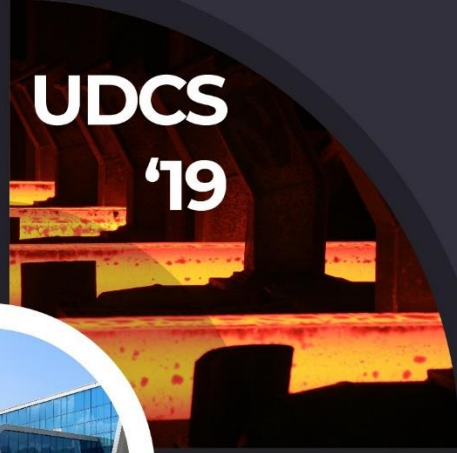




**UDCS
'19**



4th
**INTERNATIONAL
IRON & STEEL
SYMPOSIUM**

DEADLINE FOR ABSTRACT OR FULL PAPER
SUBMISSION: **JANUARY 30, 2019**

CONFERENCE DATES:
APRIL 4-6, 2019



www.udcs19.karabuk.edu.tr

UDCS'19

The Proceedings of Fourth International Iron and Steel Symposium (UDCS'19)
April 4-6, 2019, Karabuk University, Karabuk, Turkey.

Edited by

Dr. Yavuz SUN (Chairman)
Dr. Mustafa YAŞAR (Chairman)
Dr. Engin ÇEVİK (Chairman)

Copyright

ISBN 978-605-9554-36-7

© 2019, UDCS'19, Karabuk University
Karabuk, Turkey
<http://udcs19.karabuk.edu.tr/>
udcs19@karabuk.edu.tr

This proceedings include the original papers submitted to UDCS'19. It is accessed in free of charge.
All scientific and linguistic responsibilities of the published articles belong to their authors.

**The Fourth International Iron and Steel
Symposium (UDCS'19)**

4-6 April 2019

Karabuk University, Karabuk, Turkey

HONORARY COMMITTEE

Dr. Refik POLAT, Rector of Karabuk University
Dr.Mehmet KARACA, Rector of Istanbul Technical University
Dr. Veysel YAYAN, Undersecretary of the Ministry of Science, Industry and Technology
Dr. Huseyin S. SOYKAN, CEO of KARDEMIR A.S.

UDCS'19 CHAIRMAN

Dr. Yavuz SUN
Dr. Mustafa YAŞAR
Dr. Engin ÇEVİK

ORGANISING COMMITTEE

Dr. Yavuz SUN
Dr. Mustafa YASAR
Dr. Mehmet OZALP
Dr. Hayrettin AHLATCI
Dr. Engin CEVIK
Dr. Betul ERCAN
Dr. Cemal CARBOGA
Dr. Fatih AYDIN
Dr. M. Emre TURAN
Dr. Fazıl HUSEM
Dr. Alper INCESU
Yasin AKGUL
Savas AGDUK
Safa POLAT
Mustafa MUSTU
Anday DURU
Feyzullah Behlul OZKUL

SCIENTIFIC COMMITTEE

Dr. Adem KURT	Gazi University
Dr. Ahmet KARAASLAN	Yildiz Technical University
Dr. A. Macit OZENBAS	Middle East Technical University
Dr. Ahmet DURGUTLU	Gazi University
Dr. Ahmet EKERIM	Yildiz Technical University
Dr. Ali GUNGOR	Karabuk University
Dr. Ali KALYON	Karabuk University
Dr. Anthony D. ROLLETT	Carnegie Mellon University
Dr. Ali RAMAZANI	University of Michigan-Ann Arbor
Dr. Alper INCESU	Karabuk University
Dr. Behcet GULENC	Gazi University
Dr. Bilge DEMIR	Karabuk University
Dr. Bulent AYDEMIR	TUBITAK-UME
Dr. Bulent KURT	Nevsehir Hacı Bektas Veli University
Dr. Carl D. LUNDIN	The University of Tennessee Knoxville
Dr. Cemal CARBOGA	Nevsehir Hacı Bektas Veli University
Dr. David K. MATLOCK	Colorado School of Mines
Dr. Emrah DENIZ	Karabuk University
Dr. Engin GEDIK	Karabuk University

Dr. Enver OKTAY	Istanbul Univerity
Dr. Erkan KOC	Karabuk University
Dr. Ertugrul ESMERAY	Karabuk University
Dr. Eyup Sabri KAYALI	Istanbul Technical University
Dr. Fatih HAYAT	Karabuk University
Dr. Fatma MEYDANERI TEZEL	Karabuk University
Dr. Filiz ERSOZ	Karabuk University
Dr. Fuat SIMSIR	Karabuk University
Dr. Hakan ATES	Gazi University
Dr. Hakan AYDIN	Uludag University
Dr. Halil DEMIR	Karabuk University
Dr. Hamza SIMSIR	Karabuk University
Dr. Hani HENEIN	University of Alberta
Dr. Harun CUG	Karabuk University
Dr. Hasan GOKKAYA	Karabuk University
Dr. Hasan KARABULUT	Karabuk University
Dr. Hatice EVLEN	Karabuk University
Dr. Hayrettin AHLATCI	Karabuk University
Dr. Hayriye ERTEK EMRE	Karabuk University
Dr. Huseyin CETIN	Karabuk University

Dr. Huseyin CIMENOGLU	Istanbul Technical University
Dr. Huseyin DEMIRTAS	Karabuk University
Dr. Huseyin KURT	Necmettin Erbakan University
Dr. Huseyin ZENGİN	Karabuk University
Dr. Ivan Enrique Campos SILVA	Instituto Politecnico Nacional
Dr. Idris KABALCI	Karabuk University
Dr. Ihsan KORKUT	Gazi University
Dr. Inan KESKIN	Karabuk University
Dr. Irinei RADOMIR	Transilvania University of Brasov
Dr. Ismail ATILGAN	Karabuk University
Dr. Ismail EKMEKCI	Istanbul Commerce University
Dr. Ismail ESEN	Karabuk University
Dr. Jahan RASTY	Texas Tech University
Dr. Kamil ARSLAN	Karabuk University
Dr. Kemal DAVUT	Atilim University
Dr. Kerim CETINKAYA	Karabuk University
Dr. Kiyotaka MATSUURA	Hokkaido University
Dr. Mahdi MAHFOUF	Sheffield University
Dr. Mehmet EROGLU	Firat University
Dr. Mehmet Akif ERDEN	Karabuk University

Dr. Mehmet Baki KARAMIS	Erciyes University
Dr. Mehmet OZALP	Karabuk University
Dr. Mehmet OZKAYMAK	Karabuk University
Dr. Mehmet UNAL	Karabuk University
Dr. Melik CETIN	Karabuk University
Dr. Metin ZEYVELI	Karabuk University
Dr. Mihai Alin POP	Transilvania University of Brasov
Dr. Muharrem DUGENCI	Karabuk University
Dr. Mustafa ACARER	Selcuk University
Dr. Mustafa BOZ	Karabuk University
Dr. Mustafa GUNAY	Karabuk University
Dr. Mustafa URGEN	Istanbul Technical University
Dr. Niyazi OZDEMIR	Firat University
Dr. Nizamettin KAHRAMAN	Karabuk University
Dr. Nurettin ELTUGRAL	Karabuk University
Dr. Oğuz KOCAR	Bulent Ecevit University
Dr. Peter DEARNLEY	Birmingham University
Dr. Ramazan KACAR	Karabuk University
Dr. Salim ASLANLAR	Sakarya University
Dr. Selami SAGIROGLU	Karabuk University

