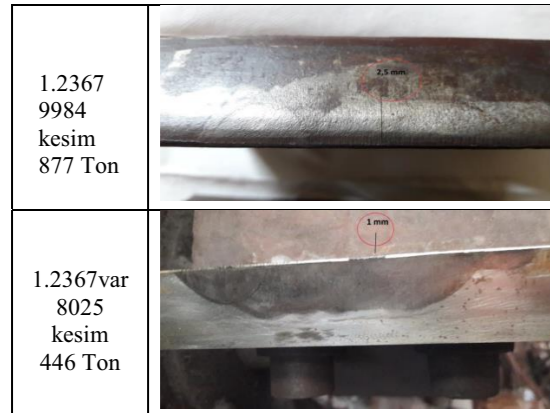


Şekil 6. 400 °C'de yapılan darbe deneyi sonrası numunelerin kırık yüzeylerinin 500 (solda) ve 1000 (sağda) büyütmede elde edilen SEM görüntüleri.

Kullanılan bıçak kalitelerinin kesim sayısı ve kesilen ara ürün miktarı, orijinal bıçağın bir fotoğrafı ve bıçakların söküldükten sonraki yüzey görünümünü gösteren fotoğraflar ile birlikte Şekil 7'de verilmiştir. Şekilden anlaşılacağı üzere, 1.2344 kalite ile yapılan bıçaklarda sürekli olarak taşlamaya ihtiyaç duyulmuş ve bıçağın üçüncü vardiyayı tamamlamadan kırıldığı gözlemlenmiştir. 1.2367 kalite bıçak ise iyi bir çalışma performansı sergilemiş olup herhangi bir kırılma olmaksızın çalışmıştır. 1.2367 kalite bıçağın kesici ağzında meydana gelen aşınmanın derinliği 2.5 mm olarak ölçülmüştür. Sıcaklığın etkisiyle kesici kenara yakın yerlerin sertliği bir miktar düşmüş ve her kesime yayılan darbe neticesinde de bıçağın üst kısmı bir miktar yuvarlanmıştır. 1.2367var bıçakta, çok farklı çaplarda çalışmasına ve farklı ürün gruplarının kesilmesinde kullanılmasına rağmen, kırılma gözlemlenmemiş olup bıçak ağzındaki aşınma derinliği yalnızca 1 mm kadardır. Aşınma derinliklerinin Şekil 7'de verilen kesilmiş ara ürün miktarlarına kesit alanları hesaba katılarak bölünmesi ile normalize edilen değerler Çizelge 5'te verilmiştir. İncelenen bıçak malzemelerinin kesit alanı başına Çizelge 5'te verilen aşınma kayıpları Şekil 8'de bir grafik içerisinde karşılaştırılmıştır. Şekilde görüldüğü gibi 1.2367var kaliteye kıyasla 1.2367 kalite çelik ve 1.2344 kalite çelik aşınmaya daha fazla maruz kalmıştır.



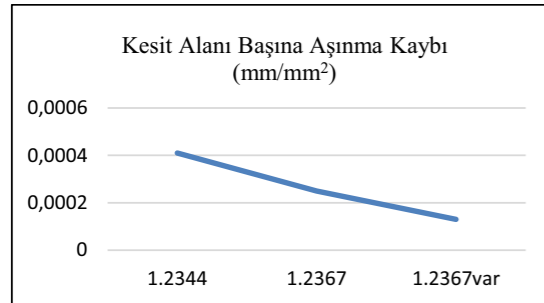




**Şekil 7.** 1.2344, 1.2367 ve 1.2367var malzemeleri ile yapılan bıçaklar ile yapılan kesim sayısı, kesilen ara ürün miktarı ile bir bıçağın çalışma öncesi fotoğrafı ve bıçakların çalışma sonrası fotoğrafları.

**Çizelge 5.** Üç bıçağın kesilmiş ara ürün kesit alanı başına aşınma kaybı.

Malzeme	Kesit alanı başına aşınma kaybı (mm/mm <sup>2</sup> )
1.2344	0.00041
1.2367	0.00025
1.2367var	0.00013



**Şekil 8.** Aşınma kaybının kesit alanına oranının grafik şeklinde gösterimi.

#### 4. Sonuçlar

Belirlenen menevişleme diyagramından yararlanılarak en uygun sıcaklık ve sürelerde ısıl işlem uygulanmış DIN 1.2344, 1.2367 ve 1.2367var kalite sıcak iş takım çeliklerinin mikroyapısına, mekanik özelliklerine ve hadde bıçak uygulamalarına takım çeliği cinsinin etkisinin incelenmesi amacıyla gerçekleştirilen bu çalışmada elde edilen genel sonuçlar aşağıda listelenmiştir:

- 1.2344 kalite takım çeliğinin 450 °C'de ikincil sertlik gösterdiği, ancak 1.2367 ve 1.2367var çeliklerinin 550

°C'de ikincil sertlik gösterdiği çizilen menevişleme diyagramından yararlanılarak belirlenmiştir.

- 1.2344, 1.2367 ve 1.2367var kalite sıcak iş takım çeliği malzemelerin oda sıcaklığında yapılan darbe deneyi sırasında absorbe ettikleri enerji miktarları sırasıyla 81, 62 ve 158 kJ/m<sup>2</sup>'dir. Sıcak iş takım çeliği malzemelerin 400 °C'de yapılan darbe deneyi sırasında absorbe ettikleri enerji miktarları ise 1.2344 için 93 kJ/m<sup>2</sup>, 1.2367 için 125 kJ/m<sup>2</sup>, 1.2367var için ise 568 kJ/m<sup>2</sup>'dir.

- Darbe deneyleri sonrası kırık yüzeyden elde edilen SEM görüntülerinde tüm sıcak iş takım çeliklerinin oda sıcaklığında gevrek bir kırılma sergilediği, 400 °C'de yapılan kırık yüzey incelendiğinde 1.2344 ve 1.2367'nin sünek bir kırılma davranışı sergilediği görülmüş, 1.2367var'ın SEM görüntülerinde ise çok sayıda ince dimple gözlemlenmiş olup bu çeliğin daha sünek bir kırılma gösterdiği anlaşılmıştır.

- Haddehanede yapılan testlerde kesit alanı başına aşınma kaybı 1.2344 için 0.00041, 1.2367 için 0.00025 ve 1.2367var için ise 0.00013 mm/mm<sup>2</sup> olarak ölçülmüştür.

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## Hadde Yatak Malzemesi Olarak Kullanılan Alüminyum Bronzunun Farklı Yağlayıcı Ortamlarında Aşınma Özelliklerinin İncelenmesi

Investigation of Wear Properties of an Aluminium Bronze Used as a Rolling Bearing Material in Different Lubricant Environments

Aleattin Kulaklı, Tuba Özeren, Talip Çitrak, Serdar Tozkoparan, Zeynep Özeşer

SAĞLAM METAL • Türkiye

#### Abstract

Nickel aluminium bronze (NAB) is a copper alloy which combines high corrosion resistance with good mechanical properties at high temperatures. NABs are considered excellent materials especially for applications that require superior resistance to corrosion and abrasive wear under heavy loads. NAB, which is included in the product list of Sağlam Metal Industry & Trade Co., is one of the most important copper alloys used in tools for bending and straightening (scoops and mandrels), wear-resistant machine parts and aircraft landing gears, as well as bearings and guideways.

This study aims to investigate the friction and wear behaviours of an aluminium bronze material having a nominal chemical composition of CuAl10Ni5Fe4 in mineral oil environment, water environment, boron oil environment and solid environment under a load of 20 N. Prior to wear resistance tests, microstructure of the alloy which had been produced in accordance to the related chemical composition was investigated by using an optical microscope while some of its mechanical properties were revealed by hardness measurements. Wear resistance tests of the alloy were performed at 26.6 °C temperature in a pin-on-disc based experimental set-up (UTS TRIBOLOG), a 100Cr6 steel ball being used as the pin. By these tests, frictional loss of volume and coefficient of friction were evaluated while wear mechanism was determined for different running conditions of the alloy so that comparisons could be made. The first findings revealed that the aluminium bronze exhibited high wear resistance in mineral oil environment, but a lower wear resistance in solid environment.

#### Özet

Nikel-alüminyum bronzu, yüksek sıcaklıklarda mekanik özelliklerin, korozyon dayanımı ile birlikte kombine edildiği bakır alaşımıdır. Nikel alüminyum bronzları özellikle ağır yükler altında üstün abrazif aşınma

dayanımı ve yüksek korozyon gerektiren uygulamalar için mükemmel malzemeler olarak kabul edilirler. Sağlam Metal A.Ş. firmasının ürün kataloğunda yer alan nikel- alüminyum bronzu, bükme ve düzeltme takımları (kaşıklar ve malafalar), aşınma dayanımlı makine parçaları, uçak iniş takımları dişli malzemesi, yatak ve kızaklarda kullanılan en önemli bakır alaşımından biridir.

Bu çalışmada, CuAl10Ni5Fe4 nominal bileşimindeki alüminyum bronzu malzemenin mineral yağ ortamı, su ortamı, bor yağı ortamı ve kuru ortam koşullarında, 20N yüklenme şartlarındaki sürtünme ve aşınma özelliklerinin incelenmesi amaçlanmıştır. Bu amaçla, belli kimyasal bileşimde üretilmiş olan alaşımın mikro yapısı optik mikroskop, mekanik özellikleri ise sertlik testleriyle incelenmiştir. Alaşımın sürtünme ve aşınma testleri ise 26.6 ° C sıcaklıkta, aşındırıcı olarak 100Cr6 çelik bilye pin-on-disk esaslı bir deney sisteminde (UTS TRIBOLOG) gerçekleştirilmiştir. Bu deneyler sonucunda, alaşımın farklı çalışma şartlarındaki aşınma (kütle) kayıpları, sürtünme katsayısı değişimleri ve aşınma mekanizmaları belirlenerek karşılaştırmalar yapılmıştır. İlk bulgulara göre, alüminyum bronzu, mineral yağ ortamında yüksek, kuru ortamda ise düşük aşınma direnci sergilemiştir.

#### 1. Giriş

Demir çelik sektöründe yatak malzemesi olarak en yaygın kullanım alanı bulan bakır alaşımları; kalay, kurşun ve alüminyum bronzlarıdır [1]. Alüminyum bronzları, birincil alaşım elementi olarak % 5-12 Al içerir. Demir, nikel ve manganez ilaveleri bu alaşımın ticari olarak kullanılmasını sağlamaktadır [2]. Nikel alüminyum bronzları, yüksek mukavemet, aşınma direnci ve korozyon dirençlerinden dolayı oldukça yoğun kullanılan malzemelerden biridir [3]. Bu malzemelerden üretilmiş yatakların yüksek darbe ve aşınma dayanımı, iyi korozyon direnci, düşük sürtünme katsayısı, yüksek yüklenme kapasitesi gibi özelliklere sahip olması beklenmektedir.

Hadde yataklarındaki aşınma mekanizmaları birçok faktöre bağlı olarak değişkenlik göstermektedir. Bu faktörler ve etkileri tribolojik sistem içerisinde incelenebilir. Bu faktörler; temel sürtünme malzemesi, karşı sürtünme malzemesi, ara madde, çevre, uygulanan yük ve hareketten oluşmaktadır. Bu çalışmada bir nikel alüminyum bronz, pin-on-disk esaslı aşınma cihazında aşındırılarak mineral yağ ortamı, su ortamı, bor yağı ortamı ve kuru ortam koşullarında sürtünme katsayısı ve aşınma kayıpları belirlenmiştir.

## 2. Deneysel Çalışma

### 2.1. Malzeme

Bu çalışmada dövülmüş standart bir CuAl10Ni5Fe4 alaşımı referans malzeme olarak kullanılmıştır. Alaşımın kimyasal bileşimi Hitachi Inspire the Next marka spektral analiz cihazı ile belirlenmiş ve Çizelge 1'de verilmiştir.

**Çizelge 1.** Dökülmüş alüminyum bronzunun kimyasal bileşimi.

% Cu	% Zn	% Al	% Fe	% Ni	% Mn	% Si
79,79	0,12	9,88	4,77	4,0	1,23	0,16

### 2.2. Mikroyapısal incelemeler

Mikroyapı karakterizasyonları Nikon Eclipse MA100 model ters metal mikroskobu kullanılarak gerçekleştirilmiştir. Numunelerin mikro ölçekte kimyasal olarak dağlanması 50 ml HCl, 10 ml HNO<sub>3</sub> ve 10 g FeCl<sub>3</sub> içeren 100 ml saf su içerisine daldırma yoluyla yapılmıştır.

### 2.3. Mekanik özelliklerin incelenmesi

Alaşımın mekanik özellikleri, sertlik testi yardımıyla karakterize edilmiştir. Vickers mikro sertlik testleri Future-Tech FM800e marka bir cihaz kullanılarak 1000 g yük altında ölçülmüştür.

### 2.4. Abrazif aşınma deneyi

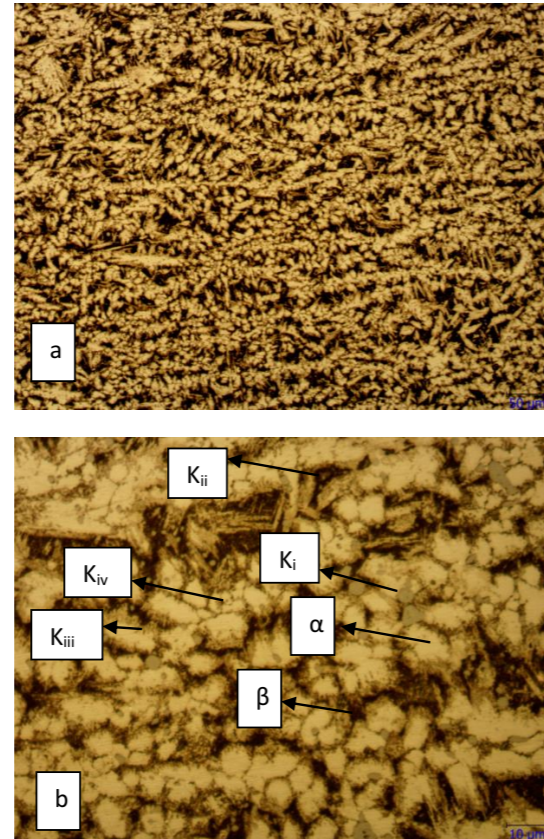
Dövülmüş alaşımların sürtünme ve aşınma deneyleri pin-on-disk tipi bir Universal sürtünme aşınma test sistemi (UTS TRIBOLOG) ile gerçekleştirilmiştir. Aşınma testleri için çapı 30mm, kalınlığı 10mm boyutlarında numuneler hazırlanmıştır. Numuneler; 20N yük altında ve 251,2 mm/s kayma hızında testlere tabi tutulmuştur. Her bir şarttaki kayma mesafesi 1000m, dönme hızı ise 300d/dk olarak belirlenmiştir. Aşınma miktarları kütle kaybı olarak hesaplanmıştır. Sürtünme katsayısı ise kayma mesafesine göre çizdirilmiştir.

## 3. Deneysel Sonuçlar

### 3.1. Mikroyapısal inceleme

Nikel alüminyum bronzunun dökülmüş durumdaki tipik mikroyapısı, bakırca zengin yumuşak  $\alpha$  (alfa) fazı, sert martenzitik  $\beta$  (beta) fazı ve pek çok sert intermetalik  $\kappa$  (kappa) fazından ( $\kappa_1$ ,  $\kappa_{ii}$ ,  $\kappa_{iii}$  ve  $\kappa_{iv}$ ) oluşmaktadır [4].

Nikel içeren alüminyum bronzlarının aşınma davranışı ve mekanik özellikleri büyük ölçüde mikroyapısına bağlıdır. Yumuşak  $\alpha$  fazının hacimce oranı azaldıkça ve sert  $\kappa$  fazlarının hacimce oranı arttıkça sertlik artma eğilimine girer [5]. Thossatheppitak ve arkadaşları [6] nikel alüminyum bronzlarının sıcak deformasyon koşullarında mikroyapılarını incelemiş ve 750°C - 800°C aralığında sıcak deformasyonun mikroyapı üzerinde önemli bir etkisinin olmadığını, 850 °C üzerinde ise  $\kappa_{ii}$ ,  $\kappa_{iii}$ , fazlarının tamamen çözündüğünü,  $\kappa_{iv}$  fazının ise uygulanan deformasyon miktarına göre azaldığını raporlamışlardır. Çalışmada kullanılan ve 800 °- 850°C aralığında dövülen CuAl10Ni5Fe4 alaşımına ait tipik dövme mikroyapıları Şekil 1'de verilmiştir. Mikroyapıda  $\alpha$ ,  $\beta$ ,  $\kappa_1$ ,  $\kappa_{ii}$ ,  $\kappa_{iii}$  ve  $\kappa_{iv}$  fazları olduğu tahmin edilen fazlar gösterilmiştir.



**Şekil 1.** Dövülmüş alüminyum bronzunun ışık mikroskobu görüntüleri (Büyütme: a) 100x b) 500x).

### 3.2. Sertlik değeri

Nikel alüminyum bronzunun sertlik değeri 214 HV ölçülmüştür (Çizelge 2). Bu değer nikel alüminyum bronzu dövme ürünleri için ortalama bir değerdir.

**Çizelge 2.** Dövülmüş alüminyum bronzunun sertlik değeri.

Malzeme	Yük	Ortalama Değer
CuAl10Ni5Fe4	1000 g	214 HV

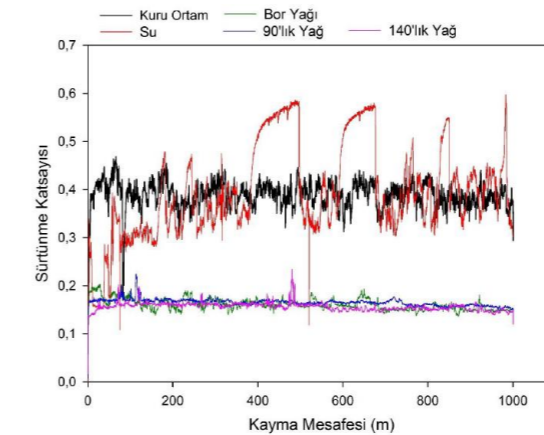
### 3.3. Aşınma deneyi sonuçları

Malzemelerin aşınma davranışları kütle kayıpları üzerinden incelenmiştir (Çizelge 3). Yağlayıcı ortamda yapılan deneylerde aşınma dayanımı oldukça artmıştır. En düşük kütle kaybı kinematik viskozitesi 140 olan yağ ortamında elde edilmiştir. Kuru ve su ortamında yapılan deneylerde yüksek sürtünme katsayısının neticesi olarak numunelerde daha fazla aşınma gözlenmiştir.

