MS&IA
Modern Steels & Iron Alloys
INTERNATIONAL CONFERENCE · WARSAW 2021

BOOK OF ABSTRACTS

Faculty of Production Engineering
WARSAW UNIVERSITY OF TECHNOLOGY

Faculty of Materials Science and Engineering
WARSAW UNIVERSITY OF TECHNOLOGY

ADVISORY BOARD

	Tuesday, 21 September 2021
$9^{30}\div9^{45}$	**Opening: Professor Tomasz Chmielewski** Dean of the *Faculty of Mechanical and Industrial Engineering* and **Professor Anna Boczkowska** – Vice-Dean of the *Faculty of Materials Science and Engineering*, Warsaw University of Technology
	Session I: Advanced Heat Treatments of Modern Steels ***Chairperson:* Professor Adam Grajcar**
$9^{45}\div10^{35}$	***Keynote lecture* – Dr. Francisca Caballero**: Advanced Heat Treatments and Hierarchical Structures for High Performance Steels
$10^{35}\div11^{00}$	**Sumit Ghosh**: In-situ characterization of various competing mechanisms operating during quenching and partitioning process
$11^{00}\div11^{15}$	BREAK
$11^{15}\div11^{40}$	**Carl Slater**, B. Bandi, P. Dastur and C. Davis: Rapid Alloy Processing to obtain a non-banded dual phase steel through compositional design and segregation control
$11^{40}\div12^{05}$	**Bharath Bandi**, C. Slater, D. Farrugia, C. Davis: Enhancement of ductility/strength balance in commercial dual-phase steels through industrially relevant composition changes using Rapid Alloy Processing approach
$12^{05}\div12^{20}$	**Pedram Dastur**, C. Slater, B. Bandi, C. Davis: Intercritical annealing optimisation and parameter sensitivities for dual phase steels
$12^{20}\div13^{40}$	LUNCH BREAK

	Session II: Nanostructured bainitic steels *Chairperson:* Dr. Francisca Caballero
13^{40}÷14^{30}	***Keynote lecture*** **-** **Dr. Carlos Garcia-Mateo**: Retained Austenite Destabilization during Tempering of Low-Temperature Bainite
14^{30}÷14^{55}	**Jarosław Marcisz**, B. Garbarz, T. Tomczak: Characterization of banded microstructure in nanobainitic steel containing 0.6%C and the consequences for mechanical properties
14^{55}÷15^{20}	**Pentti Kaikkonen**, M. Somani, A. Pohjonen, V. Javaheri, J. Kömi: Development of Processing Route For Low-Temperature Ausformed Ultrafine Bainitic Steels
15^{20}÷15^{40}	**Magdalena Bagrowska - Stalska**, K. Wasiak, W. Świątnicki: A new B-Q&P heat treatment shaping properties of carburised steel
15^{40}÷15^{55}	BREAK
	Session III: Industrial Heat Treatments ***Chairperson:* Professor Jarosław Marcisz**
15^{55}÷16^{20}	**Adam Gołaszewski**: Increasing the fatigue strength of steel gears through nanostructuring in high pressure quench furnaces
16^{20}÷16^{45}	**Piotr Pawluk**, S. Marciniak, M. Węsierska-Hinca, M. Kubicki, W. Świątnicki: Industrial austempering - effects of temperature heterogeneity during gas cooling on mechanical properties of hot work tool steel

Wednesday, 22 September 2021	
	Session IV:. Advanced High Strength Steels - New Achievements ***Chairperson:*** **Dr. Carlos Garcia-Mateo**
$9^{40} \div 10^{30}$	***Keynote lecture*** **-** **Professor Wolfgang Bleck**: New insights into the properties of high manganese steels
$10^{30} \div 10^{55}$	A. Kozłowska, **Adam Grajcar**, K. Radwański, W. Pakieła, J. Opara, P. Nuckowski: Microstructure and temperature-dependent mechanical behavior of hot-rolled TRIP-assisted microalloyed steel
$10^{55} \div 11^{10}$	BREAK
$11^{10} \div 11^{35}$	**Aleksandra Kozłowska**, A. Skowronek, M. Morawiec, A. Grajcar: Microstructure evolution and dilatometric study of Al-alloyed medium-manganese steel manufactured by double-step intercritical annealing process
$11^{35} \div 11^{50}$	**Adam Skowronek**, A. Grajcar, A. Kozłowska, M. Morawiec: Influence of intercritical annealing time on the microstructure and retained austenite fraction in 5%Mn lean medium-Mn steel
$11^{50} \div 12^{05}$	**Marcin Szczygieł**, G. Łukaszewicz, E. Skołek, K. Wasiak, M. Węsierska-Hinca, K. Chmielarz: Analysis of the possibility of producing a fine-crystalline multiphase microstructure consisting of martensite, bainite and austenite in X38CrMoV5-1 steel austempered below Ms.
$12^{05} \div 12^{20}$	**Łukasz. Szczepanek**, K. Wasiak, M. Węsierska-Hinca, E. Skołek: Effect of austempering treatment on the microstructure and mechanical properties of K360 tool steel
$12^{15} \div 13^{40}$	LUNCH BREAK