Dr. Selcuk SELIMLI	Karabuk University
Dr.Suleyman GUNDUZ	Karabuk University
Dr. Suleyman YASIN	Karabuk University
Dr. Senol GURSOY	Karabuk University
Dr. Tamila ANUTGAN	Karabuk University
Dr. Ulas MATIK	Karabuk University
Dr. Ulvi SEKER	Gazi University
Dr. Veli CELIK	Yildirim Beyazit University
Dr. Volkan KILICLI	Gazi University
Dr. Yakup KAYA	Karabuk University
Dr. Yasin KANBUR	Karabuk University
Dr. Yasar YETISKEN	Karabuk University
Dr. Yuksel AKINAY	Van Yuzuncuyil University
Dr. Yunus TUREN	Karabuk University

SYMPOSIUM SECRETARIAT

Mustafa Yunus ASKIN

Ferhat SARIÇAM

Sacit MADEN

Tugba AVSAR

Gozde GUNEY KAPTANOGLU

Tugba COSKUN

**METALLURGY AND MATERIALS STUDENT ASSOCIATION
KARABUK UNIVERSITY**

Ali AKKUŞ

Beste ÖZKAN

Burcu ÇETİNTAŞ

Elif COŞKUN

Gökhan İNCE

Hatice Kübra SÖNMEZ

Sakine OBUZ

Salih BEKTAŞ

Serap ÇATAL

Şeyma Nur ÇAYIR

Tuğçe İLERİOK

Yusuf GÖKALP

**UDCS'19 is organised by
Iron and Steel Institute**

**Karabuk University
78050 Karabuk, Turkey
T: +90 370 433 88 33
F: +90 370 433 88 32
E-mail: dce@karabuk.edu.tr
<http://dce.karabuk.edu.tr>
<http://udcs19.karabuk.edu.tr>**

**Fourth International Iron and Steel
Symposium (UDCS'19)
4-6 April 2019
Karabuk University, Karabuk, Turkey**

ÖNSÖZ

Karabük Üniversitesi Demir-Çelik Enstitüsü organizasyonunda gerçekleştirilen "4. Uluslararası Demir-Çelik Sempozyumu" 04-06 Nisan 2019 tarihlerinde Demir-Çelik Enstitüsü Konferans salonunda gerçekleştirilmiştir.

Türkiye'de ilk ve tek olan Karabük Üniversitesi Demir-Çelik Enstitüsü 2013 yılında hizmet vermeye başlamıştır. Enstitümüzün kuruluş amacı; "bölgemizdeki ve ülke genelindeki demir-çelik sektörü başta olmak üzere, tüm metal alışımaları üreten sektörlerin ihtiyaç duydukları akredite test ve kalite kontrol hizmetleri vermek, üniversite-sanayi iş birliği kapsamında Ar-Ge çalışmalarına destek olmak" şeklinde ifade edilebilir.

Enstitümüz, 2018 yılı itibariyle yaklaşık 60 sanayi kuruluşuna ve 16 farklı üniversiteye hizmet vererek bölgemiz ve ülkemiz için ne kadar önemli bir kurum haline geldiğini göstermiştir. Kurulduğu ilk günden beri üniversite-sanayi iş birliğine büyük önem veren enstitümüz, bu kapsamda gerek özel sektör gerekse kamu kuruluşlarıyla farklı projeler gerçekleştirmektedir. Bunlara örnek olarak, Kardemir ile birlikte gerçekleştirdiğimiz "Mantarı Sertleştirilmiş Ray Projesi" ve Çevre Bakanlığı ile yürütmekte olduğumuz, halen devam etmekte olan "Entegre Kirlilik Önleme EKÖK" projesi verilebilir. Bunun yanı sıra enstitümüz yine üniversite-sanayi iş birliği kapsamında, ülkemizde büyük eksikliği hissedilen Uluslararası Demir-Çelik Sempozyumunu geleneksel olarak iki yılda bir düzenlemeye başlamıştır.

Bu sene 4. düzenlediğimiz sempozyum sayesinde üniversite ve sanayi kuruluşları bir araya gelmekte, mevcut durum ve gelecek hedefleri adına yeni fikirler, yeni iş birliklerinin doğmasına öncülük etmektedir. Bu sene düzenlediğimiz sempozyuma 170 adet bildiri gönderilmiştir. Bu bildirilerin 14 tanesi poster sunum, geri kalan 156 tanesi sözlü sunum olarak gerçekleşmiştir. Gönderilen bildirilerin 37 tanesi sanayi kuruluşlarımızda görev yapan mühendis ve Ar-Ge personeli tarafından hazırlanmıştır. Ayrıca 40 farklı üniversitedeki akademisyenler tarafından 116 adet bildiri gönderilmiştir. Bunun yanı sıra 11 farklı ülkeden 17 adet bildiri sempozyumumuza gönderilerek uluslararası olma yolunda bize güç vermiştir.

Bu sempozyumun hazırlanmasında büyük emeği olan çalışma arkadaşlarıma, başta TÜBİTAK olmak üzere tüm sponsorlarımıza ve her şeyden önemlisi her zaman desteğini esirgemeyen Üniversitemiz Rektörü Sayın Prof.Dr. Refik POLAT'a şükranlarımı arz ediyorum. 5. Uluslararası Demir-Çelik Sempozyumunda tekrar görüşmek üzere herkese saygılarımı sunuyorum.

Prof. Dr.Yavuz SUN

**Demir-Çelik Enstitüsü Müdürü
Sempozyum Başkanı**

ACKNOWLEDGEMENTS

We wish to thank the following co-organisers Universities, TUBITAK and associations as panellists for their contribution to the success of this symposium.