**Çizelge 3.** Aşınma deneyi sonuçları (Kütle kayıpları).

Kuru Ortam	Su Ortamı	Bor Yağı	90'lık Yağ	140'lık Yağ
0,0182	0,0164	0,0029	0,0010	0,0008

Çalışma kapsamında nikel alüminyum bronzuna ait sürtünme katsayıları belirlenmiş ve sürtünme katsayısının mesafe ile değişimi Şekil 2 'de verilmiştir. Kuru ortamda ve su ortamında yapılan testlerde oldukça yüksek sürtünme katsayısı değerleri elde edilirken, bor yağı ve mineral yağ ortamlarında yapılan testlerde düşük sürtünme katsayıları elde edilmiş olup bu değişim kayma mesafesi boyunca devam etmiştir. Yağlayıcı ortamda yapılan testlerde sürtünme katsayısının oldukça azaldığı görülmektedir.



**Şekil 2.** Alüminyum bronzunun 20 N yük altında sergilediği yola bağlı sürtünme katsayısı değişim grafiği.

## 4. Sonuçlar

Bu çalışmada nikel içeren bir alüminyum bronzunun (CuAl10Ni5Fe4 alaşımı) farklı çalışma ortamlarında yapılan aşınma deneylerinde aşağıdaki sonuçlar elde edilmiştir:

1. Yağlı ortamlarda nikel alüminyum bronzların sürtünme katsayısı ve aşınma kayıpları kuru ve su ortamlarına göre daha düşük elde edilmiştir.

2. Yağlı ortamlarda yapılan deneylerde sürtünme katsayısının oldukça azaldığı görülmektedir. Bu numunelerde çok az miktarda aşınma gözlenmiştir.

3. En düşük sürtünme katsayısı ve kütle kaybı, kinematik viskozitesi 140 olan yağ ortamında yapılan aşınma deneyinde elde edilmiştir.

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## Türkiye Demir - Çelik İşletmelerinin Enerji Tasarrufu Potansiyeli

Potential of Energy Savings in Turkish Iron & Steel Plants

Uğur Cengiz, Oğuzhan Sakarya

BİLECİK DEMİR ÇELİK • Türkiye

### Abstract

It is important to adopt and maintain a systematic approach in energy efficiency in Iron - Steel company. For this reason, the existence of TS EN ISO 50001 Energy Management System (EnMS), energy studies and studies to increase energy efficiency have become imperative. As in all management systems, the PDCA cycle is based on the "Plan, Do, Check, Act" ranking in the Energy Management System. In addition to this, energy efficiency for Iron - Steel sector is both an environmental problem, a strategic problem in terms of sustainability, and a current imperative to reduce costs with increasing competition. Increasing and optimizing energy efficiency in enterprises has attracted attention by managers, the methods and tools used for efficient consumption of energy have become more important. This scope of study, Bilecik Demir Çelik, includes energy management system implemented to increase energy efficiency and applicable studies covering all steel meltshop and rolling mills. Studies have shown that energy costs can be reduced between 5% and 20% per year with EnMS and its tools.

### Özet

Demir - Çelik işletmelerinde enerji verimliliğinde sistematik bir yaklaşımın benimsenmesi ve sürdürülmesi önemlidir. Bu nedenle işletmelerde TS-EN ISO 50001 Enerji Yönetim Sistemi (EnYS)'nin varlığı, enerji etütlerinin ve enerji verimliliğini artırıcı çalışmaların uygulanıyor olması zorunluluk haline gelmiştir. Her yönetim sisteminde olduğu gibi enerji yönetim sisteminde de "Planla, Uygula, Kontrol Et, Önlem al" sıralamasında PUKO döngüsü temel alınmaktadır. Bunun yanında, Demir - Çelik sektörü açısından enerji verimliliği hem çevresel bir sorun, hem sürdürülebilirlik açısından ele alınan stratejik bir problem, hem de artan rekabet ile birlikte maliyetlerin

düşürülmesi için güncel bir zorunluluktur. İşletmelerde enerji verimliliğinin artırılması ve optimize edilmesi yöneticiler açısından önemli bir problem olarak ortaya çıkmış, enerjinin verimli şekilde tüketilmesi için kullanılan yöntem ve araçların önemi daha da artmıştır. Bu çalışma kapsamında; Bilecik Demir Çelik San. Tic. A.Ş.'de enerji verimliliğini arttırmak üzere uygulanan enerji yönetimi sistemine ve tüm Çelikhane ve Haddehaneleri kapsayan uygulanabilir etütlere yer verilmiştir. Araştırmalar göstermiştir ki, EnYS ve araçları ile yıllık enerji maliyetleri %5 ile %20 arasında düşürülebilir.

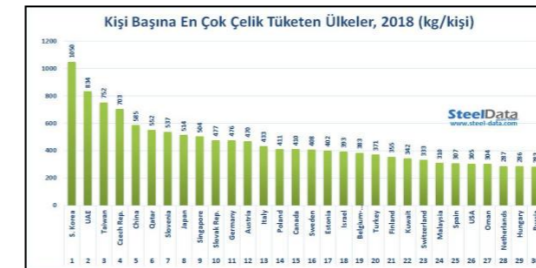
### 1. Giriş

Aynı ya da daha fazla miktarda ürün üretmek için daha az enerji kullanımı olarak ifade edilen "Enerji Verimliliği"nin; sanayi sektörleri içinde en çok enerji tüketen sektörlerden biri olan Demir - Çelik endüstrisinde önemi giderek artmaktadır. Enerjiyi yoğun kullanan Demir - Çelik sektörünün, Türkiye'nin toplam enerji tüketimi içerisindeki payı, %7,5 sanayi tüketimi içerisindeki payı %21 civarındadır. Demir - Çelik sektöründe, enerjinin girdi maliyetlerindeki payı ise hammadeden sonra 2. sırada yer almakta ve % 15-25 civarında yüksek bir orana karşılık gelmektedir. Enerjinin üretim maliyetleri içerisindeki payı, enerjinin Demir - Çelik sektörü açısından nasıl bir öneme sahip olduğunu göstermeye yetmektedir. Bu nedenle "Enerji Yönetimi" enerji maliyetlerini azaltmak için çelik üreticilerinin öncelikli konularından biri haline gelmektedir.

Son yıllarda daha fazla gündemde olmasına karşın, aslında enerji geçmişte de büyük öneme sahip olan bir konu idi. Çünkü enerji kaynaklarına sahip olmak ve enerji yollarını yönetmek isteyen ülkeler birbirleri ile

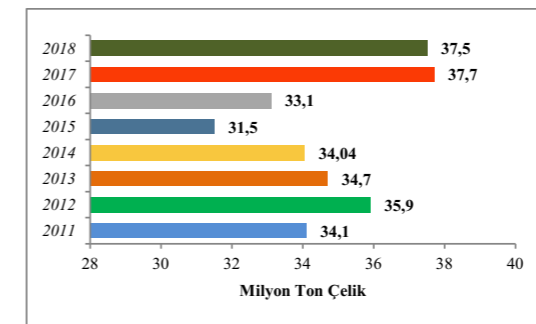
devamlı savaşmışlardır. Dünya savaşlarının arka planına baktığımızda asıl konunun enerji kaynakları ve enerji yolları olduğunu görürüz. Ülkelerin rekabet üstünlüğü sağlamada istifade ettikleri en önemli unsurlardan biri olan enerji, içinde bulunduğumuz yeni dönemde ise teknolojik yenilikler, sermaye hareketleri için sınırların hemen hemen kalkmış bulunması ve iletişim alanındaki önemli gelişmeler, hem Dünya'daki enerji kullanımının miktar ve hızını arttırmış, hem de enerjiyi üzerinde durulması gereken en önemli sorun alanlarından birisi haline getirmiştir.

Diğer bir yaklaşımla, ülkelerin gelişmişlik seviyelerini belirleyen göstergelerden biri olan kişi başına demir - çelik tüketiminin Dünya ve Avrupa Birliği değerlerini yakalaması amacıyla, ülkede sektör, Türkiye Cumhuriyeti'nin kurulmasıyla beraber başlayan sanayileşme sürecinde her zaman önemli bir yere sahiptir. Bu değer, 2000 yılı için Avrupa Birliği'nde ortalama 385 kg/kişi, Türkiye'de ise aynı yıl için 196 kg/kişi, 2005 yılı için 230 kg/kişi, 2018 yılı için ise Şekil 1'de belirtildiği gibi 371 kg/kişi'dir.

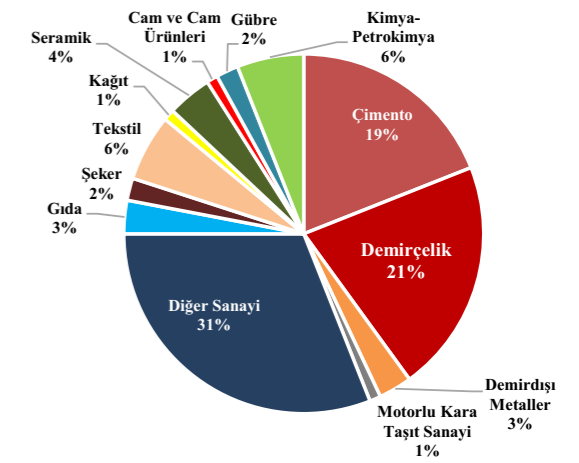


Şekil 1. Kişi başına en çok çelik tüketen ülkeler

Şekil 2'de belirtildiği gibi 2018 yılında 37,3 milyon ton çelik üretimi gerçekleştiren Türkiye, çelik sektöründe, bir önceki döneme göre (37,5 milyon ton) ham çelik üretimi yaklaşık %0,6 oranında azalmıştır. Üretimdeki düşüşe rağmen Türkiye, Dünya ham çelik üretim sıralamasında, ilk 10 ülke arasında 8. sıradaki yerini korumuştur.



Şekil 2. Yıllık bazında ülkemizin ham çelik üretim miktarı



Şekil 3. Türkiye'de Sanayide Tüketilen Nihai Enerjinin Sektörel Dağılımı (2012)

### 1.2. Enerji Verimliliği Nedir?

Enerji verimliliği, tüketilen enerji miktarının, üretimdeki miktar ve kaliteyi düşürmeden, ekonomik kalkınmayı ve sosyal refahı engellemeden en aza indirilmesidir. Daha geniş anlamıyla enerji verimliliği, gaz, buhar, ısı, hava ve elektrikteki enerji kayıplarını önlemek, çeşitli atıkların geri kazanımı ve değerlendirilmesi veya ileri teknoloji ile üretimi düşürmeden enerji talebinin azaltılması, daha verimli enerji kaynakları, gelişmiş endüstriyel süreçler, enerji geri kazanımları gibi etkinliği artırıcı önlemlerin bütünüdür [1]. Bu bağlamda, enerji yönetimi, enerji kaynaklarının ve enerjinin verimli kullanılmasını sağlamak üzere yürütülen eğitim, etüt, ölçüm, izleme, planlama ve uygulama faaliyetleridir (5627 Sayılı Enerji Verimliliği Kanunu,200:2).

### 1.3. Endüstriyel İşletmelerde Enerji Yönetim Sistemi

Enerji yönetim sistemi, enerji politikasını ve amaçlarını belirlemek ve bu amaçlara ulaşmak için birbirleriyle ilişkisi olan veya karşılıklı etkileşime giren öğeler kümesidir. Enerji politikası ve hedeflerini oluşturmak için birbirleriyle bağlantılı veya etkileşen öğeler grubu ve bu hedeflere ulaşmak için uygulanan proses ve prosedürlerdir [2]. Enerji yönetim sisteminin temel amacı üretilen hizmet ve servislerin en düşük enerji maliyeti ve en az çevresel etki ile sağlanmasıdır [3]. Enerji yönetiminin hedefleri üretim ve kaliteyi düşürmeden enerji maliyetlerini / israfını ve çevresel etkilerini en aza indirmektir [4].

İşletmelerde enerji yönetimi sistemini kurmak planlı bir çabayı gerektirir. Enerji tasarruflarını hedef alan, hedeflere dayanan bir strateji oluşturulmalıdır. Etkin bir enerji yönetimi sistemini kurmak, hedeflere sistematik olarak ulaşmak için aşağıda belirtilen adımlar endüstriyel işletmeler tarafından atılmalıdır ve bu alanlarda iyileştirme yapılmalıdır.

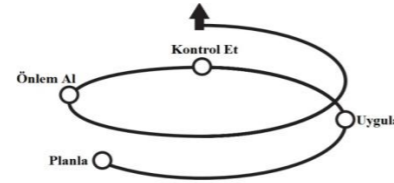
- Verimsiz iş alanları, ekipmanlar ve prosesler belirlenmelidir,
- Kullanılan veya kullanılacak enerji kaynakları hakkında her türlü detay teknik bilgiye sahip olmalıdır,
- İşletmede kullanılan ekipmanların ve üretim prosesinin teknik detay bilgisine hâkim olmalıdır,
- İşletme içerisinde enerji tüketiminin gerçekleştiği başlıca proses noktaları ve ekipmanları belirlenmelidir,
- Detaylı ve derinlemesine olacak şekilde belirlenen bu noktalarda verimsizlikler belirlenmeli ve yok edilmelidir,
- Teknoloji ve ekipman ihtiyacının belirlenmesine yönelik çalışma yapılmalıdır,
- Kaynakları gereksinimi hakkında karar aşamalarında teknik analizler, tartışma ve görüş alışverişleri, beyin fırtınası gibi teknikler kullanılmalıdır,
- İnsan gücü, makine ve teknolojisi gibi kaynaklar yönetilmelidir,
- Hareket planlarını değerlendirilmeli, yatırım dönüş hızları hesaplanmalıdır,
- Yeni üretim süreçleri, yeni teknolojik gelişmeler ve yeni geliştirilmiş makineler sürekli izlenmeli ve uygulanması yönünde değerlendirilmelidir,
- Yapılan çalışmalar değerlendirilmeye tabi tutulmalı ve güncellenmelidir.

Endüstriyel işletmelerde enerji yönetiminin varlığı için bazı ana bileşenlerin bulunması gereklidir;

- Firma üst yönetim taahhüdünün yapılmış olması,
- Enerji yönetim sistemi ve programın hedefleri açıkça tanımlanmış olması,
- Organizasyonel yapı, tanım ve sorumlulukların belirlenmiş olması,
- Kaynakların (*insan&para*) sağlanabiliyor olması,
- Ölçme ve izlemenin sağlanıyor olması,
- İlerlemelerin düzenli olarak inceleniyor olması [5,6].

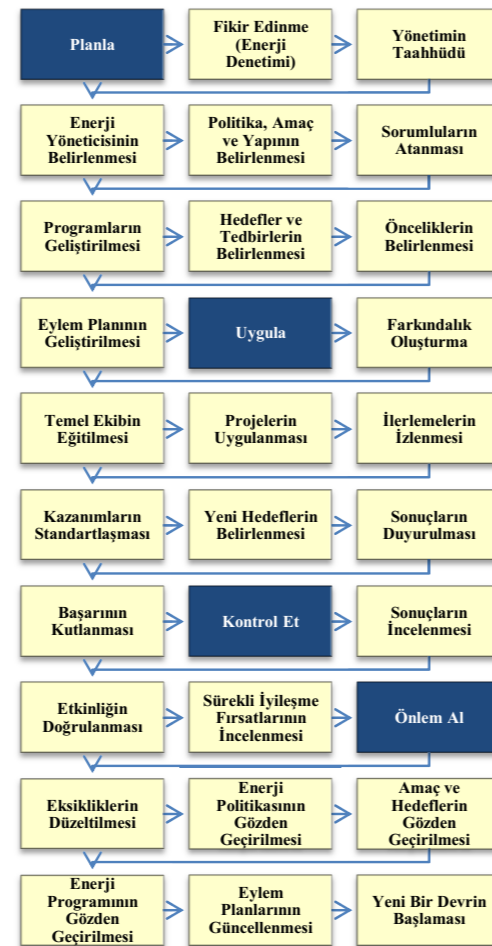
Hemen her yönetim sisteminde olduğu gibi, Enerji Yönetim Sistemlerinde de yönetim akışı, Şekil 4'te verilen, PUKÖ (*planla, uygula, kontrol et, önlem al*)

döngüsüyle sembolize edilebilir. Yönetim sistemlerinin ilk adımı, enerji politikasının oluşturulmasıdır. Sistem yönetiminin bu konudaki vizyonunu ve misyonunu belirlemesi gerekir. Uygulanabilir politikalar ve ulaşılabilir hedefler tespit edilerek iyileştirme çalışmaları başlatılır [5,6].