	Session V: Modern Cast Steels and Iron Alloys. ***Chairperson:* Professor Wolfgang Bleck**
13^{40}÷14^{15}	*Invited lecture -* **Professor Marcin Górny**, Ł. Gondek, G. Angella, E. Tyrała, M. Kawalec: Shaping the Structure and Properties of Austempered Ductile Iron
14^{15}÷14^{40}	**Dawid Myszka**: Surface properties of austempered ductile iron
14^{40}÷15^{05}	**Janusz Krawczyk**: Qualitative and quantitative analysis of the microstructure of stepped steel castings
15^{05}÷15^{20}	**Piotr Nawrocki**, E. Skołek, D. Myszka: Shaping the fine-grained microstructure of ductile iron in isothermal hardening processes
15^{20}÷15^{35}	BREAK
	Session VI: Surface Engineering of Steels and Iron Alloys ***Chairperson:* Professor Janusz Krawczyk**
15^{35}÷15^{50}	**Wojciech Pakieła**: Laser cladding of S235 steel with a mixture of carbide and tool steels powders to improve mechanical and tribological properties
15^{50}÷16^{05}	**Marcin Staszuk**: Investigations of nitride-oxide coatings obtained in the hybrid PVD/ALD process on 316L steel substrates
16^{05}÷16^{25}	**Monika Węsierska-Hinca**, K. Wasiak, E. Skołek, M. Tacikowski, W. Świątnicki: Modification of low-temperature bainite steel surface by nitriding process

Thursday, 23 September 2021	
	Session VII: Innovative methods of manufacturing of steels ***Chairperson:* Professor Marcin Górny**
9^{30}÷10^{05}	***Invited lecture*** - **Professor Massimo Pellizzari** F. Deirmina, S. Amirabdollahian, P. Bosetti, A. Molinari: Properties of tool steels fabricated by additive manufacturing
10^{05}÷10^{20}	J. Górka, **Tomasz Kik**, M. Burda: Attempts to modify austenitic steel with carbon nanotubes
10^{20}÷10^{45}	**Magdalena B. Jabłońska**, K. Kowalczyk, M. Tkocz, R. Chulist, K. Rodak, I. Bednarczyk: Ferritic Steel behaviour during SPD process
10^{45}÷11^{10}	**Mateusz Morawiec,** A. Kozłowska, A. Grajcar: Dependence of manganese content on the kinetics of phase transformation in intercritically treated medium-Mn alloys
11^{10}÷11^{25}	BREAK
	Session VIII: Welding of Advanced Steels ***Chairperson:* Professor Jacek Górka**
11^{25}÷12^{00}	***Invited lecture*** - **Aleksandra Królicka**, A. Żak, R. Kuziak, K. Radwański, A. Ambroziak: Decomposition mechanisms of bainitic rail in the critical Heat-Affected Zone of a flash-butt welded joints
12^{00}÷12^{25}	**Krzysztof Kwieciński**, M. Urzynicok, M. Węglowski: Electron Beam Welding of New Generation Martensitic Steel - THOR 115
12^{25}÷13^{40}	LUNCH BREAK

	Session IX: Computer modeling and machine learning methods in steel development ***Chairperson:* Professor Massimo Pellizzari**
13^{40}÷14^{15}	***Invited lecture –*** **Dr. Wangzhong Mu**, M. Rahaman, F. L. Rios, J. Odqvist, P. Hedström: Combination of machine learning and physical modelling to evaluate microstructure in steels: A case study to predict deformation induced martensite transformation in austenitic stainless steels
14^{15}÷14^{40}	**Grzegorz Łukaszewicz**: Machine learning meets steels - the latest trends
14^{40}÷14^{55}	**Anna Wojtacha**, M. Morawiec, M. Opiela: Effect of plastic deformation on the shape of CCT-diagram of new-developed steel for drop forgings
14^{55}÷15^{10}	**Krzysztof Chmielarz**, G. Łukaszewicz: Evaluation of bainitic transformation kinetics models for different steels
15^{10}÷15^{20}	**CLOSING**

Keynote and invited lectures

Session I: Advanced Heat Treatments of Modern Steels

Keynote lecture: "*Advanced Heat Treatments and Hierarchical Structures for High Performance Steels*"

Dr. Francisca Caballero

Department of Physical Metallurgy, National Center for Metallurgical Research (CENIM-CSIC), Madrid, Spain

Prof. Ms. Francisca G. Caballero is Research Professor at the Spanish National Centre for Metals Research (CENIM-CSIC). She obtained her Ph.D. in Physics from the Complutense University of Madrid in 1999 for studying solid-solid phase transformations in steels during reheating. From 1997 to 2000, she worked as a research associate at the University of Cambridge in UK with Prof. Bhadeshia on the design of carbide-free bainitic steels. She returned to CENIM with a Ramón y Cajal fellowship to work on advanced super-high strength steels. She was appointed Tenured Scientist in 2005, Senior Scientist in 2009 and Research Professor in 2018. Prof. Caballero's current research interests involve both applied and fundamental aspects of the design, processing and characterization of nanocrystalline steels.

Additionally, between September 2013 and October 2014 she has been the Deputy Director of Science at CENIM, and Vice-Rector for Postgraduate Studies and Research at Menendez Pelayo International University (UIMP) between October 2014 and December 2018. Since August 2018, she is Editor-in-Chief of the Encyclopedia of Materials: Metals and Alloys to be published by Elsevier Inc.

She has co-authored over 200 papers in international peer-reviewed journals and 3 licensed priority patents on advanced steels, and has held a visiting scientist position at the Oak Ridge National Laboratory in Oak Ridge-TN-USA since 2004.