KARDEMİR A.Ş.
<http://kardemir.com>



ERDEMİR GRUBU
<http://erdemir.com.tr>



MARZINC
<http://marzinc.com.tr>



ÇAĞ ÇELİK
<http://cagcelik.com.tr>



MAK ELEKTRONİK
<http://makelektronik.com.tr>



ANKA ANALİTİK
<http://ankaanalitik.com.tr>



ETİMADEN
<http://etimaden.gov.tr>



LEICA
<http://leicaturkiye.com>

UDCS'19 FULL PROGRAMME

DAY 1	4 APRIL THURSDAY		LOCATION	
8.30-09.30	Registration		Iron and Steel Institute Conference Hall	
09.30-09.50	Turkish National Anthem and Musical Notation			
09.50-10.00	Presentation of Karabuk University and Iron & Steel Institute			
10.00-10.40	Speech of Protocol			
10.40-11.10	Keynote Speech Kamal Bin YUSOH - Progress on Graphene – Based Steel Composites			
11.10-11.30	Coffee Break			
11.30-12.00	Keynote Speech Mehmet EROGLU - Advanced High Strength Steels (AHSS): Production and Applications			
12.00-12.30	Keynote Speech Murat BAYDOGAN - Hot Dip Aluminum Coating Process in Steel and Cast Iron			
12.30-14.00	Lunch			
14.00-16.00	Panel - 2023 Vision of Iron and Steel Huseyin CIMENOGLU (Istanbul Technical University) Huseyin SOYKAN (KARDEMIR Inc.) Sinan BOZKURT (ERDEMIR Inc.) Veysel YAYAN (Ministry of Science, Industry and Technology) İbrahim TOZLU (MATIL Inc.) Şerafettin ONER (ÇELSAANTAS Inc.)	Poster Presentations		Iron & Steel Institute
16.00-16.15	Coffee Break			
16.15-16.45	Keynote Speech Olekandr BABACHENKO - Investigation of the Kinetics of Decomposition of Supercooled Austenite with Continuous Cooling of K76Φ Steel for Rails	Oral Presentations 1		
16.45-17.45	Presentations Sponsor Companies			
19.30	Gala Dinner			
DAY 2	5 APRIL FRIDAY		LOCATION	
9.00-10.30	Oral Presentations 2		Iron & Steel Institute	
10.30-11.00	Coffee Break			
11.00-11.30	Keynote Speech Peter DEARNLY - Thermochemical Surface Engineered Steels – Their Behavior In Tribology			
11.30-12.00	Keynote Speech Mertol GOKELMA - Extracting REE (Rare Earth Elements) from the Ferric Fraction of Processed WEEE (Waste of Electrical and Electronic Equipment)			
12.00-12.30	Keynote Speech Ahmet KARAASLAN - Laser Welding of Different Metal Pairs with Steel			
12.30-14.00	Lunch			
14.00-14.30	Keynote Speech Bulent AYDEMIR - The Place in the World of Test Laboratories in Turkey - According to ISO 6892-1 Standard			
14.30-15.00	Keynote Speech Igor BELIC - Modeling of 3D Grain Size Distribution			
15.00-15.30	Keynote Speech Fevzi KAFEXHIU - Image Analysis of Size and Distribution Of Particles in Tempered Martensite			
15.30-16.00	Coffee Break			
16.00-17.30	Oral Presentations 3			
19.30	Dinner			
DAY 3	6 APRIL SATURDAY			LOCATION
9.00-10.30	Oral Presentations 4			Iron & Steel Institute
10.30-11.00	Coffee Break			
11.00-12.30	Oral Presentations 5			

ORAL PRESENTATIONS

SESSION 1

Parallel Session – Room : Magnetite -- 04.04.2019 – (16:15 – 17:45)		
Paper ID	Title	Speaker
75	The Effect Of Addition Of Si And Cr Alloying Elements To The Severe Abrasive Wear Behavior Of Medium Carbon Steels	Esma KESKIN
108	Investigation Of Hot Forged And Cooled Material Properties By Numerical Simulation Method	Osman CULHA
114	Reduction Behaviour and Pelletizing of Mill Scale – Oily Sludge Pellets	Samet BALLI
115	Effect of Section Thickness on Austemperability of GGG-70 Nodular Cast Iron Crankshafts	Mehmet YILDIRIM
118	Hot Shortness Mechanism and Mill Scale Characterization in Low Carbon Steels	Selçuk YEŞİLTEPE
123	Investigation of Material Properties of Cardan Shaft Fixed Joint Forked Flange Produced by Hot Forging and Cooling in Different Environments	Osman CULHA

Parallel Session – Room : Wustite -- 04.04.2019 – (16:15 – 17:45)		
Paper ID	Title	Speaker
18	Influence of Additions of Titanium and Boron on the Structural Evolution of the As-Cast State of 27Cr High Chromium White Cast Iron	Serdar Osman YILMAZ
23	Effect of Ultrafine-Grained Formation on Tribological Properties of Low Carbon Shipbuilding Steel	Dursun Murat SEKBAN
28	Microstructure and Mechanical Properties of Ultrafine-Grained Low Carbon Shipbuilding Steel Processed by Equal-Channel Angular Pressing	Dursun Murat SEKBAN
126	Structural and Physical Properties of Sintered Distaloy AE Alloy Compacts	Ayşe Nur ACAR
165	Characterization of Nano Aluminium Oxide Reinforced Iron Oxide Composites Produced by Powder Metallurgy	Abuzer AÇIKGÖZ
169	Effect of Ta Addition on Microstructure and Hardness of Low Alloy Cr-W Steels	Gökhan ARICI

Parallel Session – Room : Limonite -- 04.04.2019 – (16:15 – 17:45)		
Paper ID	Title	Speaker
3	Product Goals Optimization With Fuzzy Goal Programming Approach And An Application Integrated Iron And Steel Plant	Neslihan Yagci KOSE
57	Torpedocars Level Measurement And Location Tracking System	Cemil BAYRAMOGLU
58	Tavan Vinçlerinde Spesifik Otomasyon Uygulamaları	Mehmet SONMEZ
59	Blast Furnace Top Imaging System	Sertac KAYA
137	Applicatibility Of Computerized Maintenance Management System At Kardemir Rail & Section Mill	Semih DOĞAN

Parallel Session – Room : Hematite – 04.04.2019 – (16:15 – 17:45)		
Paper ID	Title	Speaker
1	Effect of Ti-B Addition In GX300CrMo27 and Heat Treatment on Wear Behavior of GX300CrMo27	Serdar Osman YILMAZ
6	Analysis of Mechanical and Metallurgical Properties as a Result of Cooling Process Alternative to Microalloying in Profile Production by Hot Rolling Process	Mehmet AKKAS
147	Effects Of Antioxidant Additions On The Material Properties Of Magnezya Karbon Bricks	Sadettin ZENCİ
15	Assessment of Weldability by Friction Welding Process of AISI1040 and High Chromium White Cast Iron	Mustafa OZARSAN
17	Friction Welding of High Chromium White Cast Iron and AISI1030 Steel Couple with Nickel Interlayer	Eyyüp Murat KARAKURT
92	Sürekli Dökümlü Üretilen Kütüklerde Soğutmanın Ve Manyetik Karıştırıcıların Kütük Makro Yapısına Etkisinin İncelenmesi	Cemalettin YAMAN

SESSION 2

Parallel Session – Room : Conference Hall – 05.04.2019 – (09:00 – 10:30)		
Paper ID	Title	Speaker
47	Mechanical Properties of Low Carbon Steel Processed by Equal Channel Angular Pressing	Muhammet DEMİRTAS
13	Wear Behaviour Of Iron Base Hardfacing On A Tool Steel	Yigit ERCAYHAN
134	The Effect of Iron Matrix Composition on Properties of Diamond Cutting Tools for Used Producing Natural Stone	Berrak BULUT
171	Investigation of Microstructure and Hardness of Co-containing and Co-free Cr-W alloy	Gökhan ARICI
125	The Effect Of Different Quenching Media And Tempering Temperature On The Hardness Value Of R260 Quality Asymmetric Profile	Gürkan GÜMÜŞ