Şekil 4. PUKÖ döngüsü

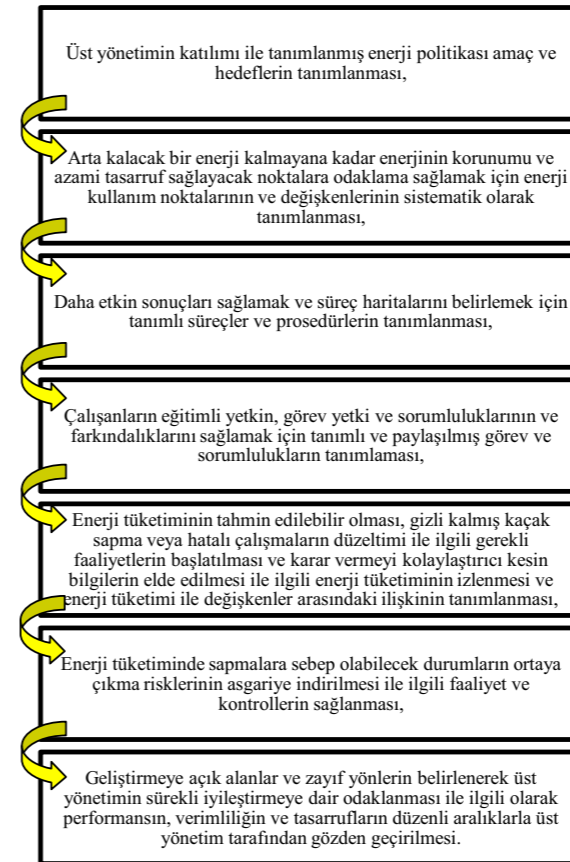
Sürekli gelişim içerisinde PUKÖ döngüsü içerisinde her döngüde de birbirini takip edilmesi gereken süreçler vardır. Temel bir fikir vermesi açısından örnek bir enerji yönetimi yaklaşım planı Şekil 5'de verilmiştir [5,6].



Şekil 5. Enerji yönetimi yaklaşım planı

Endüstriyel işletmelerin Enerji Yönetim Sistemi kurmada ve sürdürülebilirliğini sağlamada ISO 50001 EnYS standardı Dünya çapında uygulanabilir bir standarttır. Mevcut enerji kaynaklarının daha verimli kullanılmasına, rekabet gücünün artırılmasına, sera gazı emisyonları ve diğer ilgili çevresel etkilerin azaltılmasına katkıda bulunur. ISO 50001 EnYS standardı, kullanılan enerji türlerine bağlı olmaksızın uygulanabilir [5,6].

ISO 50001 EnYS'nin ana hatları ve kuruluşa sağladığı faydalar şunlardır;



### 1.3. Demir - Çelik Sektöründe Enerji Verimliliği

Demir - Çelik sektörümüzde, enerji verimliliğini arttırmak amacıyla;

- Kaliteli girdi malzeme tedariki ve kullanımı,
- Hammadde depolama, elleçleme, taşıma ve harmanlama işlemlerinde oluşan difüz emisyonların azaltılması,
- Hurdanın kapalı ortamda stoklanmasına dikkat edilmesi,

- Hurda içeriğinin satın alma aşamasından itibaren takip edilerek hurdaların sınıflandırılması ve istenen çelik kalitesine göre kullanılması,
- Tufal içeren çamurun, bağlayıcı madde eklenerek briket haline dönüştürülmesi ve konverte - EAO - İO'ya şarj edilmesi,
- Brülör ve tav fırınlarında yanma verimliliklerinin artırılması ve emisyonların kontrolü,
- Yakıt-hava oranının izlenmesi ve optimize edilmesi,
- Tesisteki önemli enerji akışları ve yanma prosesleri için online izleme - kontrol sistemlerinin kullanılması,
- Proses kontrol tekniklerinin geliştirilmesi ve otomasyon uygulanması,
- Reaktif gücün boyutunu azaltmak için alternatif akım (AC) devresinde kapasitörlerin kurulması,
- Her bir prosesin enerji tüketimini kontrol etmek için raporlama ve analiz araçlarının (Pinch Analizi, PUKÖ döngüsü vb.) kullanılması,
- Soğutmada su tüketimini azaltacak kuru soğutma sistemlerinin yaygınlaştırılması,
- Yüksek verimli elektrik motoru kullanımı,
- Aydınlatma, ısıtma, pompalar, kompresörler gibi, ana üretim hatlarına göre, enerji tüketimi daha düşük olan yardımcı tesislerde de, enerji tasarrufu yapılması,
- Enerji yoğunluğunu düşürmek amacıyla, katma değeri yüksek ürün üretimine geçilmesi,
- Etkin bir enerji yönetim sisteminin oluşturulması ve enerji tüketimlerinin izlenmesi,
- Her türlü yan ürün ve atığın geri kazanımı,

gibi başlıca konularda azami çaba gösterilmelidir.

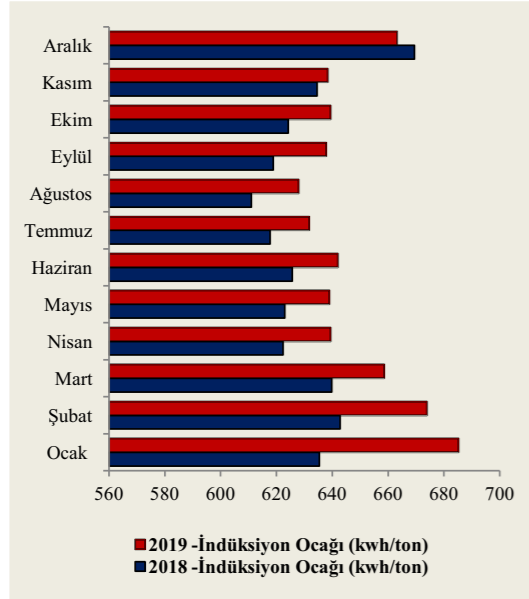
### 2. Deneysel Çalışmalar

Çelikhanelerde, enerji tüketiminin fazla olduğu ünitelerde, yüksek fırın, kok fabrikaları, ark ocağı, indüksiyon ocağı, tav fırınında, ocağı besleyen enerji sistemlerinde, toz tutma ve su soğutma sistemlerinde enerji tüketimini azaltacak çalışmalar yapılmalıdır. Ark ocağı, pota ısıtma, tandış ısıtma ve haddehane tav fırınlarında yakıt olarak, verimliliği yüksek ve düşük karbonlu doğal gaz kullanımının artırılmasıyla, fuel oil ve motorin kullanımından kaynaklanan çevresel etkiler azaltılmalıdır.

Hammadde kalitesi ve kompozisyonu, enerji tüketimini doğrudan etkileyen çok önemli bir parametredir. Nemli hurda, toprak, taş ile kirlenmiş hurda ve oksitli hurda eriyerek, cürufa karışır, cüruf



bazikliğini sağlamak için, ilave kireç kullanımı gerekir. İçerisinde, alüminyum, bakır, çinko, kurşun vb. metallerin bulunduğu hurda, üretim hızını, dolayısıyla, enerji tüketimini arttırırken, çelik kalitesini düşürücü bir etki yaratır. Sektörümüzde, kirli hurdanın olumsuz etkilerini giderebilmek için, hurda elleçleme büyük öneme sahiptir.



Şekil 6. Farklı mevsimsel koşullarda birincil ergitme ünitesinin ton çelik başına enerji tüketimi

BDÇ, ergitme ünitesi olarak indüksiyon ocaklarını kullanmaktadır. İndüksiyonla ergitme, metal parçaların (*şarj malzemesi*) belirtilen sıcaklık ve sürelerde ısıtmakta kullanılan temassız bir ısıtma ve ergitme yöntemidir. Denetim ve yatırım kolaylığı, yüksek enerji verimliliği, yüksek elektrik iletim verimliliği, yüksek metalik malzeme verimliliği, tam otomatik üretime uygunluğu, göreceli düşük emisyon ve atık, çevre kirliliği yaratmaması gibi üstünlüklerinden dolayı indüksiyon ocakları son yıllarda demir – çelik sektöründe ilgi çekici uygulamalar olmuşlardır.[7].

İndüksiyon ocaklarına beslenen demir hurdası (*şarj malzemesi*) tamamen ergiyince oluşan cüruf temizlenir. Ocağa şarj edilen hurdanın kirli olması (*plastik, toz, nemli, ıslak şarj malzemesi vb.*) cüruf miktarının artmasına ve ocak enerji tüketiminin yükselmesine neden olmaktadır. Cüruf süzülükten sonra ise sıvı metal sıcaklığı yakalanır, enerji kesilerek ocak kaldırılır ve sıvı metal potaya alınır [7].

BDÇ'nin indüksiyon ocaklarında kış mevsimi şartlarında ergitilen her 1 ton çelik hürdası içerisindeki %5 oranındaki suyun uzaklaştırılması için gereken teorik elektrik enerjisi 37,5 kWh'dır. Bu doğrultuda Şekil 6'da gösterilen pratik uygulamadaki mevsimsel faktörlerin etkisi teorik hesaplama sonucunda elde edilen değer ile ilişkilendirilmiştir. Hurda neminin buharlaştırılması sırasında harcanan enerjiyi azaltmak amacıyla hurdalar ergitilmeden önce işletme içerisinde kapalı ve yağış almayan bir bölgede stoklandıktan sonra ergitilmesinin temini ile birim enerjiler üzerinde %3.2 ile %6 arasında enerji tasarrufu sağlanabileceği öngörülmektedir.

Haddehanelerde ise genel olarak enerji tüketim değerleri incelendiğinde çelikhane prosesinden farklı olarak doğalgaz tüketimleri ön plana çıkmaktadır. İndüksiyon ocağında elektrik tüketimine dayalı bir enerji sarfiyatı söz konusu iken haddehanede daha ziyade doğalgaz tüketimine dayalı bir enerji sarfiyatı söz konusu olmaktadır. Bu sarfiyatın özellikle yarı mamul olan kütüklerin haddeleme öncesinde yeniden ısıtma işlemine tabi tutulduğu tav fırınından kaynaklanmaktadır. Bununla birlikte elektrik sarfiyatı da söz konusu olmaktadır. Elektrik sarfiyatının da büyük çoğunluğunun haddeler ve su tesislerinden kaynaklandığı söylenebilir.

Tablo 1. Bilecik Demir Çelik 2018 ve 2019 yılları için çelikhane ve haddehane elektrik/doğalgaz tüketimleri

Bölüm	Çelikhane		Haddehane	
	2018	2019	2018	2019
Doğalgaz Tüketimi (m <sup>3</sup> )	375.000	750.000	10.500.000	11.000.000
Elektrik Tüketimi (kWh)	220.000.000	247.000.000	18.000.000	20.000.000

Tablo 1'de Bilecik Demir Çelik 2018 ve 2019 yılları için çelikhane ve haddehane elektrik/doğalgaz tüketimleri kıyaslamalı olarak verilmiştir. Bu değerlerden anlaşıldığı gibi haddehane için doğalgaz tüketimi, çelikhane için ise elektrik enerjisi tüketimi ön plana çıkmaktadır.

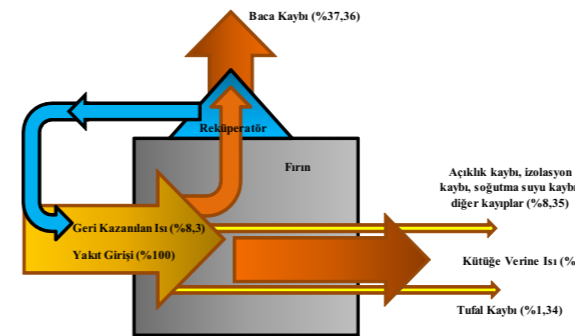
Çelikhanedan gelen yarı mamul kütükler kristalizasyon sıcaklığının üzerinde, genellikle 900-1250°C arasında bir sıcaklığa kadar homojen bir şekilde ısıtılarak haddeleme yoluyla şekillendirme için uygun bir hale gelmektedir. Bu ısıtma işlemi Şekil 7'de belirtilen haddehane tav fırınlarında gerçekleştirilmektedir.



Şekil 7. Haddehane tav fırını

Genellikle doğalgaz kullanan bu tav fırınları, haddehanenin büyük oranda enerji tüketiminden sorumlu olmaktadır. Dolayısıyla gerek yakıt tüketimi açısından gerekse bacadan atılan yanma gazlarının oluşturduğu kirlilik açısından bu fırınlar enerji tasarrufu yöntemleri için oldukça önemli olmakta ve mümkün olduğunca verimli çalıştırılması gerekmektedir.

Haddehane tav fırınlarında en büyük kayıp baca kayıdır. Baca kayıplarının bu denli büyük olmasının nedeni brülörlerde gerçekleşen yanma sonucunda sistemden atılan gazın yüksek sıcaklıklarda olmasıdır. 650°C sıcaklıklarda olan baca gazının enerjisi sisteme ilave edilen *reküperatör* ile yakma havasının ön ısıtılmasında kullanılarak enerji geri kazanımı sağlanabilmektedir.



Şekil 8. Tav fırını toplam enerji denkleği Sankey diyagramı

Şekil 8'de ki Sankey diyagramından da görüleceği gibi fırına verilen enerjinin %52,45'i kütüklere aktarılmakta, %8,35'i açıklık, izolasyon ve diğer kayıplar, %37,86'sı bacadan yanma gazı ve %1,34 ise tufal ile ısı kaybı olarak atılmaktadır. Bacadan yanma gazı ile kaybedilen ısının %8,3'ü reküperatör ile geri kazanılabilmektedir [8].

Fırınlarda ısıtma enerjisi taban, yan duvarlar, tavan ve kapak izolasyonundan kaybolmaktadır. Açık kalan kapak ve menfezler ile baca kayıpları verilen enerjinin büyük bir kısmının kaybına neden olmaktadır. Bunlar dışında soğutma suyu kayıpları ve diğer kayıplar da dikkate alınmalıdır.

Fırınlar için ilk bakışta oldukça iyi bir enerji tasarrufu yöntemi olan sıcak şarj yöntemi kullanılabilmektedir. Bu uygulamada sürekli döküm makinesinden çıkan yarı mamul kütükler, tamamen soğumaları beklenmeden 500 ile 800°C arası sıcaklıklarda tav fırınına sevk edilmektedir (*İşletmenin kütükleri tav fırınına şarj edebilme pratiğine göre değişmektedir, BDÇ'nin çelikhane ve haddehane tesisleri arasında lojistik imkanı bu şarj yöntemine uygun değildir, fakat Şekil 9'da belirtilen vince entegre edilen aparat yardımıyla tav fırınına sıcak şarj yapılabilmektedir*).



Şekil 9. Tav fırınına sıcak şarj aparatı

Böylelikle yarı mamulün fırınlarda haddeleme için istenen sıcaklığa getirilmesi çok daha az enerji tüketimiyle ve kısa sürede gerçekleşmekte, üretimde ve verimlilikte artış sağlanabilmektedir. Aynı zamanda depolama faaliyetlerini de azaltarak stok maliyetlerini de düşürecektir. Bu uygulamanın yapılabilmesi için çok iyi bir üretim planlaması yanında çelikhane ile haddehanenin lojistik olarak uygun bir yerleşim planı içerisinde bulunması şarttır. Bu uygulama özellikle çelikhane ve haddehane tesisleri arasında lojistik imkanı kolay olan ve aynı tip nihai mamulleri seri olarak imal eden üreticiler için bir avantaj olarak değerlendirilebilmektedir.

Fırınlarda yarı mamullerin homojen olarak ısıtılmaları esastır. Fırın tipine göre kütüklerin şarj edilme yöntemi değişmektedir. İtmeli fırınlarda kütükler ard arda şarj edilirken, yürüyen kirişli fırınlarda kütüklerin aralarında belirli mesafeler bırakılarak şarj edilir. Ard arda şarj edilen itmeli fırınlarda kütüklerin yüzeyleri temas etmekte ve homojen ısıtma imkanı sağlanamamaktadır. Bu durum yürüyen kirişli

fırınlarda söz konusu değildir fakat bu tip fırınlarda da kütükler arası mesafenin düzgün hesaplanması gerekmektedir. Fırınlarda yüksek sıcaklıklara çıktığı için özellikle 800°C'den sonra fırın içerisinde radyasyon ile ısıtma büyük ölçüde etkin olmaktadır. Dolayısıyla yüksek sıcaklıklarda hem fırının kapasitesini verimli kullanabilmek hem de ısıtmanın homojen ve verimli olmasını sağlayabilmek için fırın içerisindeki kütükler arası mesafeler önemli olmaktadır. Genellikle şarj edilen kütükler arasında, kütük yüzey mesafesinin bir buçuk katı kadar mesafe bırakmak yoluyla bunu sağlamak mümkün olabilmektedir. Eğer bu mesafe fırın kapasitesini yükseltmek için azaltılırsa iki kütük arasında ısıma kaynaklı bir ısı duvarı oluşabilir. Bu durum ise kütüğün homojen tavlmasını ve tavlama süresini geciktirmekte, verimden ziyade kayıplara neden olabilmektedir.

Çelikhane ve Haddehanelerde verim artırıcı yönde yapılacak belli başlı bazı iyileştirmelerle, haddehane ve çelikhane pota ısıtma brülörlerinde yakıt optimizasyon programı uygulanarak sistemin otomasyon ile kontrol altına alınabilir (*dijital yanma kontrolü, geniş alevli brülörler vb.*) ve yakma havası ile oksijen zenginleştirilmesi yapılarak doğal gaz tasarrufu sağlanabilir. Tav fırın kapasitesine ve tipine göre optimum şarj ve kütük mesafesinin belirlenmesi gerekmektedir. BDÇ'de haddehaneye giren yarı mamul kütüklerde % 1.5 düzeyinde tufal kaybı olmaktadır. Tufal oluşumunu engellemek için tav fırınının içerisindeki havayı kontrol etmek, fırın içi oksitleyici ortamı kontrol altına almak ve fırın duvarlarının sürekliliğini & izolasyonunu kontrol etmek gereklidir.

#### 4. Sonuçlar ve Öneriler

Sonuç olarak, uygulanabilir etütler Demir - Çelik sektöründe enerji tasarrufu potansiyelinin yüksek olduğunu açıkça göstermektedir. Bu önemli potansiyelin ekonomiye bir artı değer olarak kazandırılması ise ancak bu konuda enerji yönetimi sistemleri gibi kararlı politikaların uygulanması ile mümkündür. Sanayi kuruluşlarının üretimde enerji verimliliğini sürekli ön planda tutmaları, piyasaya yeni ürünler üretirken enerji verimliliği yüksek ürünleri tercih etmeleri ve tasarımları gerekmektedir. Bu nedenle Çelikhaneler ve Haddehaneler verim artırıcı, rekabet koşullarında avantaj sağlayacak enerji verimliliği uygulamaları için kendi imkanları ve

kararları ile kolayca yapabilecekleri çalışmaları vakit geçirilmeden uygulamaya koymalıdır.