In addition, Prof. Caballero is member of the Phase Transformation Committee of The Minerals, Metals and Materials Society (TMS) of USA, of the Board of Review of the journal Metallurgical and Materials Transactions A, and of the Editorial Board of the journals Materials Science and Technology and International Journal of Metals. Moreover, she is member of different Evaluation Committees including the H2020 Environment and Resources Program and the

Research Fund for Coal and Steel Program of the European Commission, and the Center for Nanophase Materials Sciences Program of Oak Ridge National Laboratory (USA).

Session II: Nanostructured bainitic steels

Keynote lecture: "*Retained Austenite Destabilization during Tempering of Low-Temperature Bainite*"

Dr. Carlos Garcia-Mateo

MATERALIA Research Group, Department of Physical Metallurgy, National Center for Metallurgical Research (CENIM-CSIC), Avenida Gregorio del Amo, 8, 28040 Madrid, Spain

Dr. Carlos Garcia-Mateo is Senior researcher at the Spanish National Centre for Metals Research (CENIM). He obtained his M.Sc. in Physics from the Complutense University of Madrid in 1995. Then he joined CEIT-TECNUM in San Sebastian, to work on solid-solid phase transformation and thermomechanical heat treatments of V-steels.

He gained his Ph.D. in 2000 at the University of Navarra, and his research was awarded with the Meritorious Award for Best Products and Forging Paper (October 26, 1999 at the 41st Mechanical Working and Steel Processing Conference in Baltimore, Maryland) and also with the Vanadium Award-Council of the Institute of Materials, Minerals and Mining-UK (2000).

Dr. Garcia-Mateo worked as a research associate at the University of Cambridge in UK from 2000 to 2003. He then joined CENIM in 2003 as a research associate, in 2004 he obtained a Ramón y Cajal fellowship to work on the design and development of advanced steels. Finally, he was appointed Tenured Scientist in 2007 and Senior Researcher in 2018. He has coauthored 5 books, over 140 papers in international peer-reviewed journals and 1 licensed priority patents on advanced nanostructured bainitic steels, which is his main research line.

He is an active member of different project evaluation panels (Poland, Romania, Spain) and editor of METALS and Materials (MPDI Group). He combines his research activity with that of supervising students (national and international), PhD, M.Phil., internships etc.

Session IV: Advanced High Strength Steels - New Achievements

Keynote lecture: "*New insights into the properties of high manganese steels*"

Professor Wolfgang Bleck

Steel Institute of RWTH Aachen University, Germany

Wolfgang Bleck has been the head of the Steel Institute at the RWTH Aachen University in Germany for 25 years. He received a Dipl.-Ing. degree and subsequently a Dr. -Ing. degree in physical metallurgy. He was affiliated with an industrial research department before he was appointed professor of ferrous metallurgy at the RWTH Aachen University, where he teaches materials science at the undergraduate and graduate levels, and participates in research activities on national and international level. He has supervised more than 100 PhD students, authored more than 250 publications and holds several patents.

Wolfgang Bleck also served as a member of the senate, as dean, and as vice-rector of the University. He has been initiator and spokesman of the collaborative research center „steel – ab initio". He served in the steering committee of the research cluster "production in high-wage countries". He holds an adjunct professorship in Korea and honorary professorships in China. He is a member of the scientific councils of a Russian and a Thai University. He served in several supervisory boards of industrial companies.

Wolfgang Bleck's research activities are the development and characterization of new steels, their processing and application as well as numerical modelling of material and component properties.

Session V: Modern Cast Steels and Iron Alloys.

Keynote lecture: "*Shaping the Structure and Properties of Austempered Ductile Iron*"

Professor Marcin Górny
AGH University of Science and Technology, Faculty of Foundry Engineering, Department of Cast Alloys and Composites Engineering, Reymonta St. 23, 30-065 Krakow, Poland

Marcin Górny, Professor, Dean of the Faculty of Foundry Engineering, AGH-University of Science and Technology, Krakow, Poland. His research activities are focused in the following areas: High quality ductile and compacted iron's; Solidification of ferrous and non-ferrous alloys; Thin wall castings. He has participated in more than 20 industrial and scientific projects. As a Principal investigator he leaded two research projects respecting innovative thin wall ductile and compacted graphite cast iron technology, and the influence of moulding sands thermodynamic properties on the solidification characterization. The author of numerous publications and two monographs "Refining of casting aluminum alloys – selected issues" and "Structure formation of ultra-thin wall ductile iron castings".

Session VII: Innovative methods of manufacturing of steels

Keynote lecture: "*Properties of tool steels fabricated by additive manufacturing*"

Professor Massimo Pellizzari
University of Trento, Department of Industrial Engineering, Via Sommarive 9, 38123 Trento, Italy

Massimo Pellizzari was born in 1970, in Bolzano, Italy and got his Master Degree in Materials Engineering in 1996 at the University of Trento. In 2000 he got a PhD in Metallurgical Engineering at the University of Padova. Since 2006 prof. Pellizzari is associate professor at the University of Trento. His research activity is mostly focused on production, heat treatment and surface engineering of steels, deep cryogenic treatment, properties of tool steels, special cast irons, development of powder metallurgical tool steel by ball milling and Spark Plasma Sintering and additive manufacturing. He is the author of more than 90 papers in peer reviewed international journals and 2 chapters in books (H-index:22, citations>1700 – Scopus). Since 2015, he's member of the executive committee of the International Federation for Heat Treatment and Surface Engineering (IFHTSE). Prof. Massimo Pellizzari is a member of the scientific committee of "La Metallurgia Italiana", of the editorial board of "International Journal of Microstructure and Materials Properties", of the Scientific Council of the Journal "Inzynieria Powierzchni" ("Surface Engineering"), Institute of Precision Mechanics (Poland), and of the editorial board of "Metals", published by MDPI.