Parallel Session – Room : Magnetite -- 05.04.2019 – (09:00 – 10:30)		
Paper ID	Title	Speaker
128	Influence Of Treatment Time On Microstructure Of Intercritical Austempered GGG40 Cast Iron	Cengiz BAĞCI
177	Effect Of Nitriding On Surface Characteristics And High Temperature Wear Behaviour Of Inconel 718 Superalloy	Hasan GÜLERYÜZ
182	Effect Of Alloying Elements On The Wear Properties Of Cryogenically Treated Medium Carbon Spring Steels	Reşat Can ÖZDEN
183	Effects Of Deep Cryogenic Treatment On The Mechanical Properties Of 52CrMoV4 Steel	Reşat Can ÖZDEN
199	Impact Sliding Wear Performances Of Quenched And Tempered Hot Work Tool Steels	Faiz MUHAFFEL
200	Influence Of Nitriding On Impact Sliding Wear Behavior Of Aisi H13 Tool Steel	Mertcan KABA
226	Effect of Isothermal Annealing on Microstructure and Mechanical Properties of a High Carbon Steel	Faiz MUHAFFEL

Parallel Session – Room : Wustite – 05.04.2019 – (09:00 – 10:30)		
Paper ID	Title	Speaker
29	The Effect of Sintering Temperature on Fe Based Al ₂ O ₃ Particle Reinforced Composites	Hasan KARABULUT
30	Investigation of the Effect of Sintering Temperature on Hardness in Fe Based SiC Reinforced Composites	Hasan KARABULUT
152	Investigation of the corrosion properties of hybrid composite coatings produced on AISI 316L stainless steel using TIG method	Mehmet AKKAS
160	Microstructural characterization of Cu-FeCr-FeB composites	Mehmet AKKAS
225	Effect of Different Welding Parameters on Weld Bead Geometry and Mechanical Properties of Synergic Controlled MIG/MAG Welding	Yavuz Selim CERAN

Parallel Session – Room : Limonite – 05.04.2019 – (09:00 – 10:30)		
Paper ID	Title	Speaker
218	Analysis Of Turkey's Iron-Steel Industry In The World Trade	Hayrettin KESKINGOZ
219	Comparative Analysis Of The Competitiveness Of Turkey's Iron-Steel Industry	Hayrettin KESKINGOZ
145	Impact Test Applications in Steel Industry, Testing and Uncertainty Calculation	Haldun DİZDAR
175	Innovations in the New TS-648 Steel Structures Design Regulations	Ayşegül YILMAZ
176	Evaluation of proficiency test results of tensile testing for metallic material	Bülent AYDEMİR

Parallel Session – Room : Hematite – 05.04.2019 – (09:00 – 10:30)		
Paper ID	Title	Speaker
60	Investigation Of The Microhardness - Applied Load Relationships In Induction Surface Hardening Steels	Aykut ARGINCIKLIGİL
63	Characterization of Earing Behaviour in Tin Plates by EBSD Method	Ramazan UZUN
122	Prevention of Section Reduction of Stand Pipes	Adnan NEHROZOĞLU
155	Determination and Modelling of the Most Suitable Parameters That Effect Springback in U-Bending Operations	Selin YILDIRIM
156	Investigation of the Formability of DP600 Dual Phase Sheet Material by Fluid Pressure Assisted Single Point Incremental Forming Method	Onur ÇETİNKAYA
166	Investigation Of The Springback And Microstructural Deformation For Different Sheet Metals Forming	Abdulsamet ÖZDEN

SESSION 3

Parallel Session – Room : Conference Hall – 05.04.2019 – (16:00 – 17:30)		
Paper ID	Title	Speaker
46	The Effect of Applied Load on Vickers Micro-Hardness Values of Steels	Erdal KARADENİZ
84	Effects of Blast Furnace Sludge (BFS) and Tar Decanter Sludge (TDS) on Coal Coking Process	Tayfun PAMUKSUZ
93	The Corrosion Behaviour of Zinc Plated Steel in an Aqueous Medium	Mustafa MASLAK
148	The Corrosion Behaviour of Zinc Plated Ç1080 Steel	Mustafa MASLAK
98	Influence Bias Voltage and Working Pressure on the Microstructure, Scratch and Wear Properties of TiAlZrN Films Prepared by CFUBMS Technique	Yasar SERT
173	Thermal Properties Of Graphene Reinforced Fe-Cr-Cu-Ni High Entropy Alloy Fabricated By Powder Metallurgy	Yüksel AKINAY

Parallel Session – Room : Magnetite -- 05.04.2019 – (16:00 – 17:30)		
Paper ID	Title	Speaker
141	Detection of Defects of Rolling Rolls by Deep Learning Method	Selim ÖZDEM
142	Coke Oven End Flue Repair By Using Fused Silica Bricks	Bülent ÖZTÜRK
143	Determination of Mechanical Properties of CO2 Laser Welded Dual Phase Steels	Ekrem ÖZTÜRK
144	Electrochemical Corrosion Behavior of Solution Treated UNS32205 Duplex Stainless Steel	Alptekin KISASÖZ
150	Surface Modification of Co-Based Stellite 6 Hardfacings by Laser Surface Melting: Microstructural and Reciprocating Wear Resistance Evaluations.	Ali Abdulmunim ALHATTAB
213	CrMnFeCoNiAl Yüksek Entropili Alaşimin Vakum Arc Melting Yöntemi İle Üretimi	Yusuf KARACA
227	An Experimental study of Taguchi Analysis on output parameters in EDM process	Ali Abdulmunim ALHATTAB

Parallel Session – Room : Wustite -- 05.04.2019 – (16:00 – 17:30)		
Paper ID	Title	Speaker
50	Greenhouse Gas Effects of the Energy Efficiency Projects	Irem GURSOY
80	Importance of Flue Gas Oxygen Measurement in Combustion Optimization	Saban PUSAT
81	Importance of Flue Gas Waste Heat Recovery	Saban PUSAT
87	Weight Reduction Study On A Heavy Duty Cast Iron Diesel Engine Block	Umit KIRENCİ
101	Waste Management and Zero Waste Studies in Iron and Steel Industry	H. Duygu BILGEN
198	Use of Biomass Waste in the Production of Iron Nugget from Magnetite Concentrate	Bayram BOSTANCI

Parallel Session – Room : Limonite – 05.04.2019 – (16:00 – 17:30)		
Paper ID	Title	Speaker
170	İnce Kesitli Kati Yuvarlak Tellerin Dönel Eğmeli Yorulma Test Cihazı Tasarımı Ve İmalatı	Emre DEMİRCİ
217	The transformation of structure steel with thermal strengthening of the disk railway wheel	Harun ÇUĞ
68	32CrMoV Alaşımına Gaz Nitrasyon İşleminin Halka Üzeri Pim Tipi Aşınma Davranışına Etkisi	Ali AKKUS
78	The theoretical description for the cathodic synthesis of polymer corrosion-protecting coating, based on wedelolactone	Volodymyr TKACH
53	A Mathematical Method for the Consumption Optimization of Cold Rolling Mill Rolls	Aykut BASKAYA
202	Stainless Steel - CuNP Selective Surfaces Coated by Thermal Evaporation Technique	Ahmed S. ABBAS