Demir - Çelik sektöründe sistematik kalıcı ve bir şekilde enerji yoğunluğunun düşürülmesi için *TS-EN ISO 50001 Enerji Yönetim Sistemi (EnYS)* izlenmeli, yasal mevzuat ve süreçler yakından takip edilmeli, enerji etütleri, gönüllü anlaşmalar, verimlilik artırıcı projeler, teşvikler ve enerji verimliliği danışmanlığı şirketlerinin desteği ile enerji verimliliğini arttırmaya yönelik çalışmalar sürekli gündemde tutulmalıdır. Araştırmalar göstermiştir ki, Enerji Yönetim Sistemi ve araçları ile yıllık enerji maliyetleri %5 ile %20 arasında düşürülebilir.

#### Referanslar

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- [4]BEE, Bureau of Energy Efficiency (2005), Question Bank for Energy Managers and Energy Auditors, New Delhi, India. s:1-5.
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- [8]Emre BARAN - haddeleme prosesinde tav fırını (*annealing furnace in hot rolling process*) - Dokuz Eylül Üniversitesi, Metalurji ve Malzeme Mühendisliği Bölümü, Tınaztepe Yerleşkesi, İzmir, e-posta: emre.baran@deu.edu.tr

## AISI 304 Kalite Paslanmaz Çeliğin, Soğuk Deformasyon Oranı, Faz Miktarı ve Isıl İşlem Proseslerine Bağlı Mekanik Özelliklerinin İncelenmesi

Investigation of Mechanical Properties of AISI 304 Quality Stainless Steel, Connected to Cold Deformation Rate, Phase Quantity and Heat Treatment Processes

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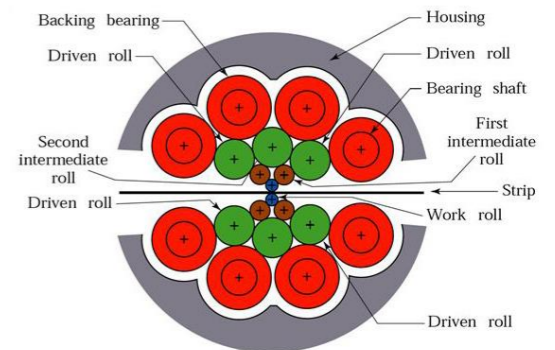
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#### Özet

Paslanmaz çelikler yüksek korozyon dayanımları ve yüksek şekillendirilebilirlik kabiliyetleri ile endüstride oldukça geniş bir kullanım alanına sahiptirler. Paslanmaz çelik yassı malzemeler, dökümden sonra sıcak haddeleme, tavlama ve soğuk haddeleme ile üretilir ve ardından tavlama ve yüzey pasivasyonu sağlanarak servis hatları için hazırlanır. Bu çalışmada 304 kalite paslanmaz çeliklerin farklı deformasyon oranlarında haddelendikten sonra çözelti tavlama öncesi ve çözelti tavlama sonrasında farklı kalınlıklardaki malzemelerin çekme testleri yapıldıktan sonra mühendislik akma ve çekme mukavemetleri baz alınarak gerçek akma ve çekme mukavemetleri hesaplanmıştır. Hesaplanan bu değerler yardımıyla haddede soğuk işleme maruz kalmış malzemelerin dayanım sabiti ve deformasyon sertleşmesi üssü değerleri teorik olarak hesaplanmaya çalışılmış, bu değerlerin malzemenin mekanik özellikleri ve malzemenin oluşturduğu sertleşme kabiliyeti ile bu sabitler arasındaki ilişki incelenmiştir.

#### 1. Giriş

Soğuk haddeleme, en az iki tane merdanelinin basma kuvvetinin etkisiyle araya giren malzemeye soğuk olarak plastik şekil verme işlemidir. Soğuk haddeleme, paslanmaz çelik levha üretiminde sürekli döküm, sıcak haddeleme ve tavlama-asitleme işleminden sonra malzemeye farklı mekanik özellikler kazandırmak ve nihai kullanım kalınlığına indirmek için yapılır. Sendzimir hadde (Şekil 1) on adet yukarıda on adet de aşağıda olmak üzere yirmi merdaneli bir hadde tipidir. İş merdanelerinin düşük çapta olması malzeme yüzeyindeki temas alanını daraltarak paslanmaz çelik gibi alaşım çeliklerin haddelenmesini kolaylaştırır.



Şekil 1: Sendzimir Hadde Merdane Dizilimleri Şematik Gösterimi

Metalik malzemelerin soğuk şekillendirilmesi sırasında genellikle hadde yönüne doğru tane uzaması görülür. Bu durum belirli oranlarda mukavemet artışına sebep olur. Bazı malzemelerde ise soğuk hadde sırasında yüksek baskı kuvveti nedeniyle tane uzaması ile birlikte tane kırılması ve faz dönüşümü birlikte görülür. Bu durum özellikle östenitik Paslanmaz çeliklerde yoğun olarak karşılaşılan bir durumdur [1,2]. AISI 304 östenitik paslanmaz çeliklerde bu faz dönüşümü östenit → Alfa-martenzit şeklinde olur [2]. Deformasyon sonrasında martenzitik dönüşüm oranı ve dönüşüm enerjisini belirleyen etkenlerden birisi de alaşımın krom ve nikel eş değerleridir. Özellikle nikel eş değerliğinin yüksek olması martenzitik dönüşüm serbest enerjisini düşürmektedir. [3] Aynı zamanda malzemenin maruz kaldığı deformasyon oranı, mekanik özellikleri ve martenzitik dönüşüm oranları üzerinde etkilidir. Krom ve nikel eş değerlik oranları aşağıda gösterilen 1. ve 2. Denklemler ile hesaplanmaktadır[4].

$$Cr_{es} = \% Cr + \% Mo + 1,5.\%Si + 0,5.\% Nb \quad (1)$$

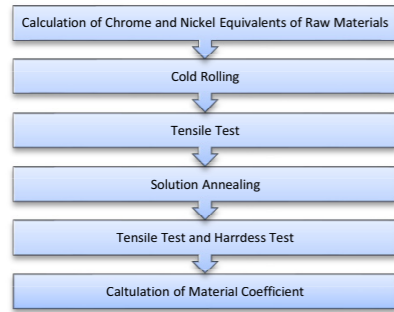
$$Ni_{es} = \% Ni + 30.\% C + 30.\% N + 0,5.\% Mn + 0,4.\% Cu \quad (2)$$



Soğuk haddeleme sonrası AISI 304 paslanmaz çelikler çözelti tavlama işlemine tabi tutulur. Tavlama işleminin amacı, malzemeyi östenit dönüşüm sıcaklığına çıkararak martenzit → östenit faz dönüşümünü sağlamak, iç gerilmeleri gidermek, tane sınırına çökelmiş metalkarbürleri çözmek, oluşan dislokasyonları dağıtmak, malzemeyi nihai kondisyonuna getirmektir. [5]

## 2. Deneysel Süreç

Malzeme sabitlerinin elde edilmesinde 3 mm giriş kalınlıklarına sahip sıcak hadde ürünü Paslanmaz çelik levhalar farklı kalınlıklara haddelenerek farklı deformasyon oranlarına indirilmiştir. Nihai kalınlıktaki haddelenmiş rulolardan tavlama ve asitleme prosesi öncesinden numuneler alınarak çekme testleri gerçekleştirilmiştir. Aynı malzemelerin tavlama ve asitleme hattı sonrasında da tavllanmış hallerinin numuneleri alınarak aynı şekilde çekme ve sertlik testleri gerçekleştirilmiştir. Elde edilen bulgular neticesinde malzeme sabitleri teorik olarak hesaplanmış ve modellenmiştir. Şekil 2'de deneysel süreç şematize edilmiştir.



Şekil 2: Deneysel Süreç Akış Şeması

Proses çalışmaları, Trinox Metal Çorlu fabrikası üretim makinelerinde gerçekleştirilmiştir. Haddeleme operasyonu Sendzimir makinasında, tav operasyonu Atlas makinasında yapılmıştır. Çekme testi ve sertlik sonuçları, Trinox Metal kalite kontrol laboratuvarında ölçümlenmiştir.

Sertlik kontrolleri Emcotest DuraScan 10 marka cihazla yapılmıştır. Cihaz Şekil 3'te verilmiştir. Çekme testleri de MTS marka Alliance RT/100 marka cihaz ile gerçekleştirilmiştir. Çekme cihazı Şekil 4'te gösterildiği gibidir.



Şekil 3: Emcotest DuraScan 10 Sertlik Cihazı



Şekil 4: MTS Alliance RT/100 Çekme Testi Cihazı

### 2.1. Malzeme Sabiti Hesaplamaları

Malzeme sabitlerinin hesaplanmasında kullanılan formülasyonlar aşağıda belirtildiği gibidir;

$$\sigma = \frac{F}{A} \quad (3)$$

$$e = \frac{(L-L_0)}{L_0} \quad V_i = V_0 \quad (4)$$

$$V_i = A_i \times L_i = A_0 \times L_0 \quad (5)$$

$$e = \frac{\Delta L}{L_0} = \frac{L_i - L_0}{L_0} = \frac{L_i}{L_0} - 1 \quad (6)$$

$$\frac{L_i}{L_0} = 1 + e \quad (7)$$

$$\varepsilon = \int_{\varepsilon_0}^{\varepsilon_i} \frac{dL}{L} = \ln \frac{L_i}{L_0} \quad (8)$$

$$\frac{L_i}{L_0} = 1 + e \quad (9)$$

$$\varepsilon = \ln \frac{L_i}{L_0} = \ln(1 + e) \quad (10)$$

$$\sigma_t = \sigma_e(1+e) \quad (11)$$

$$\sigma_{true\ tensile} = \sigma_{engineering\ tensile}(1 + e) \quad (12)$$

$$\sigma_{true\ yield} = \sigma_{engineering\ yield}(1 + e) \quad (13)$$

$$\sigma_{true\ tensile} = K \times \varepsilon^n \quad (14)$$

$$n = \frac{\log \left( \frac{\sigma_{true\ tensile}}{\sigma_{true\ yield}} \right)}{\log(500 \times \varepsilon)} \quad (15)$$

$$K = 500^n \sigma_{true\ yield} \quad (16)$$

$$SC = (Ni_{cs} / Cr_{cs}) * 100 \quad (17)$$

$$DR = (t_0 - t_i) / t_0 \% \quad (18)$$

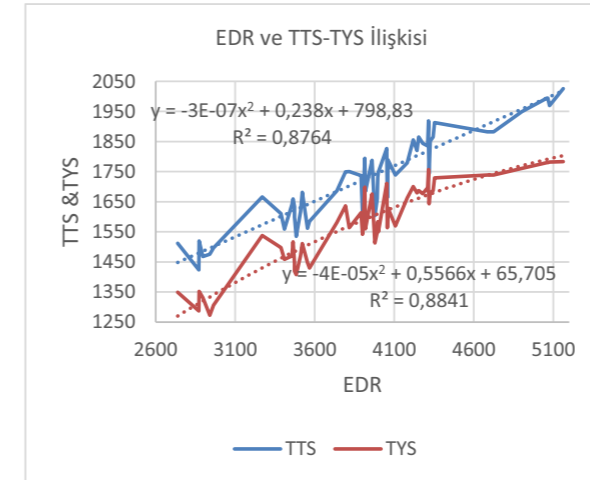
$$EDR = SC * DR \quad (19)$$

Terms and abbreviations in equations are as follows;  $\sigma$ : Engineering Tensile Stress,  $\sigma_t$ : True Tensile Stress,  $\sigma_e$ : Engineering Tensile Stress,  $A$ : Area,  $e$ : Engineering Strain,  $\varepsilon$ : True Strain,  $L_0$ : Length (t = 0),  $L_i$ : Length (t = i),  $n$ : Strain Hardening Coefficient,  $K$ : Material Factor

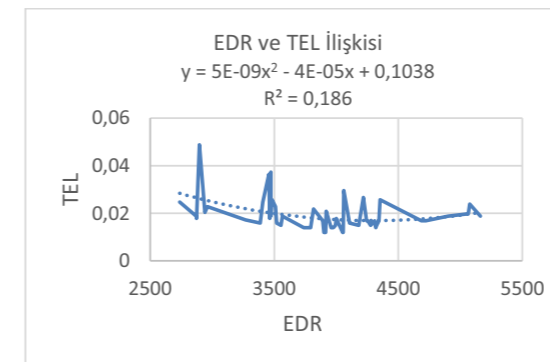
## 3. Deneysel Sonuçlar

Yapılan deneyler sonucunda malzemelerin akma dayanımları, çekme dayanımları ve yüzde uzama miktarlarına ulaşılmıştır. Elde edilen verilerle malzeme sabitleri ve gerçek uzama gerçek akma ve gerçek çekme dayanımları hesaplanmıştır. Yapılan hesaplama sonucunda elde edilen veriler analize tabii tutularak aralarındaki bağımlar incelenmiştir.

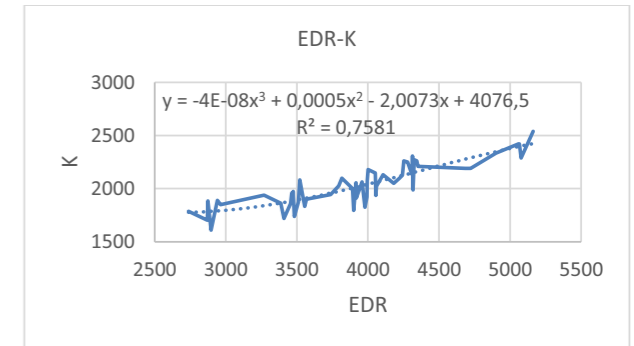
### 3.1 Isıl İşlem Öncesi Numunelerin Deney Sonuçları



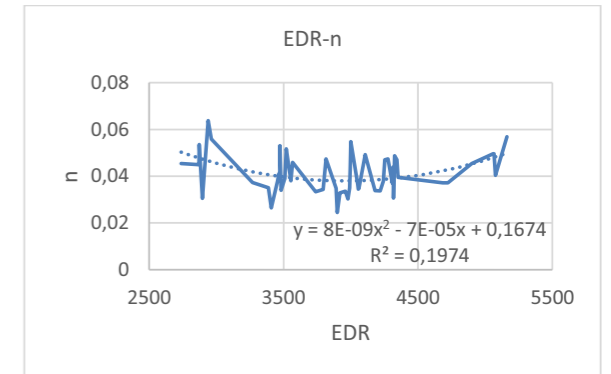
Şekil 5: Etkin Deformasyon Oranının (EDR) Gerçek Çekme Dayanımı (TTS) ve Gerçek Akma Dayanımı (TYS) Arasındaki İlişki



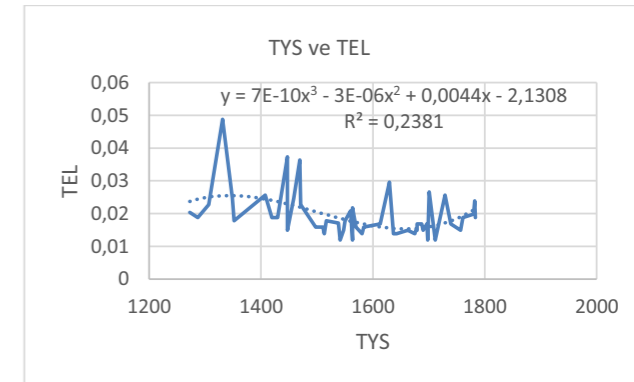
Şekil 6: Etkin Deformasyon Oranı (EDR) ve Gerçek Uzama Miktarı (TEL) Arasındaki İlişki



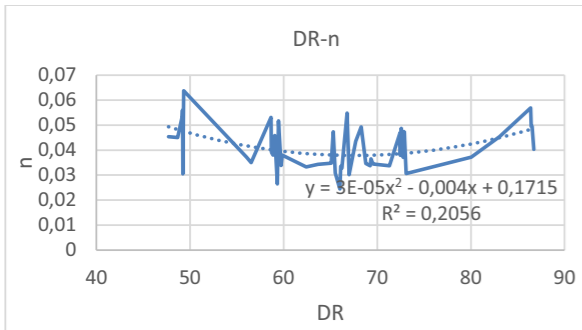
Şekil 7: Etkin Deformasyon Oranı (EDR) ve Rijitlik Katsayısı (K) Arasındaki İlişki



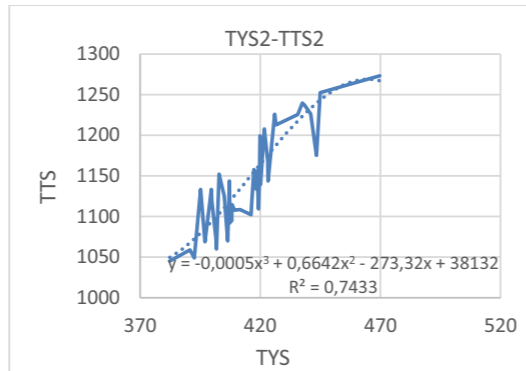
Şekil 8: Etkin Deformasyon Oranı (EDR) ve Deformasyon Sertleşmesi Üssü Arasındaki (n) İlişki



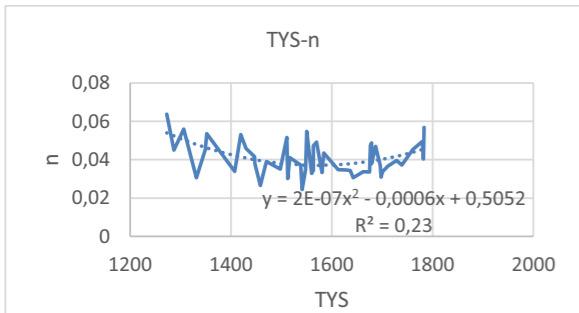
Şekil 9: Gerçek Akma Dayanımını (TYS) ile Gerçek Uzama (TEL) Arasındaki İlişki