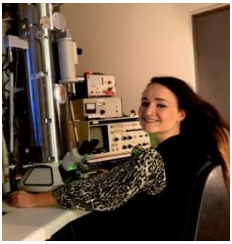
Prof Pellizzari is the Reference professor for the Master's Degree in Materials and Production Engineering and local coordinator of the EIT Raw Materials Master Program on Sustainable Materials (SUMA) and of the EIT RM Master Course on Circular Economy and Materials Processing.

Evaluator of research proposals for the Italian Ministry (MIUR) and, since 2016, for the Slovenian Research Agency (ARRS). Supervised 6 PhD thesis + 2 in progress. Current team: 1 post-doc, 2 PhD students (as main supervisor). Years of research experience: 22.

Session VIII: Welding of Advanced Steels

Keynote lecture: "*Decomposition mechanisms of bainitic rail in the critical Heat-Affected Zone of a flash-butt welded joints*"

Aleksandra Królicka
Department of Metal Forming, Welding and Metrology, Wroclaw University of Science and Technology, Wybrzeże Wyspiańskiego 27, 50-370 Wroclaw, Poland



Aleksandra Królicka is a Ph.D. student and research assistant at the Wrocław University of Science and Technology in Poland. Her doctoral dissertation concerns the welding processes of high-strength bainitic steels and is focused on an in-depth analysis of microstructural changes in heat-affected zones. She is a member of the electron microscopy laboratory. Aleksandra's field of scientific interest also includes heat treatment processes, nanoscale bainitic steels, fatigue performance, abrasive wear, fractography, grain growth analysis, the thermal stability of retained austenite in bainitic steels, as well as nano- and micro-scale materials characterization using TEM, SEM, EBSD methods. Currently, she is implementing a project Preludium 19 (National Science Centre in Poland) on the concept of novel grades of nanobainitic steel with improved thermal stability and weldability.

Session IX: Computer modelling and machine learning methods in steel development

Keynote lecture: "*Combination of machine learning and physical modelling to evaluate microstructure in steels: A case study to predict deformation induced martensite transformation in austenitic stainless steels*"

Dr. Wangzhong Mu

Department of Materials Science and Engineering, KTH Royal Institute of Technology, Brinellvägen 23, SE-100 44 Stockholm, Sweden

Dr. Wangzhong Mu is currently a permanent research scientist, teacher and leader of material thermal physical property at KTH Royal Institute of Technology, Department of Materials Science and Engineering, Unit of Structure. He got his PhD degree from KTH in 2015. Subsequently, he has worked as a Postdoc Fellow in McMaster University Steel Research Center (2015-2017), and a JSPS International Research fellow in Tohoku University, IMRAM (2019) prior to work in KTH. His research interest was focused on the following topics: (i) Correlation of processing, microstructure and property in advanced steels; (ii) Particles behavior during materials processing; (iii) Advanced material design by machine learning and physical modelling; (iv) Deformation of metals: characterization and modelling; (v) Recycling of industrial waste materials. To sum up, his research prefers to the fundamental study but within a background of industrial application.

Dr. Mu has been worked as PI and Co-PI for 14 national and international research grants with comprehensive topics. So far, he has published 53 papers in the peer-reviewed international journals, e.g. J. Amer. Ceram. Soc., Metall. Mater. Trans. A/B, Mater. Deg., Mater. Sci. Eng. A, J. Alloy Comp., Ceram. Int., etc. Also he has been give over 40 times key note, and oral presentations in international conferences/seminars. He has been served as the session organizer, organization committee, etc. in a few conferences including TMS2020-2022, IPES2020, CSSCR2016, etc. Furthermore, he has served as guest editor/member of youth editor team in seven peer-reviewed international journals, e.g. Frontiers in Mater., Crystals, Smart Mater., Rare Metals, J. Iron Steel Res. Int., etc. In addition, he has obtained a few research awards, e.g. First prize for Natural Science Academic Achievements in Liaoning Province, China.

ABSTRACTS

Tuesday, 21 September 2021 9:45-10:35

Dr. Francisca Caballero

Department of Physical Metallurgy, National Center for Metallurgical Research (CENIM-CSIC), Madrid, Spain

Advanced Heat Treatments and Hierarchical Structures for High Performance Steels

Nowadays, different treatments are considered to achieve complex ferritic structures with a controlled retained austenite volume fraction that improves the Transformation-Induced-Plasticity (TRIP) effect and the work-hardening of high strength structures. Among these heat treatments, austempering, quench and partitioning (Q&P) and quench and tempering (Q&T) are widely used to produce complex steels containing different mixtures of martensite (fresh and/or tempered), bainitic ferrite and retained austenite, with a desirable combination of strength, ductility, and toughness. In this work, structures obtained by different heat treatments are investigated by multiple techniques (XRD, EBSD, SEM, TEM and APT) revealing that analogous lath-like ferritic structures with similar austenite content can be achieved by adjusting the isothermal holding temperature. However, certain differences in hardness are observed, which are consistent with differences on the precipitation state, and with the crystallographic size distribution of ferritic grains.