Parallel Session – Room : Hematite – 05.04.2019 – (16:00 – 17:30)		
Paper ID	Title	Speaker
121	Improvement Of Mechanical Properties By Means Of Titanium Alloying To Steel Teeth Used In The Excavator	Ali KELEŞ
106	International Market Selection for Turkish Steel Sector Based on MCDM	Merve BAYATA
136	Effect of Pulse Frequency on Mechanical Properties of Nd:YAG Laser Welded Dissimilar DP Steels	Oğuz TUNÇEL
162	Controlling Of Pearlite Volume Fraction By Air Cooling From Intercritical Austenitizing Temperatures In Ggg70 Ductile Cast Iron	Volkan KILIÇLI
163	Effect Of Austenitizing Time At Intercritical Austenitizing Temperatures On Microstructural Features Of Ductile Cast Iron	Volkan KILIÇLI
181	Effect of Welding Current on Mechanical Properties of Dissimilar Steels Joined Triple by Electrical Resistance Spot Welding	Oğuz TUNÇEL
27	An Application Example For Absorption Cooling System From Waste Heat Of Basic Oxygen Furnace	Aytaç AYDIN

SESSION 4

Parallel Session – Room : Conference Hall – 06.04.2019 – (09:00 – 10:30)		
Paper ID	Title	Speaker
88	An Investigation On The Weldability And Mechanical Tests Of Carbon Steel And Stainless Steel	Bunyamin CICEK
89	Investigation of post-weld mechanical properties of P91 and P22 steels with high creep resistance	Bunyamin CICEK
146	Investigation of Mechanical Properties of Hydrothermal Carbon-Iron Composites via Powder Metallurgy	Hamza ŞİMŞİR
211	Investigation of The Effect of Ball Diameter on Tensile Strength of Nonalloyed Powder Metallurgy Steels in Mechanical Alloying	Mehmet Akif ERDEN
94	Effect of reduced graphene oxide (rGO) on microstructure, hardness and corrosion performance of iron matrix composite	Hüseyin ZENGİN
230	Investigation of Thermal Conductivity for CuNP Deposited on 316L Stainless Steel by PVD as a Solar Absorber Surface	Ali Abdulmunim ALHATTAB

Parallel Session – Room : Magnetite -- 06.04.2019 – (09:00 – 10:30)		
Paper ID	Title	Speaker
7	Akımsız NiP/NiB Dupleks Kaplamanın Korozyon Dayanımı	Ulas MATIK
8	Akımsız NiP Alaşım ve NiP/nano BN Kompozit Kaplamaların Sentezi ve Karakterizasyonu	Ulas MATIK
34	Challenges Of New Entrepreneurs In The Welding Sector And Possible Solutions	Volkan TEMIZKAN
99	The Effect Of Cyclic Intercritical Annealing On Microstructure Of Dual Phase Steels	Ayse KAVRUK
44	Paslanmaz Çelik Matrisli Fonksiyonel Derecelendirilmiş Malzeme Üretimi ve Karakterizasyonu	Batuhan OZUSTA
69	Nokta Direnç Kaynaklı Çift Fazlı Çeliklerin Genliğe Bağlı Yorulma Ömürlerinin Karşılaştırılması	Muhammed ELITAS

Parallel Session – Room : Wustite -- 06.04.2019 – (09:00 – 10:30)		
Paper ID	Title	Speaker
83	A Theoretical Study On The Total Cross Sections Of The Natural Iron Isotopes	Necla ÇAKMAK
131	Some nuclear and magnetic properties of Fe-Co and Co-Ni alloys	Necla ÇAKMAK
77	Experimental Investigation of The Effect Of Different Cutting Parameters On Surface Roughness Values in Laser Cutting Processes of AISI 304 Stainless Steel	Ahmet Serdar GULDIBI
109	Chip Formation in Orthogonal Cutting of Corrax PH Steel	Ahmet Serdar GULDIBI
188	Evaluation Of The Cost And Profitability Performance By Topsis Method: A Case Of Iron Steel Company	Ömer KARAKAYA

Parallel Session – Room : Limonite -- 06.04.2019 – (09:00 – 10:30)		
Paper ID	Title	Speaker
71	The Relationship of the Force Effect with the Effect of Current on Weld Quality in Resistance Spot Welding	Abdulkarim ALZAHOUGI
95	Tarımsal Alanda Çapa Olarak Kullanılan 5630 Kalite Çeliğinin Şiddetli Abrasif Aşınma Davranışına Isıl İşlemlerin Etkisi	Sefik TUGAN
209	Machinability of AISI 304 Austenitic Stainless Steel with Abrasive Water Jet Process	Huseyin ÇETİN
190	Texturing Methods for Cold Mill Work Rolls	Bilal ÇOLAK
133	Improvement Of Industrial Extraction In The Steel Production Process	Halil İbrahim EMİROĞLU
135	The Effect Of Bof Gas On Id Fan Abrasion Among The Base Oxygen Furnace (BOF)	Halil İbrahim EMİROĞLU

Parallel Session – Room : Hematite – 06.04.2019 – (09:00 – 10:30)		
Paper ID	Title	Speaker
70	Çift-Fazlı Çelik Nokta Kaynaklı Birleştirmelerinin; %3,5 NaCl Ortamındaki Yorulma Dayanımlarının İncelenmesi	Mustafa GOKTAS
130	The Effect Of Heat Treatment On Microstructure And Mechanical Properties In Dual Phase Steels	Burak BARUTÇUOĞLU
100	Investigations on Austenite Grain Growth in Bainitic Forging Steels	Sibel UN
76	Yüksek Kromlu Dökme Çeliklerin Korozyon Davranışına Korozif Ortamin Etkisi	Mustafa Ali KUCUK
85	The Investigation of Tribological Behaviour Fe Matrix Hybrid Composites by Powder Metallurgy	Fatih AYDIN
203	Effect of Termite Welding Process on residual stress and wear behavior of R260 quality rail	Mustafa DURSUNLAR

SESSION 5

Parallel Session – Room : Conference Hall – 06.04.2019 – (11:00 – 12:30)		
Paper ID	Title	Speaker
61	ER7 Kalite Tren Tekerin Şiddetli Abrasif Aşınma Davranışına Isıl İşlemin Etkisi	Burcu CETINTAS
157	Diş Telinin Yalın Eğmeli Test Metoduyla Yorulma Davranışına Korozif Ortamin Etkisi	Rahma SHAABAN
158	Finite Element Modelling of Cutting Forces in Hard Turning of AISI 52100 Steel	Mehmet Erdi KORKMAZ
214	Surface roughness optimization and modeling of finishing operation for hardened X40CrMoV51 steel with ceramic tool	Mehmet Erdi KORKMAZ
161	0,5 C'lu Çeliğe Gaz Nitrasyon İşleminin Aşınma Davranışına Etkisi	Yusuf GÖKALP
216	Investigation of wear and microstructure properties of 21CrNi5 steel with different boron content	Cemal ÇARBOĞA
105	A comparative study on Wear Properties of Fe-Graphite and Fe-Graphene composites	Salih BEKTAS