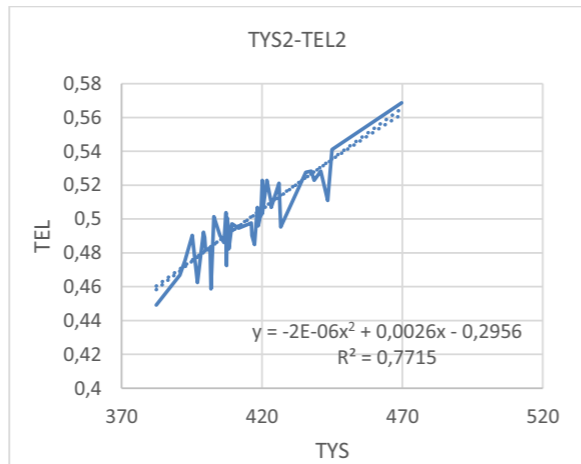
Şekil 10: Deformasyon Oranı (DR) ile Deformasyon Sertleşmesi Üssü (n) Arasındaki İlişki



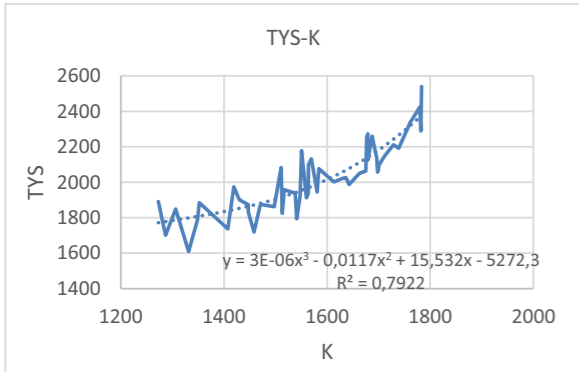
Şekil 13: Çözeltili Tavlama Sonrasında Gerçek Akma Dayanımı (TYS) ve Gerçek Çekme Dayanımı (TTS) Arasındaki İlişki



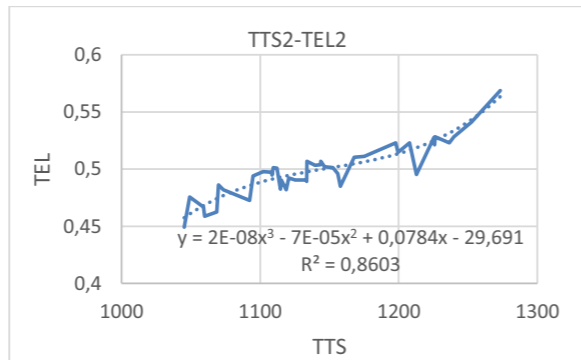
Şekil 11: Gerçek Akma Dayanımı (TYS) ile Deformasyon Sertleşmesi Üssü (n) Arasındaki İlişki



Şekil 14: Çözeltili Tavlama Sonrasında Gerçek Akma Dayanımı (TYS) ile Gerçek Uzama (TEL) Arasındaki İlişki

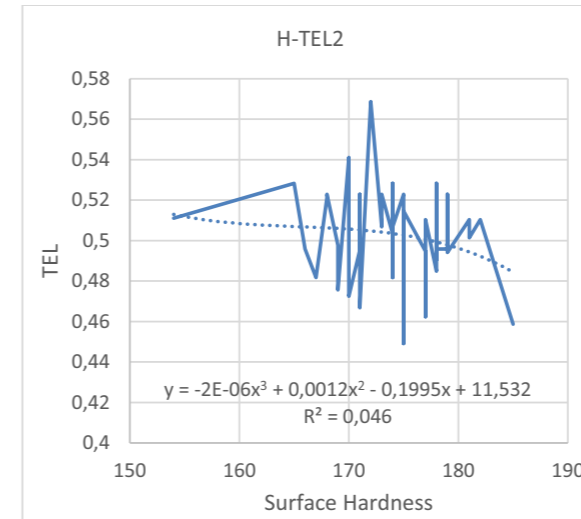


Şekil 12: Gerçek Akma Dayanımı (TYS) ile Rijitlik Katsayısı (K) Arasındaki İlişki

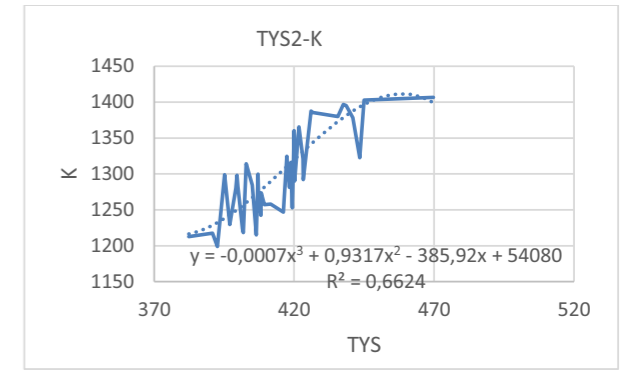


Şekil 15: Çözeltili Tavlama Sonrasında Gerçek Çekme Dayanımı (TTS) ile Gerçek Uzama (TEL) Arasındaki İlişki

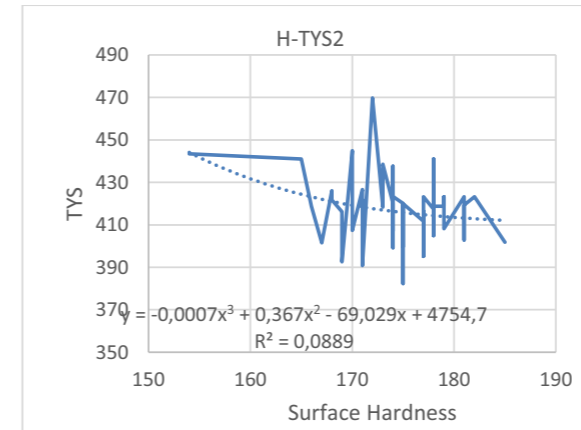
### 3.2 Isıl İşlem Sonrası Numunelerin Deney sonuçları



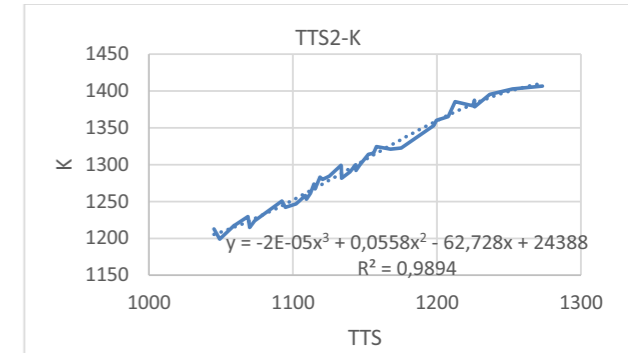
Şekil 16: Çözeltili Tavlama Sonrasında Sertlik (H) ile Gerçek Uzama (TEL) Arasındaki İlişki



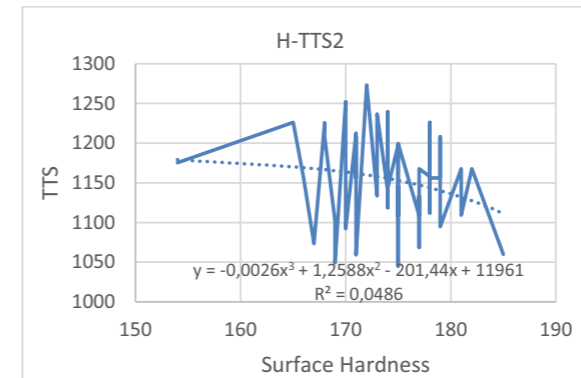
Şekil 19: Çözeltili Tavlama Sonrasında Gerçek Akma Dayanımı (TYS) ile Rijidite Kat Sayısı Arasındaki İlişki



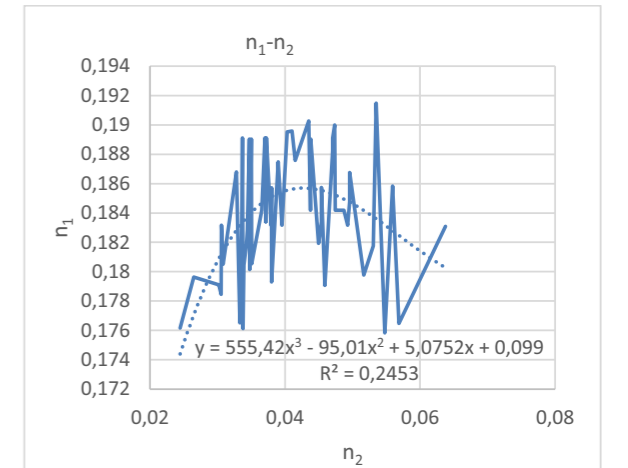
Şekil 17: Çözeltili Tavlama Sonrasında Sertlik (H) ile Gerçek Akma Dayanımı (TYS) Arasındaki İlişki



Şekil 20: Çözeltili Tavlama Sonrasında Gerçek Çekme Dayanımı (TTS) ile Rijidite Katsayısı Arasındaki İlişki

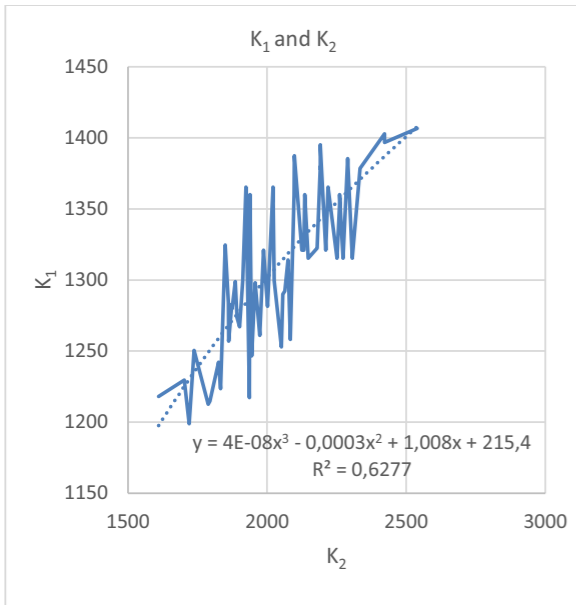


Şekil 18: Çözeltili Tavlama Sonrasında Sertlik (H) ile Gerçek Çekme Dayanımı (TTS) Arasındaki İlişki



Şekil 21: Çözeltili Tavlama Öncesi ve Sonrası Deformasyon Sertleşmesi Üssü (n) Değerleri Arasındaki İkili İlişki





**Şekil 22:** Çözelti Tavlaması Öncesi ve Sonrası Rijidite Kat Sayısı (K) Değerleri Arasındaki İkili İlişki

#### 4. Tartışma

Isıl işlem Öncesi numunelerin mekanik özellikleri sayısal olarak incelendiğinde etkin deformasyon oranı ile akma dayanımı ve çekme dayanımı arasında güçlü bir bağlantı olduğu görülmüştür(Şekil 5).

Özellikle akma ve çekme dayanımları arasında artan etkin deformasyon oranıyla birlikte verilerin birbiriyle örtüştüğü saptanmıştır(Şekil 5).

Artan etkin deformasyon oranı akma ve çekme dayanımlarını arttırırken uzama ile herhangi bir ilişkisi olmadığı açıkça görülmektedir(Şekil 6).

Deformasyon oranındaki artışla çekme ve uzama değerleri arasındaki artış malzemenin uygulanan plastik şekil verme işlemi sonrasında iç yapıda meydana gelen faz dönüşümlerinden ve artan dislokasyon oranından kaynaklandığı düşünülmektedir. AISI 304 kalite paslanmaz çelik TWIP (Twinning induced plasticity) çelikleri grubuna dahil olduğu için deformasyonla sertleştirilebilir çeliklerdendir. Uygulanan plastik şekil verme işleminden sonra taneler ikizlenmiş, birbirinin içine girmiş ve östenit fazı Alfa-martenzit fazına dönüşmüştür[1]. Oluşan dislokasyonlar malzemede gevrek bir yapı oluşturmakla kalmamış malzemede mekanik özelliklerin birçoğunda artışa neden olmuştur. Akma ve çekme dayanımlarındaki bu artışın bir diğer nedeni anizotropik östenit fazının sınır bölgelerinde Alfa-martenzit fazı oluşmuş olabilir. Oluşan bu faz tetragonal hacim merkezli olup kübik yüzey merkezli yapı içerisinde sert bölgeler oluşturarak tanelerin birbiri üzerinde kaymasını engellemiştir. Böyle bir durumda malzemenin akma ve çekme dayanımlarında artış beklennirken uzama değerlerinde azalış beklenir.

Etkin deformasyon oranı ve uzama arasında bir ilişki bulunamamıştır(Şekil 6). Isıl işlem öncesi malzemenin mekanik özelliklerini etkileyen ana etmen dislokasyon oluşumu ve

marteniztik dönüşüm olduğu için malzeme üzerinde uzama ilişkisi kurulamamıştır. Ayrıca veriler incelendiğinde uzama değerlerinin çok düşük olduğu görülür. Burada dikkat edilmesi gereken nokta deformasyonla birlikte uzamada oluşan ciddi azalmadır.

Deformasyon sertleşmesi üssü ve akma çekme dayanımları ve etkin deformasyon oranı arasında istatistiksel bir ilişki bulunamamıştır (Şekil 11).

Isıl işlem sonrasında gerçek akma ve gerçek çekme değerleri arasında ilişki kurulabildiği görülmektedir(Şekil 13). Çekme ve uzama arasındaki ilişkinin akma ve uzama arasında ilişkiye göre daha yüksek olduğu görülmektedir.

Sertlik değerleri ile akma, çekme ve uzama değerleri ile ilişki kurulamamıştır Şekil (16,17,18). Bu durumda sertlik malzemenin mukavemet göstergeleri arasında yer almasını gerektirecek bir unsur değildir.

Isıl işlem sonrası akma mukavemeti ile dayanım kat sayısı arasında anlamlı bir ilişki kurulamazken (Şekil 19) çekme mukavemeti ile dayanım kat sayısı arasında oldukça yüksek bir ilişki kurulabilmektedir(Şekil 20).

Isıl işlem öncesi ve sonrası n ve K değerleri karşılaştırıldığı vakit bu değerler arasında da herhangi anlamlı bir ilişki kurulamamıştır. Fakat k değeri n değerine göre daha ısı işlem öncesi ve sonrası daha ilişkili olduğu saptanmıştır (Şekil 21,22)

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## Demir ve Çelik Endüstrisinde Nitelikli Bakım Ekibi Çalışmaları

Qualified Maintenance Team Work in Iron & Steel Industry

Mustafa Ceyhun, Hicret Batuhan Aldemir

İSKENDERUN DEMİR VE ÇELİK • Türkiye

#### Abstract

In rolling processes, which have line-length productions in the iron and steel industry, production continuity is directly dependent on the quality of maintenance, and this process has a direct impact on many processes reaching product quality, product costs and customer satisfaction. Production line efficiency is directly proportional to the competence of maintenance personnel and unfortunately there is not enough education infrastructure or systematic structure in our country. There is a need for a different and experienced maintenance team on this subject. A pilot study was carried out in the Iskenderun Iron and Steel Co. (ISDEMİR) to realize this need and establish a qualified maintenance team. It is aimed that the established maintenance team will work along the hot rolling mill line to gain experience, develop their competencies and provide added value to the system. It was explained that the maintenance unit established in this paper was established in order to ensure an integrated maintenance system between the units by taking part in every unit in the factory.

#### Özet

Demir ve çelik endüstrisinde hat boyu üretimleri olan haddeleme işlemlerinde, üretim sürekliliği doğrudan bakım kalitesine bağlıdır ve bu sürecin ürün kalitesi, ürün maliyetleri ve müşteri memnuniyetine ulaşan birçok süreç üzerinde doğrudan etkisi vardır. Üretim hattı verimliliği, bakım personelinin yeterliliği ile doğru orantılıdır ve maalesef ülkemizde yeterli eğitim altyapısı veya sistematik yapı bulunmamaktadır. Bu konuda farklı ve deneyimli bir bakım ekibine ihtiyaç vardır. İskenderun Demir ve Çelik A. Ş. 'de (İSDEMİR) bu ihtiyacı karşılamak ve nitelikli bir bakım ekibi kurmak için pilot çalışma yapılmıştır. Kurulan bakım ekibinin sıcak haddeleme hattı boyunca çalışarak tecrübe kazanmak, yeterliliklerini geliştirmek ve sisteme katma değer sağlamak hedeflenmektedir. Bu makalede kurulan bakım ünitesinin, fabrikadaki her üniteye yer alarak üniteler arasında entegre bir bakım sistemi sağlamak amacıyla kurulduğu açıklanmıştır.

#### 1. Giriş

Dünya'da sanayii devriminden bu yana gelişen üretim teknikleri ve buna paralel olarak artan talepleri karşılamak için tüm fabrikalarda mekanik ve otomasyon sistemlerinin kullanımını yoğun olarak arttırmıştır. Son yıllarda bu üretim sistemlerinin, kontrolü, yönetimi ve sürekliliğine dair Endüstri 4.0 ve üzeri versiyonlar ile daha da akıllı hale gelmiştir. Üretim sistemlerinin mekanik sistemlere olan bağımlılığı devam etmekte ve artarak daha da önemli hale geldi. Böylece bu sistemlerin düzenli çalışmaları da önem kazandı. Bant, entegre veya proses üretimi olan her tesiste makinaların/ekipman etkinliği/emre ağırlığı en önemli unsur haline geldi. Yaşanan arızalardaki kayıplara, günümüz rekabet koşulları nedeniyle tahammüller azaldı ve bu tesislerde bakım en önemli faktör haline geldi. Şirketlerin bu arızaları önlemek için nitelikli bakıma dolayısıyla, nitelikli bakım kadrolarına ihtiyaç olduğu gerçeği ortaya çıkmıştır. Günümüz teknik eğitim sistemi bu ihtiyaca cevap verecek şekilde olmadığından, her şirket kendi bünyesinde kendi ihtiyaçlarını karşılayacak şekilde çözüm aramaktadır. Ülkemizdeki halen yetişmiş nitelikli bakım işgücüne ihtiyaç var olup, bu bildiri konusu, İSDEMİR'de şirket içinde nitelikli bakım personeli yetiştirilmesine dair yapılanları anlatmaktadır.