Tuesday, 21 September 2021 10:35 – 11:00

Sumit Ghosh[1] Khushboo Rakha[2], Shahriar Reza, Mahesh Somani[1], Jukka Kömi[1]

1 Materials and Mechanical Engineering, Centre for Advanced Steels Research, University of Oulu, Oulu 90014, Finland
2 Department of Metallurgical and Materials Engineering, Indian Institute of Technology Ropar, Rupnagar 140001, Punjab, India

In-situ characterization of various competing mechanisms operating during quenching and partitioning process

Quenching and partitioning (Q&P) processing of steels has attracted enormous interest worldwide due to its potential in imparting an excellent combination of mechanical properties including high/ultrahigh strength, adequate low temperature toughness, improved uniform and total elongations and high strain hardening capacity. Besides the core mechanism of carbon partitioning from supersaturated martensite to untransformed austenite, several microstructural mechanisms do operate during the Q&P process either in parallel or in succession and are not yet fully understood. In this study, an in situ discernment of various mechanisms operating during the Q&P processing of 0.4 wt.% C steels with varying Si contents (0.25-1.5 wt.%) has been carried out using dilatometric analysis combined with detailed microstructural characterization to identify and confirm the occurrence of various mechanisms including phase transformations and formation of carbides at low temperatures. It was found that the steel with low Si content (0.25 wt.%) exhibited substantial bainitic transformation alongside carbon partitioning and only a small fraction (~ 4 %) of austenite was retained at room temperature. In contrast, a high Si content (1.5 wt.%) in the steel enabled stabilization and retention of a high austenite fraction (~ 18 %) under similar Q&P conditions. Carbide precipitation resulted mainly from tempering of martensite and also partial decomposition of the carbon-enriched austenite. Transmission electron microscopy (TEM) revealed presence of η-carbides (Fe2C) and θ-cementite (Fe3C) precipitated in the high and low-Si variants, respectively, following partitioning under similar conditions (quenched to 150 °C and partitioned for 1000 s in the temperature range 200–300 °C). Further, 3D Atom probe tomography (APT) was employed to study the carbon redistribution after Q&P treatment. Apart from carbides, segregation of carbon clusters in martensite lath boundaries has been observed through APT analysis. Furthermore, an attempt has been made to detect and understand the nature

of possible formation of a metastable, hexagonal □-phase within the boundaries of nano-twinned high carbon martensite.

Keywords: Quenched and partitioned steel; Dilatometric analysis; Bainitic transformation; Carbide precipitation; Atom probe tomography; Omega phase

Tuesday, 21 September 2021 11:15 – 11:40

Carl Slater, Bharath Bandi, Pedram Dastur, Claire Davis

Warwick Manufacturing Group (WMG), University of Warwick, Coventry, CV4 7AL, UK

Rapid Alloy Processing to obtain a non-banded dual phase steel through compositional design and segregation control

Dual phase (DP) steels are important grades for the automotive industry due to their excellent strength/ductility ratio, ease of processing and relatively low cost. These advanced high strength steels (AHSS) have a two-phase structure (typically ferrite and martensite) with various second phase fractions (through changes in composition and final annealing process conditions) depending on the application requirements. Due to the slab casting and subsequent hot and cold rolling DP steels typically show characteristic banding of the second phase martensite distribution that is located in the solute rich regions, caused by segregation on solidification and subsequent deformation. This banding affects the mechanical properties, giving anisotropic behaviour and is detrimental to out of plane bending, such as hole expansion or complex sheet forming.

Through a combination of phase field simulation, alloy design then subsequent experimental verification using lab casting, hot and cold rolling and final annealing a new DP alloy has been designed that does not have a final product banded structure. The aim of the alloy design is to minimise segregation effect, which in conventional DP steels is dominated by Mn segregation, by reducing the Mn content and counteracting the austenite stabilising segregated Mn distribution with co-segregating ferrite stabilisers. This results in austenite forming preferentially on ferrite triple points rather than the solute rich regions during the final annealing stage. The experimental results show that the final microstructure does not have a banded second phase distribution. Consideration of solid-solution strengthening was also included in the alloy design process in order to ensure the strength of the new alloy matched that of the conventional DP material.

Tuesday, 21 September 2021 11:40 – 12:05

Bharath Bandi[1], Carl Slater[1], Didier Farrugia[2], Claire Davis[1]

1 Warwick Manufacturing Group (WMG), University of Warwick, Coventry, CV4 7AL, UK
2 Rolling Finishing & Measurement Department, Tata Steel Europe, Warwick, UK

Enhancement of ductility/strength balance in commercial dual-phase steels through industrially relevant composition changes using Rapid Alloy Processing approach