Parallel Session – Room : Magnetite -- 06.04.2019 – (11:00 – 12:30)		
Paper ID	Title	Speaker
5	Demir Çelik ve Enerji Verimliliğinde Haddehanelerde Sanayi Etüdü Uygulaması	Yaşar YETİSKEN
208	Effects of Boron Addition on Microstructure and Tribocorrosion Behavior of 4140 Steel	Tayfun AKSOY
179	Yay Çeliklerinin Isıl İşlemi	Esmâ KESKİN
180	Yay Çelikliğinin Dönel Eğmeli Yorulma Davranışına Üretim Yönteminin Etkisi	Esmâ KESKİN
215	The Effect of Different Cooling Parameters on Fatigue Strength of 1040 Steel after Heat Treatment	Salih BEKTAS
228	Difficulties in The KIC Analysis of Materials With High Fracture Toughness	Fazıl HUSEM
229	FCG Analysis According to ASTM E647 and BS ISO 12108	Fazıl HUSEM

Parallel Session – Room : Wustite – 06.04.2019 – (11:00 – 12:30)		
Paper ID	Title	Speaker
14	Design and Manufacturing of a Cost-effective In-house Charpy Impact Tester Implemented with Arduino	Gorkem UNLU
184	Modeling Of Structural Transformations In The Additive Process Of 3d Construction	V.A. KOSTIN
185	Evaluation of high strength steel fatigue	V.I. BOLSHAKOV
201	Investigation of Drillability for Ferritic Stainless Steel with Uncoated Carbide Drill	Tolga MERAL
129	The Relationship Between Steel Production And Accredited Laboratory	Betül USTA
132	A Case Study: Investigation of the Contribution of Accredited Laboratories on the Iron&Steel Sector in Turkey	Alper İNCESU
164	Development of Certified Reference Material for Tensile Test Method in Metallic Materials	Engin ÇEVİK

Parallel Session – Room : Limonite – 06.04.2019 – (11:00 – 12:30)		
Paper ID	Title	Speaker
90	Determination of Life of Steel Pipes Used in Thermal Power Plants	Bunyamin CICEK
91	Hardness distribution in P91 steels after welding process and PWHT	Bunyamin CICEK
32	The Effect of Al ₂ O ₃ on Microstructure and Hardness Properties of Fe-C Alloy Composites	Mehmet Akif ERDEN
33	Effect of SiC Amount on the Hardness Properties of Fe Matrix SiC Reinforced Composites	Mehmet Akif ERDEN
206	The Effect of Powder / Ball Ratio on Mechanical Properties of Non-Alloyed Powder Metal Steels in Mechanical Alloying	Mehmet Akif ERDEN
207	The Effect of Alloying Time on The Tensile Strength of Unalloyed Steels In Mechanical Alloying	Mehmet Akif ERDEN
172	Investigation of boron nitride (BN) on tribological behavior of iron matrix composite produced by semi powder method	Muhammet Emre TURAN

Parallel Session – Room : Hematite – 06.04.2019 – (11:00 – 12:30)		
Paper ID	Title	Speaker
67	İş Makinesi Tırnaklarının Şiddetli Abrasif Aşınma Davranışlarına Isıl İşlemin Etkisi	Cemal OZGENC
110	Evaluation of Residual Stress Formation for ST37 Steels After Hot Rolling Process	Neslihan AKGUL
189	Investigation of Corrosion Behavior of Hot-Rolled Carbon Steel against Dimethylformamide	Yasin AKGÜL
221	Experimental Studies on the Microstructure and Hardness of Laser Surface Hardening of Low Alloy	Harun ÇUĞ
222	Effect of Laser Surface Hardening on the Microstructure and Hardness of AISI 8620 Steel	Harun ÇUĞ
223	Investigation of the Adhesion of Different Al ₂ O ₃ Powders Coated with EN 10130 steel by CMT Technique	Harun ÇUĞ
224	The Effect of Hardening Conditions on Microstructure and Hardness of EN 21NiCrMo ₂ Steel	Harun ÇUĞ

POSTER PRESENTATIONS

Location : Poster Hall - 04.04.2019 - (14:00 – 16:00)		
Paper ID	Title	Presenter
19	A Composite Surface Layer Produced with Semi-Centrifugal Casting	Serdar Osman YILMAZ
51	Estimation of Sulfur Content of Pig Iron via Basicity Elements in Blast Furnace Slag	Orhan ORUÇ
55	Distribution Of Products In ISDEMIR According To The Usage Areas And Customer Expectations	Muhammet BILEN
56	MPC (Manufacturing Practice Code) In Iskenderun Iron And Steel Works (ISDEMIR)	Muhammet BILEN
62	Study of the Effect of Deformation and Heat Treatment on the Features of the Microstructure of Steel Grade EAIN	Oleksandr BABACHENKO
96	Modeling of the Coke Quality Parameters CRI, CSR, Stability and Hardness Values from Chemical and Ash Component Analysis Results of Metallurgical Coke.	Can ERARSLAN
119	Characterization of Oily Sludge From Pipe Production Line	Samet BALLI
149	Automation Controlled Production In Rolling Mill	Metehan BACAKSIZ
187	Visual Testing Of Single-Bead Weldings	Yavuz Selin CERAN
210	Analysis of Corporate Social Responsibility Perception In Terms Of Demographic Values: A Sample Of Steel Sector	Buket ACAR

Evaluation of High Strength Steel Fatigue

V. I. Bolshakov*, V. M. Volchuk*, O. F. Parhomenko*

**Department of Materials Science,
Pridniprovsk State Academy of Civil Engineering and Architecture
24-a, Chernyshevskogo str., Dnipro, 49600, Ukraine
bolshakov@mail.pgasa.dp.ua
volchuky@gmail.com
helenaparkhomenko@mail.ru*

Abstract. Reviewed the possibility of high strength construction steel fatigue evaluation based on analysis of dislocation steel martensite structure tempering after quenching in water and tempering at 650 °C (1 hour). The degree of influence of the dislocation mechanism of destruction depending on the number of test cycles, expressed in terms of the sensitivity of cyclic stress to the fractal dimension of dislocations, is established. Experimentally established, that sensitivity of dislocation to fractal dimension is decreases with increasing number of test cycles, leading to an increase in the number of dislocations to a critical value after which the sample is destroyed. A model of predicting steel fatigue indices 14X2ГMP was obtained, which allows the use of the fractal approach in assessing the fatigue of high-strength steels with a higher dislocation density.

Keywords. high strength steel, cyclic tension, dislocation, substructure, martensite, theory of fractals.