#### 2. Projenin Amacı, Doğuşu ve Aşamaları

**Projenin Amacı;** Nitelikli bakım personellerinden oluşan tüm ünitelere hizmet verecek bakım destek ekibi oluşturmak.

#### Projenin Doğuşu

Entegre Demir Çelik Tesisi olarak üretim yapan İSDEMİR'de en kritik hatta sahip Sıcak Haddehane yönetimi tarafından, bakım duruşlarının süresi ve kalitesi yönüyle başlatılan çalışmalar kapsamında, Mekanik ve Yardımcı Atelyeler Müdürlüğünden destek istemiştir. Talep üzerine, benzer faaliyet yapan iki şirket arasında kıyaslama ve inceleme amacıyla 24 - 25 Haziran 2014 tarihinde Erdemir'e teknik ziyaret yapılmış olup, akabinde özel bir ekip oluşturma fikri ortaya çıkmıştır.

Başta Sıcak Haddehane olmak üzere, İSDEMİR'deki diğer ana işletmelerde süreli/planlı ve üretim temposu gereği

mümkün mertebe kısa zamanlı olması hedeflenen ancak mevcut bakım personelinin planlanan işlerin tamamını yapmaya yetemediği ve yeterli bakım yapılamadığı kabulü ile sürpriz duruşlar yaşanmaktadır. Bu plansız duruşları ortadan kaldırmak amacıyla istenen zamanda planlanan işlerin yapılması için ünitelere bakım zamanlarında dışarıdan destek verecek, bakım konusunda uzman bir ekibe ihtiyaç olduğu sonucuna varılmıştır. Firma marifetiyle alınan bakım destek hizmetlerinde istenen kalite ve istikrar sağlanamamakta olup, süreklilik yönüyle güvenilir bir seçenek olmaktan uzaktır.

## 2.2. Projenin Aşamaları,

### 2.2.1. Analiz

İSDEMİR'deki tesislerin öncelikle üretim zamanından, ayrılan bakım sürelerinde (duruşlar) hizmet vermesi amacıyla yetkin bir bakım ekibinin oluşturulması için detaylı iş gücü analizi yapılmıştır. Tüm yıllık duruş planları ve iş kalemleri incelenerek, işgücü sınıflandırılması ve toplam işgücü ihtiyaç saatleri ortaya çıkarıldı. Bu duruşların en efektif iş gücü ile karşılanması için testlerin duruşlarının çakışmaması için bir takım özel çalışmalar yapılmıştır. Günlük, haftalık, aylık ve yıllık bazda toplam iş gücü miktarı oluşturuldu. İnsan Kaynakları birimi ile pilot uygulama için 43 personel alımı ile süreç başlatılmış oldu.

### 2.2.2. Uygulama

**Ekibin oluşması:** Mayıs 2015 tarihinde, Teknik Öğretmen Okulu Mezunu 43 kişi ile işe alındı. Ayrıca 6 farklı üniteden işinde ehil 1 VA ve 1 Usta İşçi ile toplamda 12 kişi daha ekibe katılarak ekip nihai halini almıştır.

### Ekibin Yetkinlik Analizi:

Ekibe alınan personelleri 5 kademeli yetkinlik seviyesinde sınıflandırdık. (Tablo 1.)

**Yetkinlik 1 :** Hiçbir tecrübesi olmayan

**Yetkinlik 2 :** Staj ve okul dışında üretim tesisi ve bakım süreci görmemiş yada yakın sektörde çalışmamış kişiler

**Yetkinlik 3 :** Sanayi sektöründe çalışmış ancak tecrübesi az.

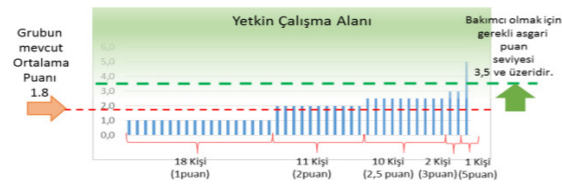
**Yetkinlik 4 :** Sanayi sektöründe çalışmış ve geçmişten gelen tecrübesi de var.

**Yetkinlik 5:** Demir Çelik sektöründe bakım işinde çalışmış

Ekip üyesi bakımçı adaylarımızı tek tek teknik mülakata tabii tutarak yetkinlik seviyelerini belirledik.

Yapılan değerlendirmelerde çalışanların başta İSG şartlarına ve ağır bakım süreçlerine yeterli hale gelebilmeleri ve bakımda görevlendirilebilmeleri için grubun ortalama başlangıç asgari yetkinlik seviyesinin 3,5 olması belirlenmiştir. Ancak mevcut durumun bundan düşük ve 1,8 seviyesinde olduğu görüldü. İlk etapta 2,5 ve üzeri puana sahip, 13 kişiye duruşlarda basit bakım işleri verilmesi kararı alındı. Diğer ekip üyelerinin de desteklenerek

geliştirilmesi ve izlenmesi ile en kısa sürede İş Güvenliği'ne de uygun olarak bakım süreçlerinde görevlendirilmesi sağlanması kararlaştırıldı.



Tablo 1. Yetkin Çalışma Alanı

### Ekibin Yetkinlik Artış Çalışmaları

Ekibin ilk 6 hafta makine atelyesi Montaj Kaynak kısmında montaj demontaj başta olmak üzere bakımçı ekiple birlikte çalışması sağlandı. Vardiyalara ve ekiplere paylaştırıldı. Usta çırak öğrenim metodu ile bire bir pratik eğitim alması sağlandı.

### Oryantasyon ve rotasyon programı

Montaj kısmında temel İSG ve teknik öğretiler sonrası fabrikadaki tüm bakım süreçlerini yerinde görmesi ve hızlı bir şekilde öğrenmesi amacıyla en çok bakım hizmeti verilecek 6 Üniteye, daha önce ekibe katılanların nezaretinde gözlem yapmak amacıyla dağıtılmıştır (Tablo:2). Öncelikle çalışma sahalarını tanımak, risk değerlendirme yapmak ve duruş hazırlıkları ile duruşlarda bakım yapacağı ekipmanı tanımak için 4'er haftalık rotasyon/oryantasyon çalışması planı yapılmıştır.



Tablo 2. Rotasyon Programı

### Ekipman ve Talimatlar

Ünitelerde rotasyon süresince, bakım yapılacak makinalara ait iş talimatları, kullanılacak alet edevatlar ile iyileştirmeye açık alanlar sürekli her çalışma sonunda raporlanmıştır. Her ay planlı bir şekilde çalışmalara katılan ekipler; yetkinlik seviyelerinin artırılarak, üniteler özelinde ekipmanların bakımlarının yapılmasında tecrübe edinmeleri sağlanarak gelişimleri sağlanmıştır. Ayrıca her bölgede iki sene boyunca yapılan çalışmalarda kullanılması gereken el aletleri, iş kolaylaştırabilecek elektrikli veya hidrolik ekipmanlar çalışma yapan her personelden geri bildirim

alınarak tespit edilmiştir. Alet edevat listeleri takip eden yılın başında talep edilerek direkt ihtiyaç olan kalemler ve adetlerde alım yapılmış olup, iyi bir takımhane kurulmuştur. Bakımı özel yetkinlik gerektiren makine veya ekipmanların dahi ihtiyaçları çıkarılmış olup bazı ekipmanların bakımının ünite kendi bakım ekipleri dışında merkezi bakım ekipleri tarafından da yapılması sağlanmıştır. İki senelik bu çalışma sırasında her bakımda öngörülen veya yaşayarak öğrenilen İSG uygunsuzlukları yine her personelden geri bildirim alınarak ve ayrıca fikirleri de alınarak yüzlerce iyileştirme yapılmıştır.

### Ekibin Motivasyonu

Ekibin oluşturulduğu ilk günden itibaren, ekibe verilen mesajlarda; İSDEMİR'de bakımçı olarak "ne yapacakları değil, neden burada oldukları" hep vurgulandı.

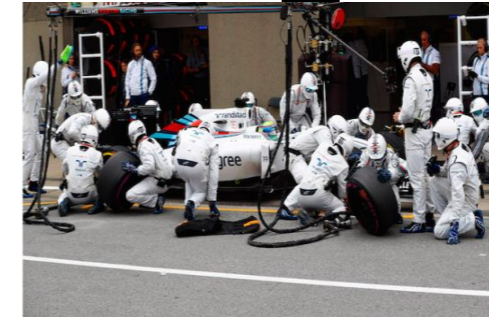
Örnek olarak: 1950'li yıllardaki Formula 1 PİTSTOPS (Resim 1.) ile 2003 yılındaki Formula 1 PİTSTOPS sürelerinde değişim gösterilmiştir. Ekibin var olma misyonuna dönüşen bu örnek hep aklımızdadır. ( 2016 Yılında Bakü'de PİTSTOPS rekoru yenilendi (Resim 2.))

### 64 Sanive süren 1950 yılındaki Pit-stoptan bir görüntü



Resim 1. 1950 Pit-Stop

### 1,92 sn Bakü Yarışı Williams takımı Dünya Pit-stop rekor



Resim 2. 2016 Pit-Stop

### Ekibin Yetkinlik Artışı

Ekiplerin işe başladıkları tarihte çalışmalara başlamadan önce bazı mülakat ve değerlendirmelere tabii olmuştu. Bu sonuçlardan ekibin yetkinlik geliştirme planı oluşturuldu

(Tablo 3.). Bakımcının bilmesi ve tecrübe kazanması gereken ana konular belirlendi.

Bunlar;

- Mekanik el aletleri
- Elektrikli/havali el aleti kullanma
- Rulman
- Isı ile montaj demontaj
- Azot ile montaj demontaj
- Pres ile montaj demontaj
- Toleranslı ve sıkı geçme
- Malzeme Bilgisi
- Kaynak yöntemleri
- Doğrultma ve sıcak/soğuk şekil verme
- Teknik resim, proje okuma
- Sapanlama
- Kaldırma ekipmanları
- Cıvata ve bağlantı elemanları
- Yüksekte çalışma
- Şaloma kullanımı (tavlama ve kesme)
- Basınçlı Tüpler/kaplar
- Dişliler
- Kaplinler
- Sızdırmazlık elemanları
- Yağlama sistemleri
- Yağlar
- Yataklar, yataklamalar
- Topoğrafya çalışması
- Balans ayarı, salgı alma, ve ilgili cihaz kullanma
- Boyutsal ölçü aletleri kullanma
- Torklama ve tork anahtarı
- Kriko ve hidrolik ekipmanların kullanımı
- Çektirme ve yardımcı ekipmanların kullanımı
- Vinç ve caraskal gibi ekipmanların kullanımı
- Talaşlı imalat bilgisi

İç ve dış kaynaklı eğitimler ile ekibin teorik/pratik eğitimleri eksik görülen kişilere yönelik plan dahilinde alındı/aldırıldı. Saha çalışmalarıyla bu konular hk bilgileri pekiştirildi, geliştirildi. Kişi bazlı yatkınlıkları tespit edilip uzmanlaşmaları için çalışmalar ona göre değerlendirildi. Bazı arkadaşlarımızın extra çabaları ve elde ettikleri tecrübe ile birlikte yöneticilik vasıflarının da yüksek olması için ayrıca destek verilerek geleceğin ekip yöneticileri de yetiştirilmeye başlanmıştır.

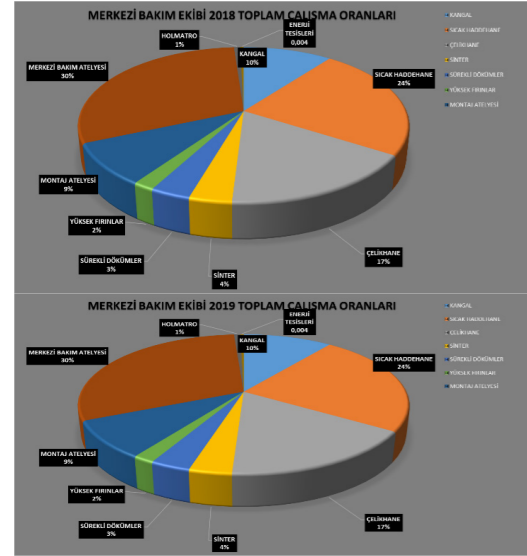
Tablo 3. Yetkinlik Analiz Tablosu



### 3. Sonuçlar ve Tartışma

#### 3.1. Ekibin Görev Performansı

Ekibimiz her yıl daha da yetkinlik kazanarak, yıllık çalışma oranlarında bugünlere geldiğimizde %72-%73 rakamlarına ulaşmıştır.(Tablo 4) Bakım süreçlerine katkısı nedeniyle, destek verilen üniteler tüm planlı duruşlarını üretim planlamasının yanında Merkezi Bakım Ekibinin programını da göz önünde bulundurarak yapmaya başlamıştır. Bu oranlar ve talepler ekibin varlığının gereğini yerine getirdiği anlamına gelmektedir.



Tablo 4. Merkezi Bakım Ekibi Çalışma Oranları

#### 3.2. Ekibin Yaptığı Önemli İşlerden Örnekler

##### Sıcak haddehane F3-F4 redüktör bakımı



Resim 3. Redüktör Değişimi

FM bölgesinde bulunan redüktör dişlileri hasarlanması neticesinde üretim yapılması mümkün değildir. Değişim süresi 2 gündür. Merkezi bakım ekibi olarak 16 saat gibi bir süre içerisinde değişimi yapılarak yeniden üretim sağlanmıştır (Resim 3.). Arıza duruş süresi planlanan zamanın yarısından kısa bir sürede Merkezi bakım ekibi tarafından teslim edilmiştir ve arıza süresince yaşanan üretim kaybının daha az olması sağlanmıştır.

#### Mandrel değişimi



Resim 4. Mandrel Değişimi

Üretimi yapılan malzemenin hatasız bir şekilde sarımı yapılan son aşamadır. Merkezi Bakım ekibi olarak demontaj ve montaj işlemleri yapılmaktadır. Ayrıca atölyelerde bakım sırasında da destek verilmektedir. (Resim 4.)

#### Yüksek fırın re-line çalışmaları



Resim 5. Yüksek Fırın Çalışmaları

2. Yüksek Fırın Re-line çalışmaları sırasında 24 adet tüyer ana soğutucu montajında, programdaki iş yükünün hafifletilmesi, aynı zamanda işi hızlandırmak adına bahsi geçen tüyer ana soğutucu işinin plandaki süreden önce merkezi bakım ekiplerince yapılmasıyla tamamlanmıştır. (Resim 5.)

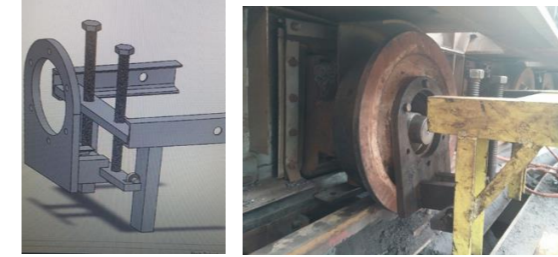
#### Çelikhane Konvertör rulman değişimleri



Resim 6. Çelikhane Rulman Değişimi

Çelikhane konvertör rulmanı hasarlanması neticesinde değişimi yurtdışından gelecek olan supervisor koordinasyonunda değişimi yapılmasına karar verildi. Fakat 3 aydan önce supervisor gelemeceğinden dolayı üretim durması çok büyük maddi kayba neden olacağından Merkezi bakım ekibimiz ve montaj atölyesi ekipleri beraber çalışarak 5 günlük süre içerisinde supervisor olmadan değişimi yapmıştır. (Resim 6.)

#### Sinter fabrikası dairesel soğutucu teker değişimleri



Resim 7. Dairesel Soğutucu Teker Değişimi

Dairesel soğutucu teker değişimi için aparat yapılarak vardiyada bir teker değiştirilirken şu anda en az iki teker değişimi yapılarak bir teker değişim süresi 2,5-3 saatlere düşürülerek bu süre ciddi anlamda kısaltılmıştır. (Resim 7.)

#### Kangal haddehanesi shaft tutucu montajı



Resim 8. Shaft Tutucu Demontaj-Montajı

Merkezi Bakım Ekibi olarak Kangal haddehanesi 1. Ara grup shaft tutucu merdane kanallarının değişimi, ayarlanması ve shaftın döngüsüne yardımcı olmaktayız. Arıza durumu haddeyi olumsuz etkilemektedir. Ekip olarak demontaj ve montajını 2-3 saatlik duruşlarda yaparak katkı sağlamaktayız. Ayrıca yedek bakımlarını da yapmaktayız. (Resim 8.)

#### SDM kütük makinesi taret rulmanı değişimi

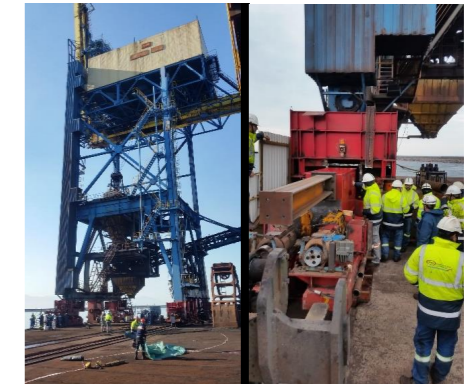


Resim 9. Taret Rulmanı Değişimi

Taret rulmanı değişiminde çalışan ekibimiz kurulduğu ilk senelerde yaptığı en riskli ve en çok tecrübe kazandığı çalışmalardandır. (Resim 9.)

#### Liman CB1 ve CB 2 Vinlerinde Çalışma

Liman Vinçlerinin yürüyüş takımlarında fırtına sonrası oluşan hasarlanmaya çok hızlı şekilde teknik ekipmanlarla müdahale edilmiştir. 1600 ton ağırlığındaki vinçin senkronize krikolar ile kaldırılıp yürüyüş takımları atelye ortamında yenilenmiş/onarılmış ve yerine montajı yapılmıştır. Merkezi bakım ekibinin yetkinliğinin görünür hale geldi özel işlerdendir. (Resim 10.)