Dual phase (DP) steels are extensively used as structural and safety components in the automotive industry, due to their excellent combination of strength and ductility. The composite like microstructure of soft ferrite phase and hard martensite islands give these steels low yield strength to tensile strength ratio, high strain hardening rate and good uniform elongation. The ductility/strength balance of these steels is highly dependent on the spatial distribution of the second phase and the strength difference between the different phases. Banded martensite morphology, and large strength differences between martensite phase and the ferrite phase are known to cause strain incompatibilities leading to premature failure, as well as giving anisotropy in the mechanical properties. Therefore, in this research work, a systematic study has been conducted using a Rapid Alloy Processing facility (RAP) to decrease the severity of the martensite banding and decrease the strength differences between the phases in conventional DP steel alloys. The RAP route involves the production of cast ingots (around 8kg), thermo-mechanically processing and annealing followed by mechanical property and microstructure characterisation. In this research work, RAP produced DP 800 steel has been benchmarked with respect to full scale commercial product to confirm upscalability and alloy / process modelling, and predictions have been made to propose DP variants (minor changes in composition and/or process parameters) with enhanced properties. This work reports on two composition changes, within the range constrained by current commercial production, of a) an increase in Nb content and decrease in Mn content to simultaneously refine the ferrite grain size and decrease martensite banding whilst not altering the hot rolled coil strength, which can affect cold rolling compatibility, and b) increase in vanadium content to promote precipitate hardening in the ferrite phase during intercritical annealing to simultaneously increase the ferrite individual strength, and reduce the strength difference with the martensite, and the overall strength of the steel.

Tuesday, 21 September 2021 12:05 – 12:20

Pedram Dastur, Carl Slater, Bharath Bandi, Claire Davis

Warwick Manufacturing Group (WMG), University of Warwick, Coventry, CV4 7AL, UK

Intercritical annealing optimisation and parameter sensitivities for dual phase steels

A new concept dual phase steel composition has been proposed to achieve a modified second phase distribution from a typical ‘banded’ to a ‘random’ structure. The modified composition involves using a lower Mn content, which is an austenite stabilising element and segregates to the interdendritic region on solidification, and higher Si content, which is a ferrite stabiliser and also segregates to the interdendritic regions. These compositional changes affect the critical temperatures during intercritical annealing that are required to obtain the desired second phase fraction. In order to determine the sensitivity, and hence optimisation, of the intercritical annealing parameters a systematic study has been carried out for both a commercial composition DP steel and the modified alloy. Different cold rolling reductions prior to annealing have been considered and the heating rate and peak temperature have been varied. A higher peak temperature is required during annealing for the modified alloy to achieve a comparable volume fraction of second phase to the commercial composition DP steel. Strong sensitivity to heating rate was seen in the commercial DP steel in terms of second phase volume fraction and spatial distribution, however, the modified alloy showed a much more consistent and predictable (based on Thermocalc TCFe10 equilibrium phase fraction calculations) volume fraction and consistently gave a little / no banding of the second phase in all conditions, whereas the commercial composition DP steel showed significant banding in the martensite distribution.

Tuesday, 21 September 2021 13:40 – 14:30

Dr. Carlos Garcia-Mateo

MATERALIA Research Group, Department of Physical Metallurgy, National Center for Metallurgical Research (CENIM-CSIC), Avenida Gregorio del Amo, 8, 28040 Madrid, Spain

Retained Austenite Destabilization during Tempering of Low-Temperature Bainite

The thermal stability of nanostructured microstructures consisting of a mixture of bainitic ferrite and carbon-enriched retained austenite has been studied in two steels containing 0.6 C (wt %) by tempering cycles of 1 h at temperatures ranging from 450 to 650 °C. Volume changes, contractions and/or expansions, due to microstructural transformations during thermal treatments were measured by high-resolution dilatometry. The correlation of these results with the detailed theoretical calculations by atomic volumes, microstructural characterization performed by X-ray diffraction and scanning electron microscope examination showed a sequence of different decomposition events beginning with the precipitation of very fine cementite particles. This precipitation, which starts in the austenite thin films and then continues in retained austenite blocks, decreases the carbon content in this phase so that fresh martensite can form from the low-carbon austenite on cooling to room temperature. In a subsequent tempering stage, the remaining austenite decomposes into ferrite and cementite, and due to carbide precipitation, the bainitic ferrite loses its tetragonality, its dislocation density is reduced, and the bainitic laths coarsen.

This is a collaborative work together with Robert Bosch GmbH and Ascometal Research (CREAS) under the auspicies of the EU Union (Research Fund for Coal and Steel, grant number RFCS-2016-754070).

Keywords: bainite, thermal stability, atomic volumes, tempering, X-ray diffraction

Tuesday, 21 September 2021 14:30 – 14:55

Jarosław Marcisz, Bogdan Garbarz, Tymoteusz Tomczak

Banded microstructure in nanobainitic steel containing 0.6%C and the consequences for physical and mechanical properties

Primary segregation of alloying and residual elements during solidification of steel causes formation of the banded microstructure, especially in the final long and flat products. Through the thickness of the plates there are sequentially distributed areas with different chemical composition and morphology of microstructure components. Changes in the content of elements in neighbouring segregated zones are not sharp, and the boundaries between them are characterized by an intermediate chemical composition between the maximum and minimum content of each segregating element. In particular, the differences in the content of elements affect Bs and Ms temperatures and the phase transformation kinetics. The material properties depend on the constituents of the microstructure which are critically prone to yielding or cracking under particular types of external load. Microcracks or local undesirable phenomena associated with the initiation of plastic deformation and/or phase transformation may preferentially form in areas of element segregation bands. Most methods of property measurements are carried out for a representative volume covering a large number of segregation bands. In fact, material at the microscale is composed of zones with different properties and the measurements result in averaged values taking into account the interactions at the borders between the zones. In nanobainitic steels the occurrence of primary segregation of a certain intensity, defined as a difference in the content of key alloying elements (Mo, Cr, Mn, and Si) and distance of surrounding bands, can lead to instability of mechanical properties, in particular to a decrease in ductility.