I. INTRODUCTION

One of the most important goal of materials science is preservation of metal strength under cyclic loading. A significant number of studies are devoted to the influence of various technological and operational factors on the fatigue characteristics of materials (see, for example, [1]). The study of fatigue fracture processes is extremely important in connection with the tightening of temperature and force modes of operation of machines and structures for various purposes, as well as the use of high-strength materials. The stronger the material, the more localized the degree of localization of the effects of fatigue. Fatigue reflects the process of gradual accumulation of damage to the material under investigation under the action of variable (often cyclic) stresses, leading to a change in its structure and properties due to the formation and development of cracks in the zone of maximum stresses, which in turn causes the material to fail during operation [1]. Fracture surfaces have a rugged irregular structure that reflects the dynamics of the destruction process. At the same time, despite the apparent randomness of the surfaces of destruction of solids, they have the property of fractals – self-similarity at the micro-, meso- and macroscopic levels [2]. For example, the fractal nature of the macro level: a fatigue crack was considered in [3]; relief strips on the surface of an aluminum single crystal $\langle 001 \rangle \{100\}$ with cyclic stretching of a sample made of aluminum alloy (type D16) associated with a single crystal [4]. At the meso-level, recorded using optical microscopy, grain structures have

fractal properties [5 and others]. The complexity of identifying the structure of tempered and tempered steels at the micro level is due to the diversity of the geometric shape of their elements (former austenitic grain, martensite package, martensite lath, subgrain within the lath), and high density of particles of the precipitated phase [6].

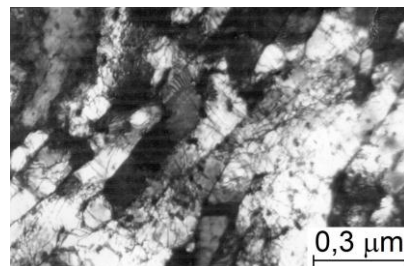
II. FORMULATION OF THE PROBLEM

Microlevel is particularly sensitive to the effects of cyclic loading, where crystal structure defects (dislocations, disclinations, point defects), whose mechanism of influence on these characteristics is not fully understood, make a significant contribution to the strength characteristics of the metal. Recording the number of dislocations in high-strength steels is difficult to implement due to the high concentration of dislocation loops, especially after cyclic deformation [1]. In this regard, there is the task of assessing the cyclic strength (fatigue) of high-strength construction steel on the basis of an analysis of its dislocation structure, since, as noted in [1], [7], the basis of fatigue failure of a metal is the dislocation mechanism of microscopic crack formation.

III. MATERIALS AND METHODS OF INVESTIGATION

To accomplish the task, steel 14X2ГMP (0,14% C; 0,25% Si; 1,04% Mn; 0,03% P, % S; 0,45% Cr; 0,03% Ni) was selected, the samples of which subjected to heat treatment: quenching in water and tempering at 650°C (1 hour). As a result of heat treatment, a metal with a surface layer consisting of tempering martensite was obtained.

Flat pieces with a size of 35×4×1mm for fatigue tests were made from blanks of size 70×15×2mm. Fatigue tests were carried out on a Schenk micropulsator under repeated stretching conditions ($\sigma_{\min} = 0 \pm 10,2$ MPa) with a maximum load of 200 kg and a loading frequency of 2800 Hz. The structure of steel 14X2ГMP is shown in Figure 1.



a

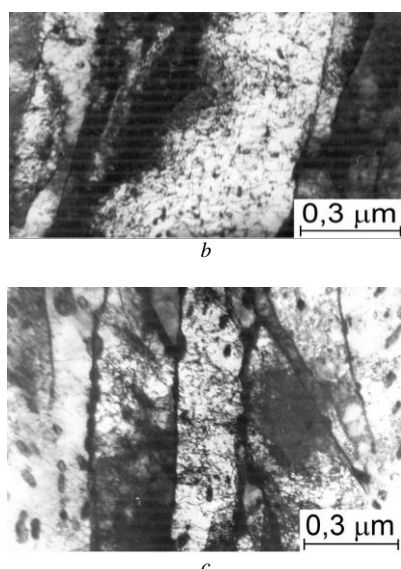


Fig. 1 The structure of tempered martensite after cyclic extension at the number of cycles $N = 3 \cdot 10^3$ (a); $N = 28 \cdot 10^3$ (b) and $N = 400 \cdot 10^3$ (c)

Registration of dislocation changes of hardened and tempered steels is proposed to be carried out using the theory of fractals [8], [9, etc.], which is due to the following factors:

- incompleteness of the formal axiom of structure identification [10] by traditional deterministic methods of approximation of its elements with a complex configuration, based on existing regulatory documents;

- identified at various scale levels by structural transformations of metals, occurring after repeated changes in their stress state.

The fractal dimension of dislocations inside the rails of tempered martensite was calculated using the Hausdorff (1) formula [11] using the method developed in and tested on various steel grades, due to the limited possibilities of estimating the increased dislocation density using traditional metallographic methods.

$$D = -\lim_{\delta \rightarrow 0} \frac{\ln N(\delta)}{\ln \delta}, \quad (1)$$

where $N(\delta)$ is the number of cells of size δ that covered the object under study.

IV. EXPERIMENTS AND DISCUSSION

The steel structure analysis consisted of the following steps:

- calculation of the fractal dimension of the dislocation structure by the formula (1);

- calculation of the sensitivity of the cyclic voltage to the fractal dimension of dislocations by the formula (2) [12]:

$$K_i = |Y_i - Y_{i+1}| / |X_i - X_{i+1}|, \quad (2)$$

where X_i and X_{i+1} – are two numbers characterizing some quality of the metal from the set of its values; Y_i and Y_{i+1} – the corresponding numerical values of the fractal dimensions, obtained on the basis of studying a certain region $i = 1, \dots, n$ of this metal.

The structure of steel 14X2ГMP was studied on samples tested to failure at stresses much higher than the fatigue limit. At the same time, a relatively large difference was observed in the structure of the same sample at different distances from the site of destruction, which is probably due to the heterogeneity of plastic deformation and localization of the processes leading to destruction. Close to the fracture, there are all signs of noticeable plastic deformation: increased dislocation density, formation of dislocation clusters, fragmentation of martensite crystals, broadening of the boundaries of the rails surrounded by dislocations (Fig. 1a). At the third, and all the more so on the objects that follow in the order of distance from the fracture, the pattern of plastic deformation appears less frequently. The fractal nature of the dislocations of a deformed metal is confirmed [13].

Indicators of fractal dimensions of dislocations of samples subjected to cyclic tests at $28 \cdot 10^3$ times (Fig. 1b), compared with indicators at $N = 3 \cdot 10^3$ (Fig. 1a), increase from 1,149 to 1,216 due to an increase in their tortuosity. An increase in the number of test cycles leads to fatigue cracks, which are associated with the result of cyclic deformation of the crystal lattice, when the maximum stress value over the cycle period is able to lead to plastic shears. There is an intense increase in the number of dislocations and their movement, both in the forward and in the opposite direction.