Resim 10. Liman Vinçleri Kaldırma İşlemleri

#### 3.3. Kazançlar, iyileştirmeye açık alanlar, devamındaki yol haritası

Ekibin kurulması ve çalışması sonucu bakım hizmeti veren firmalara bağımlılık azalmıştır. Özellikle bölgemizde çalışma gerçekleştiren firmalarda kalifiye elaman sayısının az olması, acil durumlarda veya planlanan kapsamlı çalışmalarda firmaların yetersiz olmasından dolayı katma değeri çok yüksek bir kazanç sağlamıştır. Ekibin belirli kollarda daha da profesyonelleştirilerek ekip içinde ekipler oluşturularak fabrikanın her bölgesine hizmet verecek uzman personeller yetiştirilmesi hedeflenmektedir.



## Makro İnküzyon Kusurunun SEM Analizi ile Kök Neden Tespiti

Macro Inclusion Root Cause Analysis Studies with SEM Analysis

İlker Ayçiçek, Murat Sarıoğlu

İSKENDERUN DEMİR VE ÇELİK • Türkiye

### Abstract

Macro inclusion is one of the important defects that come from steel production processes and cause quality problems in rolling processes. Basically, inclusions are divided into internal and external sources. While size of micro inclusions are less than 50 micron, size of macro inclusions are greater than 50 micron. The root causes of macro inclusions can be understood based on their size and chemical composition. In this study, chemical and dimensional investigations of macro inclusions detected before rolling were taken by taking samples from the billets with continuous casting.

### Özet

Makro inküzyon çelik üretim sürecinden gelen ve haddeleme sürecinde kalite problemi oluşturan en önemli kusurlardan biridir. İnküzyonlar temel olarak iç ve dış kaynaklı olarak sınıflandırılabilir. İnküzyon boyutu 50 mikrondan büyük olduğunda bu inküzyon makro inküzyon olarak adlandırılır. Makro inküzyonların kök nedeni, büyüklüğüne ve kimyasal içeriğine bakılarak anlaşılabilir. Bu çalışmada, haddeleme öncesinde, sürekli döküm yöntemi ile üretilen kütüklerden alınan numunelerin incelenmesi ile makro inküzyonların kimyasal ve boyutsal incelemeleri yapılmıştır.

### 1. Giriş

Sürekli döküm ile çelik üretimi verimlilik ve maliyet açısından avantajlı olmasından ötürü, 2018 yılında toplam çelik üretiminin % 96,4'si sürekli döküm yöntemi ile üretilmiştir. [1] Sürekli döküm yöntemi ile çelik üretimi sırasında karşılaşılan en önemli problemlerden biri de makro inküzyon problemidir. Makro inküzyon çelik matris içerisinde süresizlik yaratarak, bir sonraki proses olan haddeleme sürecinde kalite kusuru olarak kendini göstermektedir. Çelikte inküzyon çeşitleri genel olarak 2 ana başlığa ayrılır ve bu ayrım çelik üretim ve sürekli dökümler sürecinde iç kaynak- dış kaynak olarak isimlendirilir. İç kaynaklardan gelen inküzyonlar, çelik üretim sürecinde oksijen giderme sonrası cürufa alınmayan inküzyonlar ve alaşımlama sonrası oluşan inküzyonlar olup, dış kaynaklı inküzyonlar yeniden oksitlenme ürünleri,

pota curufu, pota ve tandış refrakterleri, stoper – daldırma nozulu malzemeleri, döküm tozu- kalıp curufu, tandış curufu gibi çeliğin temas ettiği ve bu temas ve/veya aşınma sonucu çeliğin içerisine giren metalik olmayan inküzyonlardır. İnküzyon boyutu 50 mikrondan büyük olduğunda bu inküzyon makro inküzyon olarak adlandırılır [2].

Bu çalışmada İsdemir Kütük Sürekli Döküm Tesislerinde üretimi yapılan 130\*130 mm ve 160\*160 mm kare kesitleri ve 0,40 % üzerinde karbon içeren çeliklerde tespit edilen makro inküzyonların temel olarak kimyasal yapısının belirlenmesi ile kök neden analizi üzerinde durulacaktır.

### 2. Deneysel Çalışmalar

Sürekli döküm tesisinde üretilen dökümlerin döküm ortasına gelen kütüklerden makro numunesi alınarak iç yapı incelenmesi yapılmaktadır. Alınan numune kalınlığı 30 mm olup, iç yapı incelenmesi öncesinde taşlama, sıcak asitte dağlama ve yüzey temizliği yapılmaktadır. Hazırlanan makro numuneleri görsel olarak kontrol edilmektedir. Yapılan inceleme sonucunda tespit edilen makro inküzyon kusurları iç yapıdan çıkartılarak taramalı elektron mikroskobu (SEM) incelemesine tabi tutulmuştur. Sem incelemelerinde EDS modülü kullanılarak makro inküzyonların kimyasal analizi tespit edilmektedir. Yapılan makro incelemelerde karşılaşılan makro inküzyon görseli aşağıda paylaşılmıştır.



Şekil 1. Kütük Makro İncelemesinde Tespit Edilen Makro İnküzyon Kusuru

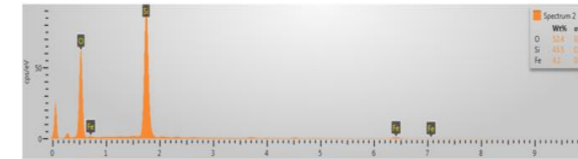
### 2.1. Döküm Sırasında Kullanılan Malzemelerin İncelenmesi

Sürekli döküm prosesinde muhtemel makro inküzyon kaynaklarının tespiti için kullanılan malzemeler incelenmiştir. İnceleme yapılan malzemeler, tandış başlatma tüpü, daldırma nozulu, nozul kaplama malzemesi, tandış curufu, tandış çeltik külü, tandış iç refrakter malzemeler, olarak belirlenmiştir. Bu malzemeler XRF ve SEM-EDS yöntemleri kullanılarak incelenmiştir.

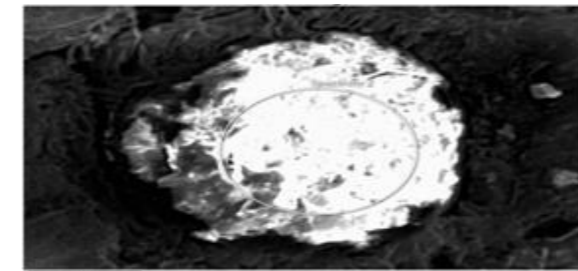
### 3. Sonuçlar ve Tartışma

İnceleme yapılan malzemelerin kimyasal analizlerinde dikkat çeken bileşikler; tandış başlatma tüpü: % 50 Al<sub>2</sub>O<sub>3</sub>, % 50 SiO<sub>2</sub>; daldırma nozulu: % 83,8 ZrO<sub>2</sub>; nozul dış kaplama malzemesi: % 51 SiO<sub>2</sub>, % 33 Al<sub>2</sub>O<sub>3</sub>; tandış curufu: % 27 SiO<sub>2</sub>, %21,8 CaO, %11,5 Al<sub>2</sub>O<sub>3</sub>; kalıp curufu:% 28,6 SiO<sub>2</sub>, % 30,2 CaO, % 7,5 Al<sub>2</sub>O<sub>3</sub>, döküm tozu: %30,8 SiO<sub>2</sub>, %18,6 CaO, %9 NaO<sub>2</sub>, tandış çeltik külü: %95 SiO<sub>2</sub>, tandış içi ateş tuğlası: %43,9 SiO<sub>2</sub>; %51,9 Al<sub>2</sub>O<sub>3</sub> olarak ölçülmüştür. Yukarıda verilen değerlerin seçilmesinde malzemeleri makro inküzyon içeriği kök neden araştırmasında kullanılan temel bileşiklerin olmasına dikkat edilmiştir.

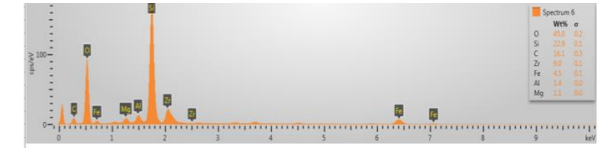
2019 yılı içerisinde kütük içyapı değerlendirmeleri sonucunda 31 adet makro inküzyon numunesi hazırlanmış ve SEM-EDS incelemesi yapılmıştır. Bu incelemelerde görülen ana elementler: 22 adet numunede Si, O elementi, 5 adet numunede Si, Zr, Al O elementi, 4 adetinde Si, Ca, Al, Na, F, O elementleri tespit edilmiştir.



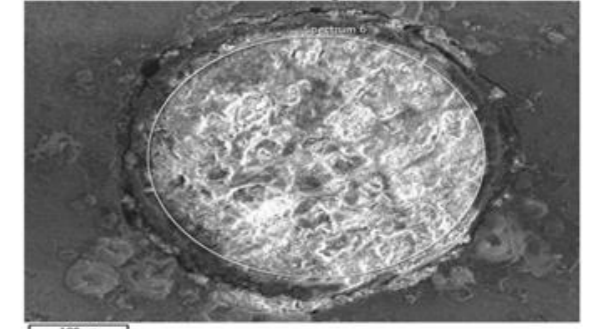
Şekil 2. Si ve O içeren Makro İnküzyon Kusuru- EDS Analizi



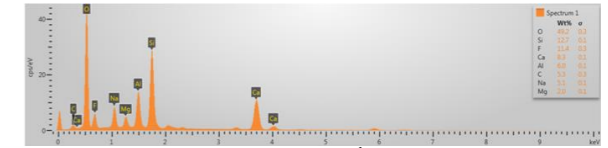
Şekil 3. Si ve O İçeren Makro İnküzyon Kusuru -SEM



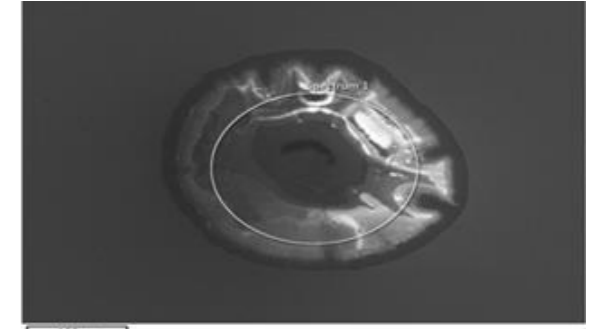
Şekil 4. Zr ve O içeren Makro İnküzyon Kusuru- EDS Analizi



Şekil 5. Zr ve O İçeren Makro İnküzyon Kusuru -SEM



Şekil 6. Na ve O içeren Makro İnküzyon Kusuru -EDS Analizi



Şekil 7. Na ve O İçeren Makro İnküzyon Kusuru -SEM

Yapılan SEM-EDS sonuçları değerlendirildiğinde sonuçların 3 ana başlıkta toplandığı görülmüştür. Yapılan incelemelerde sadece Si ve O elementlerinin görüldüğü 22 incelemenin kök nedeninin tandış içi refrakter ve tandış ısı kaybını önleyen tandış çeltik külü ve tandış curufu olduğu düşünülmektedir. Özellikle SiO<sub>2</sub> içeriği yüksek olan malzemelerin bu kusura yol açtığı düşünüldüğünden tandış metalürjisi öne çıkmaktadır. Ayrıca nozul kaplama ve başlatma tüpünde de yer alan yüksek SiO<sub>2</sub> içeriklerinin kusur üzerine etkileri incelendiğinde; nozul kaplama malzemesinin tandışın ilk dökümlerinde aşındığı ve kalıp cürufuna çıktığı göz önüne alındığında ve tandışın son



dökümlerinde de SiO<sub>2</sub> bazlı kusur tespit edildiğinden bu malzeme nedeni kusur oluşmadığı tespit edilmiştir. Başlatma tüpü kullanılmadan da yapılan denemelerde SiO<sub>2</sub> bazlı kusur görüldüğünden, kusurun başlatma tüpü kaynaklı olmadığı söylenebilir. Makro inklüzyon kusuru içerisinde tespit edilen Zr elementinin olduğu 5 incelemenin kök nedeninin daldırma nozulu (SEN) olduğu düşünülmektedir. Kalıp içerisinde sıvı çelikle tandiş döküm süresi boyunca temas eden yüzey aşınma düreci yüksek olması nedeni ZrO<sub>2</sub> içermektedir. Döküm sırasında nozul aşınmaları, delinmeleri, çatlaklamaları, kopmaları gibi nozul kaynaklı uygunsuzluklar bu kusura neden olmaktadır. Si, Ca, Al oksitlerinin yanında tespit edilen Na elementi (oksit halinde) içerikli makro inklüzyon kusurunun kalıp curufu – döküm tozu kök nedeni olduğu tespit edilmiştir. Sürekli döküm prosesinde kalıpta yağlama yapan döküm tozu, seviye oynaması, hız dalgalanması, stoper oynaması vb. gibi proses uygunsuzluklarında çelik içerisine geçip, makro inklüzyon olarak kendini göstermektedir.

Makro inklüzyonların boyutsal incelemesi yapıldığında 31 adet makro inklüzyonun ortalama çapı 405 mikron, en büyük makro inklüzyon 1000 mikron ve en küçük makro inklüzyon 200 mikron olarak tespit edilmiştir.

#### 4. Sonuç

İsdemir Kütük Sürekli Döküm Tesislerinde Kapalı olarak üretimi yapılan % 0,40 karbon üzeri kalitelere makro inklüzyon kusuru kök neden araştırması yapılmıştır. Yapılan çalışmada makro inklüzyon kusurunun kimyasal bileşiminin yanı sıra çeliğin Sürekli döküm prosesinde temas ettiği malzemelerin kimyasal bileşimi incelenmiştir. Yapılan çalışmalar sonucunda tespit edilen makro inklüzyonların % 71'inin tandiş metalürjisi kaynaklı olduğu anlaşılmıştır. % 16'lık bölümü daldırma nozulu kaynaklı, % 13'ünün ise kalıp içinde meydana gelen uygunsuzluklardan olduğu tespit edilmiştir. İnküzyonların boyutsal değerlerdirmesi yapıldığında 200-1000 mikron arası değişen ve ortalaması 405 mikron olduğu tespit edilmiştir.

#### Referanslar

[1] <<https://www.worldsteel.org/en/dam/jcr:96d7a585-e6b2-4d63-b943-4cd9ab621a91/World%2520Steel%2520in%2520Figures%25202019.pdf>>

[2] Tundish Technology for Clean Steel Production, 2008, World Scientific, Sahai Y., Emi T.

## Dört Sıralı Rulmanlarda Malzeme, Isıl İşlem ve Lojistik

Four Rows Bearings, Material, Heat Treatment and Logistics

Erçin Değirmen

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#### Özet

Demir Çelik sektöründe özellikle haddelemede dört sıralı silindirik makaralı ve konik makaralı rulman kullanımı çok yaygınlaşmıştır.

Bu seri rulmanlarda malzeme cinsi ve kalitesi, ısıl işlem yöntemleri, uygulamaya göre yüzey sertleştirmeli (case hardening) veya kesiti boyunca sertleştirmeli (through hardening) rulman tipinin kullanımına karar verilmesi ve lojistik destek (stoklarda bulabilme veya kısa sürede temin) çok önemlidir.

Ağır şartların olduğu demir çelik sektöründe şartları uygulamalara göre çok değişiklikler göstermektedir. Sahadaki uygulamaların detaylı incelenip rulman marka, tip, özellikleri itibari ile teknik destek, stok, verimlilik ve ekonomiklik sağlayacak rulman üreticileri ve dağıtıcıları ile çalışmak çok büyük fayda ve katkı vermektedir.

#### 1-DÖRT SIRALI RULMANLARDA MALZEME DÖKÜM YÖNTEMLERİNİN KARŞILAŞTIRILMASI

Dört sıralı rulmanlarda rulman çelik malzemesinin kimyasal kompozisyonunun yanında malzemenin döküm yöntemi de çok önem kazanmaktadır. Burada genel olarak iki yöntem kullanılmaktadır;

a-Sürekli döküm yöntemi

b-Kalıp döküm yöntemi

Bu iki yöntemin çelik yapılarının karşılaştırılması için üretici firma tarafından çeşitli testler yapılmıştır.

Sürekli döküm ve Kalıp döküm den alınan 60 mm çapındaki cubuk test malzemelerinin yüzeyi, ¼

yarçapı, ½ yarıçapı, ¾ yarıçapı ve merkezi incelenmiş, her iki yöntemde C, Si, Mn, Cr, Al, Ti ve diğer elementlerin katılaşma(seggregation) değerlerine bakılmıştır ve numuneler incelenmiştir

1.1-Çelik Yapıları

Test sonucunda sürekli döküm yönteminde ortalama ve maksimum parçacık boyutu kalıp döküm yöntemine göre daha büyük olduğu görülmüştür ayrıca parçacık dağılımı kalıp dökümde daha düzenlidir.

1.2--Metal olmayan malzeme karışım değerleri

Döküm sonucunda numunelerin incelenmiş ve sürekli döküm yönteminde metal olmayan malzemelerin değer ve kaba tanecikleri dağılımının kalıp döküm yöntemine göre zayıp olduğu görülmüştür

1.3-Carbide

Döküm sırasında metoduna bakılmaksızın carbide katılaşması olmaktadır ancak katılaşmanın miktarı, yeri ve homojenliği değişebilmekte, bazı ateş çatlakları (fire cracks) olabilmekte, malzeme üzerinde dallar halinde gerginlikler oluşabilmektedir, bunlarda rulmanın yorulma ömrüne etki etmektedir, Bu konu ile ilgili yapılan testlerde kalıp döküm yönteminde carbide dağılımının homojenliği, malzemenin aşırı ısınma karşısında verdiği reaksiyonlar da, yüksek ve alçak karbon bantları arasındaki sertlik değişiminin etkileri açısından çeliğin yorulma ömrünün %30 civarında iyileştiği görülmüştür.

1.4-Yorulma Ömrü

Yapılan testlerde kalıp döküm yöntemi ile sürekli döküm yöntemi yorulma ömür oranları, Lio(the rated

service life)=1,33 ve Lso(median fatigue life)= 1,22 olarak tespit edilmiştir

#### Sonuç

Kalıp Döküm yöntemi kullanılarak üretilen çeliklerden üretilen Rulmanların maliyeti daha yüksek (%15 civarında ) olmasına rağmen, daha üniform bir yapıya sahip olaması, daha homojen olması, yorulma ömrünün daha yüksek olması açısından sürekli döküm yöntemine göre %30 daha uzun ömürlü olmaktadır. Toplamda fiyat performan oranı çok daha avantajlıdır.