This paper presents an analysis of the microstructure heterogeneity resulting from primary segregation and its effect on the end-use properties of nanostructured bainitic steel. The characteristics of the banding resulting from the chemical composition of the steel and the manufacturing process, including casting, hot processing and final heat treatment, are described. Zones of material with different morphology of microstructure and hardness were found which corresponded to segregation zones. The directions of modifications of the process of manufacturing products from nanobainitic steels (in weight %, 0.55-0.60%C and 1.70-1.85%Mn, 1.60-1.75%Si, 1.40-1.50%Cr, 0.60-0.70%Mo) were indicated to reduce the influence of segregation and thus improve the homogeneity and properties of the material.

Tuesday, 21 September 2021 14:55 – 15:20

Pentti Kaikkonen, Mahesh Somani, Aarne Pohjonen, Vahid Javaheri and Jukka Kömi

Materials and Mechanical Engineering, Centre for Advanced Steels Research, University of Oulu, 90014 Oulun yliopisto, Finland; mahesh.somani@oulu.fi; aarne.pohjonen@oulu.fi; jukka.komi@oulu.fi

Development of Processing Route For Low-Temperature Ausformed Ultrafine Bainitic Steels

Physical and laboratory rolling simulations, combined with low temperature ausforming, were conducted on select high-silicon, medium carbon steels (with or without microalloying), in order to be able to design suitable cooling paths leading to phase transformation from austenite to ultrafine (~50-100 nm) bainitic plates. Not only the low temperature (500 °C) ausforming and subsequent cooling resulted in decomposition of austenite into ultrafine bainite, but also a significant fraction of finely divided austenite was retained in the final microstructures. Following ausforming, two different cooling and holding paths were attempted in the study: A) water cooling to a temperature close to martensite start (Ms) temperature (300 °C), followed by furnace holding for 60 or 90 minutes, depending on the carbon content of the steel, B) air cooling to 350 °C, followed by subsequent holding for 60 or 90 minutes. To unravel the effect of ausforming, a third sample was water quenched following hot rolling temperature directly to the isothermal holding temperature without ausforming at 500 °C and bainitized for a specified duration. Field emission scanning electron microscopy (FESEM) combined with electron backscatter diffraction (EBSD) as well as X-ray diffraction (XRD) were employed for microstructural analyses and correlations with the mechanical properties evaluated in respect of hardness, tensile and impact toughness properties. Results suggest that a multiphase bainite-martensite-austenite microstructure achieved via low temperature ausforming and subsequent air-cooling, was beneficial in respect of mechanical properties. The paper presents the salient features of the ultrafine (nanostructured) bainitic steels in respect of microstructures and properties, merits of low temperature ausforming, optimized bainitizing parameters and future work.

Keywords: Bainite, Ausforming, Thermo-Mechanical Processing, Ultrahigh strength, Martensite

Tuesday, 21 September 2021 15:20 – 15:40

Magdalena Bagrowska - Stalska, Krzysztof Wasiak, Wiesław Świątnicki

Faculty of Materials Science and Engineering, Warsaw University of Technology

A new B-Q&P heat treatment shaping propertiese of carburised steel

The aim of the study was to design a new type of heat treatment for 30NiMnCrSi6-4-4-4 steel after carburizing process. New heat treatment, named 2-steps (B-Q&P), consists of partial bainitizing (B), incomplete quenching (Q) and carbon partitioning (P). In the study the temperature and time of each step of the B-Q&P process was designed. The parameters of B-Q&P treatment were determined by dilatometric measurements of phase and microstructural transformations occurring in steel. Two-step B-Q&P process allowed to shape properties of the carburized layer and core of steel simultaneously. High hardness (> 60HRC) of the layer and high impact strength of steel core (KV > 27J at ambient temperature) was obtained. The properties of 30NiMnCrSi6-4-4-4 steel after 2-step B-Q&P heat treatment were compared with the properties of steel obtained after the conventional quenching and low tempering (Q&T) process.

Keywords: carburized layer, gradient structure, B-Q&P heat treatment, gears

Acknowledgements

This research work has been supported by Warsaw University of Technology and by a research project Nano4Gears (contract no. POIR.04.01.04-00-0064/15), financed by the National Centre for Research and Development.

Tuesday, 21 September 2021 15:55 – 16:20

Adam Gołaszewski[1], Szymon Marciniak[1], Wiesław Świątnicki[2], Waldemar Tuszyński[3], Andrzej Wieczorek[4]

1. NanoStal Sp. Z o.o.
2. Faculty of Materials Science and Engineering, Warsaw University of Technology
3. Łukasiewicz Research Network - Institute for Sustainable Technologies
4. Patentus S.A.

Increasing the fatigue strength of steel gears through nanostructuring in high pressure quench furnace

This paper has described the possibility of shaping the strength parameters of steel gears, in particular of their fatigue strength. The research consisted in scaling down the processes of bainite hardening which had been preceded by the carburizing processes in the high-pressure hardening furnaces.