The photograph of figure 1c shows the structure of the surface layers of the sample, which are deformed at the fatigue limit level: the distribution of dislocations in the ferritic matrix. Martensite rails are largely fragmented, very sinuous dislocations inside the rails form dense clusters. In the inner layers of the samples under this loading mode, such signs of increasing the degree of deformation were not observed. The fractal dimension of dislocations with increasing number of test cycles increases. So with an increase in the number of test cycles up to $400 \cdot 10^3$ times, the dimension of dislocations increased to 1.413. An analysis of the results of the conducted studies shows that, when the critical state of a polycrystalline sample is reached, the fractal dimension of dislocations can reach its threshold (in the $D \rightarrow 2$ plane). Similar results were recorded for the maximum indicators of the fractal dimension of the relief bands on the surface of a single crystal of an aluminum alloy sample upon reaching the critical state [4].

Figure 2 shows the histogram of the cyclic voltage sensitivity to the fractal dimension of dislocations, calculated according to (2).

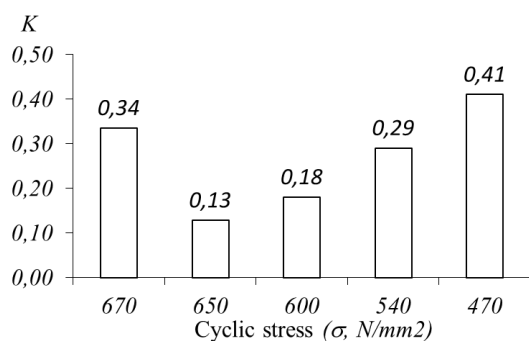


Fig. 1 The sensitivity of the cyclic extension to the fractal dimension of dislocations

The maximum sensitivity of the cyclic voltage to the fractal dimension of dislocations among the values under consideration was recorded at a voltage of 670 N/mm². The result obtained can be interpreted as a tendency to decrease the sensitivity between the considered values with an increase in the number of test cycles leading to a decrease in fatigue indices.

Based on the fractal analysis of the structure of the steel under study, a model (3) was obtained that displays the dependence of the cyclic voltage on the fractal dimension of dislocations and the number of test cycles. Changes in the density of dislocations, depending on the number of test cycles, lead to transformations of their features (for example, their geometric configuration), and as a result - to changes in their fractal dimension.

The latter probably indicates the possibility of using the numerical values of the fractal dimension of dislocations as an indicator of the substructural transformations of the metal associated with its loading (in this case cyclic).

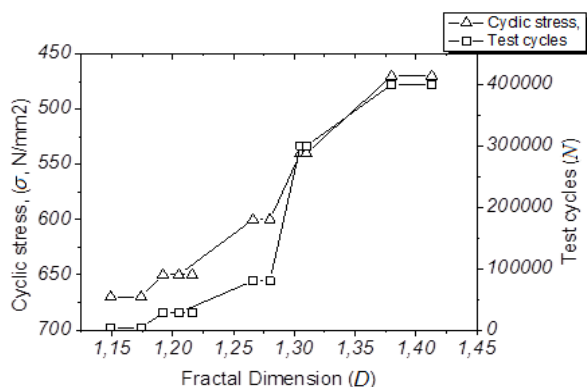


Fig. 2 Dependence of the cyclic stress on the fractal dimensionality of dislocations and the number of test cycles

The model of metal fatigue prediction is as follows:

$$\sigma = \frac{668,807 \cdot N^{0,055}}{D^{3,281}}, \quad r^2 = 0,88. \quad (3)$$

r – the coefficient of correlation of the model.

The power dependence $\sigma \sim D^{-x}$ is proposed to be interpreted as a display of cyclic stress, expressed in the fractal dimension of dislocations, the fractal nature of which is confirmed by their tortuous shape (see, for example [14]): $\rho \sim l^D$, where l^D is the dislocation length taking into account the tortuous shape).

V. CONCLUSIONS

We can use the method of high strength steel with high density of dislocations evaluation. It based on tempered martensite dislocations structure analysis, in the way of sensitivity grade establishment between this two characteristics. An increase of 1,2 times the fractal dimension of dislocations was registered due to an increase in the number of test cycles for 14X2ГМР steel samples from 3,000 to 400,000, leading to a decrease in cyclic stress from 670 to 470 N/mm². Results shows that fractal dimension can be an indicator of dislocation structure changes, in caused of cyclic extension.

REFERENCES

- [1] V. I. Bol'shakov, *Thermomechanical treatment of structural steels*, 3rd redone and added issue, Canada: Basilian Press: 1998 (in Russian).
- [2] B. B. Mandelbrot, *The Fractal Geometry of Nature*, 2nd prt. edition, New York, San Francisco, USA: Freeman, 1982.
- [3] V.K. Horváth, and H.J. Herrmann, "The fractal dimension of stress corrosion cracks", *Chaos, Solitons & Fractals*, vol. 1, issue 5, pp. 395–400, 1991.
- [4] Yu. Gordienko, R. G. Gontareva, J. S. Schreiber, E. E. Zasimchuk, and I.K. Zasimchuk, "Two-Dimensional Rectangular and Three Dimensional Rhombic Grids Created by Self-Organization of Random Nanoextrusions", *Adv. Eng. Mater.*, vol. 8, pp. 957–960, Oct. 2006.
- [5] V. I. Bol'shakov, and V. M. Volchuk, "Materials science aspects of using of wavelet-multifractal approach to an evaluation of structure and properties of low-carbon low-alloyed steels", *Metallofiz. Noveishie Tekhnol.*, vol. 33, pp. 347–360, Mar. 2011 (in Russian).
- [6] T. Gladman, and F. B. Pickering, *Flow and Fracture of Polycrystals*, Weinheim–New York–Basel–Cambride: VCH, 1983.
- [7] A. Kadic, and D. G. B. Edelen, *A Gauge Theory of Dislocations and Disclinations*, Berlin, Germany: Springer-Verlag, 1983.
- [8] V. M. Volchuk, "On the application of fractal formalism for ranging criteria of quality of multiparametric technologies", *Metallofiz. Noveishie Tekhnol.*, vol. 39, pp. 949–957, July 2017 (in Russian).
- [9] V. I. Bolshakov, V. M. Volchuk, and Yu. I. Dubrov, "Regularization of one conditionally ill-posed problem of extractive metallurgy", *Metallofiz. Noveishie Tekhnol.*, vol. 40, pp. 1165–1171, Sept. 2018.
- [10] K. Gödel, "Über formal unentscheidbare Sätze der Principia Mathematica und verwandter Systeme I", *Monatshefte für Mathematik und Physik*, vol. 38, pp. 173–198, Sept. 1931.
- [11] G. Hausdorff, "Dimension und auberes Mab", *Math. Ann.*, vol. 79, pp. 157–179, 1919.
- [12] V. Volchuk, I. Klymenko, S. Kroviakov, and M. Orešković, "Method of material quality estimation with usage of multifractal formalism", *Tehnički glasnik*, vol. 12, pp. 93–97, June 2018.
- [13] A. Vinogradov, I. S. Yashnikov, and Y. Estrin, "Evolution of Fractal Structures in Dislocation Ensembles during Plastic Deformation", *Phys. Rev. Lett.*, vol. 108, pp. 205504, May 2012.
- [14] V. Bolshakov, V. Volchuk, and Yu. Dubrov, *Fractals and properties of materials*, Saarbrucken, Germany: Lambert Academic Publishing, 2016.