## 2-RULMAN ÇELİĞİNDE (GCr15&GCr18Mo) ISIL İŞLEM YÖNTEMLERİ KARŞILAŞTIRMASI

Dört Sıralı Rulmanlarda genel olarak iki türlü ısıtım işlem yöntemi kullanılmaktadır

a-Bainite su verme (quenching)

b-Martensite su verme

Su verme yöntemine göre mekanik özellikler

### 2.1-Dayanım

#### 2.1.1-Darbe Dayanımı (impact toughness)

Martensitik işlem ve sonrasındaki düşük sıcaklık temperleme işlemi (160 C de 3 saat) ile Bainite işlem ve aynı şekilde temperleme işlemi karşılaştırıldığında darbe dayanımı açısından Bainite yönteminin %25 daha iyi olduğu görülmüştür

#### 2.1.2-Kırılma dayanımı (Fracture toughness)

Martensitik işlem ve sonrasındaki düşük sıcaklık temperleme işlemi (160 C de 3 saat) ile Bainite işlem ve aynı şekilde temperleme işlemi karşılaştırıldığında kırılma dayanımı açısından Bainite yönteminin %20 daha iyi olduğu görülmüştür.

#### 2.1.3-Aşınma dayanımı ve Kontak yorulma ömrü

Tüm Bainite yapılarında martensite yapıya göre daha iyi netice vermektedir

### 2.2-Üretim uygulamaları

#### 2.2.1 Isıl işlemden sonra boyut değişimi

Martensitik yapılarda soğutma işlemi çok hızlı olduğundan bilezikler gerekli ve yeterli genişlemeyi sağlayamadıklarından stres yüklü kalmaktadır ve daha sonraki ısıtım işlemlerinde çap yönünde daha fazla aşınmaya maruz kalmaktadır Bainite yapılar bu işlemde daha iyi performans vermektedir

#### 2.2.2 Kalıcı gerilme (Residual stres)

Martensitik yapılarda çok hızlı soğutmadan dolayı malzemenin yüzeyi ile iç kısımlarında oluşan sıcaklık farkı ve farklı büzülme miktarından dolayı kalıcı gerilme daha fazla oluşmaktadır Bainite isothermal soğutma uzun süreli surede olduğundan kalıcı gerilme daha azdır ve bu da malzemenin dayanımı artırıcı yönde etki yapmaktadır

#### 2.2.3 Boyutsal stabilizasyon

Bainite yapılarda normal ve yüksek sıcaklıklarda malzemenin iç yapısı stabil olduğu için boyutsal değişim martensitik yapılara göre daha azdır

#### 2.2.4 Deformasyon

Bainite ısıtım işlemde yüksek erime sıcaklığından kontrolü izothermal soğutma yapıldığından deformasyon daha azdır, dört sıralı rulman bileziklerinin düz ve basit bir dairesel şekle sahip olması deformasyon miktarı düşük seviyede tutulabilmektedir

#### 2.2.5 Demir çelik Dört Sıralı Rulmanlara Bainite yapının uygulama etkileri

Bainite yapının darbe dayanımı, kırılma dayanımı, aşınma dayanımı, boyutsal stabilite ve gibi üstün özelliklerinden dolayı demir çelik hadde uygulamaları gibi ağır şartların ve nispeten zayıf servis şartları olan uygulamalar için çok iyi performans sağlamaktadır.

Bainite yapı dört sıralı rulman bileziklerinin özellikle büyük çap ve genişliklerde çok önemli olan sertlik değerlerinin bileziklerin her noktasında eşdeğer olmasına olanak sağlar (maksimum sapma 1 HRC civarındadır),

Bainite yapı ile ısıtım işlem ve sonrasındaki taşlama çatlakları çok azaltılabilmektedir bu da demir çelik uygulamaları için çok önemlidir.

Özellikle dört sıralı rulmanların montajı sırasında olabilecek sert darbe halinde iç bileziklerin ve dış bilezik faturalarının çatlama ve kırılma riski Martensitik yapıda daha fazladır.

Özellikle demir çelik uygulamalarında Bainite yapı malzemenin üretilmiş dört sıralı rulmanların servis ömrü Martensitik yapıya göre %66 civarında fazla olduğu görülmüştür

## 3-YÜZEY SERTLEŞTİRME ve KESİTİ BOYUNCA SERTLEŞTİRME UYGULAMADAKİ ETKİLERİ

Dört sıralı rulmanlarda yüzey sertleştirme ve kesiti boyunca sertleştirme yöntemlerinin karşılaştırması uygulamalara ve rulmanların boyutlarına göre değişmektedir.

Dört sıralı rulman üreticileri boyuta, uygulamaya göre her iki yöntemi de kullanarak üretim yapmaktadırlar, bu yöntemlerin tanımları aşağıdaki gibi yapılabilir

a-Yüzey sertleştirme(case hardening, surface hardening, carburizing)

Düşük karbonlu bir komponent, atmosferindeki karbon miktarı dikkatli bir şekilde kontrol edilen özel bir fırına yerleştirilip belli bir süre tutulur bu sürede yüzeye istenilen derinliğe ulaşmaya kadar karbon ve/veya başka alaşımlar emdirilir, daha sonra malzeme ısıtım işlemine tabi tutulduğunda, yüzey bölümü

sert ve malzemenin iç kısmı daha yumuşak bir yapı elde edilir.

Genelde kullanılan malzeme:G20Cr2Ni4

b-Kesiti boyunca sertleştirme (through hardening)

Çeliği sertleştirmek için belli miktarda karbon, demir eriyiğinin içerisinde karıştırılıp (bu kahvenin içerisinde bir miktar sekerin karıştırılıp eritilmesine benzetilebilir) belli sürede soğutulmuş ısıtım işlemine tabi tutulması sonucunda çeliğin tüm kesiti boyunca aynı sertlikte bir yapı oluşturmasıdır.

Genelde kullanılan malzeme : GCr15SiMo ve GCr18MO.

İki Yöntem karşılaştırıldığında her ikisinde uygulamalara göre avantaj ve dezavantajları vardır, Yüzey sertleştirilmiş rulmanlarda sertleştirilmiş bir yüzey nispeten esnek ve yumuşak bir iç bölgeye sahip olmalarından dolayı dinamik halde ani darbe ve şok yüklerde çatlama ve kırılmalara karşı dayanıklıdır, buna karşın kesiti boyunca sertleştirilmiş malzemenin üretilen rulmanlarda yorulma ömrü daha yüksek çıkabilmekte ve hesaplamalarda yorulma ömrü indirgeme faktörleri yüzey sertleştirilmiş rulmanlara göre daha iyi çıkmakta ve bazı literatürde kesiti boyunca sertleştirilmiş rulmanlar için daha uzun ömür verilmektedir, ayrıca kesiti boyunca sertleştirilmiş rulmanların termal etkilenmesi daha azdır, konu çizelge1 de özetlenmiştir



Çizelge 1 Kesiti boyunca (through hardening) ve yüzey sertleştirilmiş (case hardening) rulmanların karşılaştırılması

	Kesiti boyunca sertleştirilmiş rulmanlar (through hardening), Bainite	Yüzey sertleştirilmiş rulmanlar (case hardening)
Yorulma ömrü	iyi	iyi
Termal etkilenmesi	iyi	normal
Kayma yük taşıması	iyi	iyi
Statik yükte mekanik şok	iyi	iyi
Haddelemede ani aşırı yüke maruz kalması	iyi	çok iyi
Korozyon		
Fiyat	normal	pahalı

Genel olarak sadece demir çelik sektörüne üretim yapan ESG markasının tecrübesine göre Dört sıralı rulmanlarda 600 mm den büyük iç bilezikler için yüzey sertleştirilmeye uygun malzemeden ve yüzey sertleştirilmiş ürün kullanmak daha uygun olmaktadır buna karşın daha küçük boyutdaki dört sıralı rulmanlarda kesiti boyunca sertleştirilmiş rulmanlar yeterli performansı sağlamaktadır.

#### 4-STOK ve TEMİN SÜRESİ

Dört Sıralı Rulmanlarda en önemli konulardan biri de uzun terminlere sahip olmalarıdır, bu konuda oldukça detaylı çalışmalar yapan ve sadece demir çelik için dört sıralı rulman üretimine odaklanmış bir Çin markası ESG firması, yaklaşık 140 farklı tip ve her

tip için 50 set civarında stok tutarak (tüm versiyonları ile Çelik - Bronz kafes ve değişik boşluk gruplarında) ve stoklarında olmayan tipler için çok kısa terminler vererek (yarı mamül ve malzeme stoğunu bulundurarak) bu soruna bir çözüm getirmektedir.

#### Sonuç

Hadde ve demir çelik sektöründe çok ağır şartlar vardır, özellikle ağır sanayi rulman temininde tamamiyle dışarı bağımlı olduğumuz ülkemizde, rulmanların seçimi, özellikleri, hangi kaynaktan nasıl temin edileceği ve sonrasında montaj-demontaj ve bakım yöntemlerinin doğru uygulanması, doğru cihaz, alet kullanımı ve bu konularda eğitimler alınması son derece önemlidir.









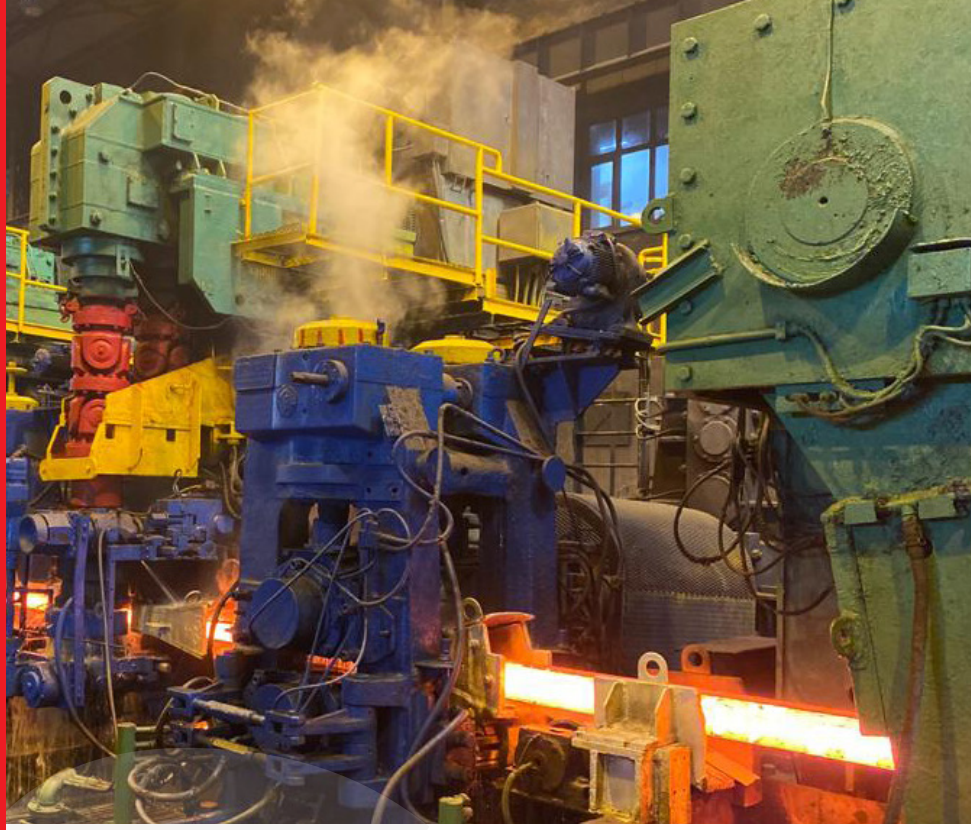




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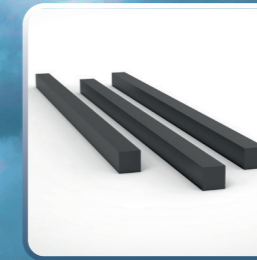
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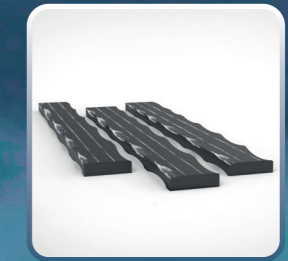
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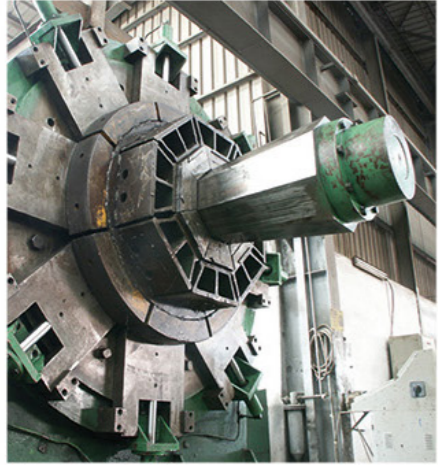
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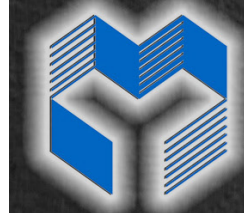


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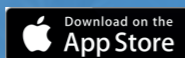
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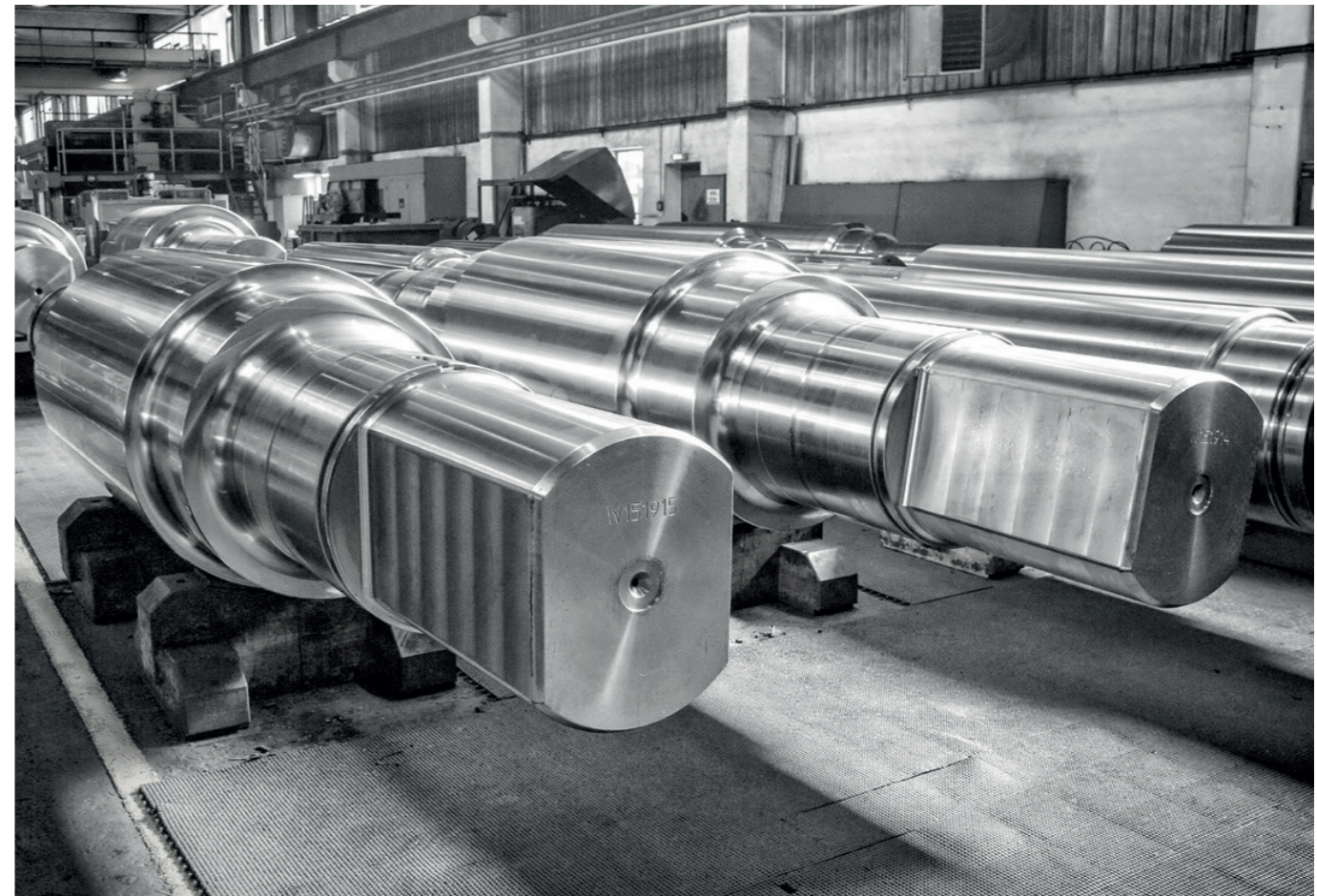
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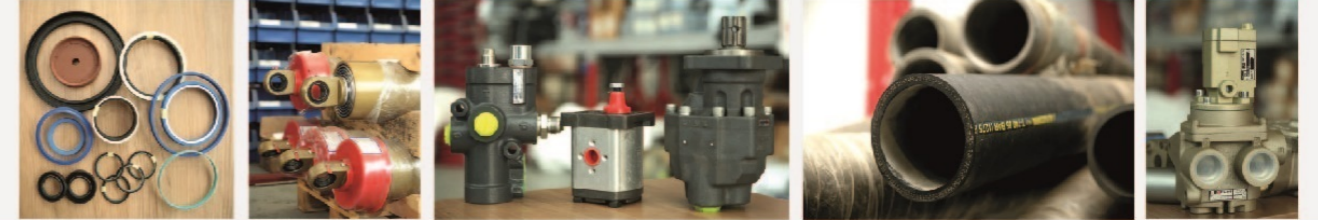
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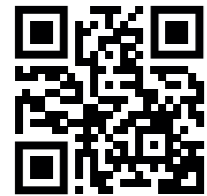
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