The research was carried out as a part of the Nano4Gear project, within which the gear transmission of conveyor drive units was designed to work in extreme operating conditions. The main purpose of this project was to develop the heat treatment technology that could be commonly used in practice for the manufacturing of gears.

The research has shown that the use of carburizing and bainitic hardening processed used on gears lead to their increased fatigue strength in comparison to the currently used solutions

Tuesday, 21 September 2021 16:20 – 16:45

Piotr Pawluk[1,2], Szymon Marciniak[2], Monika Węsierska[2], Marek Kubicki[1], Wiesław Świątnicki[2]

1 WUZETEM S.A.
2 Warsaw University of Technology, Faculty of Materials Science

Industrial austempering - temperature heterogeneity during gas cooling and its effect on mechanical properties of hot work tool steel

In order to produce nanobainitic structure, industry scale vacuum furnace equipped with high pressure gas cooling system (nitrogen) was used to perform austempering processes of small parts (injector nozzles made of hot work tool steel) with different cooling rates. Temperature uniformity was monitored using nozzle-like covers on tips of thermocouples. After performing carbide precipitation segment – with or without low pressure gas nitriding – mechanical properties of samples were tested and compared to evaluate influence of temperature heterogeneity during gas cooling.

Keywords: temperature uniformity, gas cooling, austempering, nanobainite, nitriding

Wednesday, 22 September 2021 9:40 – 10:30

Wolfgang Bleck

Steel Institute of RWTH Aachen University, Germany

New insights into the properties of high manganese steel

The alloying element Manganese is used in virtually all steels for enabling hot formability, to increase hardenability or for solid solution strengthening. Optimizing the balance of conflictive mechanical properties like strength, toughness, fatigue, formability is the key issue of current steel and process development. Therefore, new steel design concepts use Manganese for stabilizing the fcc phase and for adjusting the stacking fault energy. By this, phenomena such as the TRIP, TWIP, or MBIP effects are triggered. Especially this interest in stress-controlled or strain-induced low temperature transformations of the austenite provides the basis for new steel groups like the Advanced High Strength Steels AHSS which are of prime interest for sheet metal forming but also for new forging steel concepts.

In medium and high Manganese alloyed steels, new alloying concepts and new complex temperature-time-cycles during annealing have been combined for developing nanostructured matrices. A specific feature of these new materials is that by element partitioning on the nm-scale local enrichments of Carbon but also of Manganese can lead to a complex interplay of phases and crystal defects providing a new promising field for future materials and process development. The strong interaction of alloying elements among themselves as well as with various crystal defects are regarded as major parameters for the control of mechanical properties. Thus, developing these new steels requires the use of latest analytical techniques, modern microstructural description methods, advanced simulation techniques, and thorough evaluation of the local and global mechanical behaviour.

The lecture will look at developments in the recent past and show possible areas of application for the newly developed steels. It will provide examples of steel and process design with a focus on sheet steels for automotive car body and forging steels for drive train applications. Conclusions about the importance of new design principles are drawn.

Wednesday, 22 September 2021 10:30 – 10:55

Aleksandra Kozłowska[1], Adam Grajcar[1], Krzysztof Radwański[2], Wojciech Pakieła[1], Jarosław Opara[2], Paweł Nuckowski[3]

1 Silesian University of Technology, Faculty of Mechanical Engineering, Materials Research Laboratory, 18a Konarskiego Street, 44-100 Gliwice, Poland
2 Łukasiewicz Research Network-Institute for Ferrous Metallurgy,
12-14 K. Miarki Street, 44-100 Gliwice, Poland
3 Silesian University of Technology, Faculty of Mechanical Engineering, Materials Research Laboratory, 18a Konarskiego Street, 44-100 Gliwice, Poland

Microstructure and temperature-dependent mechanical behavior of hot-rolled TRIP-assisted microalloyed steel

The effect of deformation temperature (in a temperature range -60°C-140°C) on the kinetics of strain-induced martensitic transformation in a hot-rolled multiphase Fe-0.24C-1.5Mn-0.87Si-0.4Al-Nb-Ti steel containing 15% of retained austenite was investigated. A complex microstructural analysis was performed using experimental techniques characterized by different resolutions: the scanning electron microscopy (SEM), electron backscatter diffraction (EBSD) and transmission electron microscopy (TEM). The analysis of the tendency of different morphology retained austenite to martensitic transformation was performed. The quantitative analysis of the temperature-dependent stability of g phase was carried out using the XRD and EBSD methods. Obtained results showed that both the deformation temperature and morphology of retained austenite affect substantially the stability of retained austenite. The role of thermally-activated processes above 100°C in the extent of the TRIP effect was characterized.

Keywords: TRIP steel, tensile deformation, microalloying, thermomechanical rolling, effect of temperature, retained austenite

Acknowledgements

The financial support of the National Science Center, Poland, is gratefully acknowledged, grant no. 2017/27/B/ST8/02864

Wednesday, 22 September 2021 11:10 – 11:35

Aleksandra Kozłowska[1], Adam Skowronek[1], Mateusz Morawiec[2], Adam Grajcar[1]

1 Silesian University of Technology, Faculty of Mechanical Engineering, Department of Engineering Materials and Biomaterials, 18a Konarskiego Street, 44-100 Gliwice, Poland
2 Silesian University of Technology, Faculty of Mechanical Engineering, Materials Research Laboratory, 18a Konarskiego Street, 44-100 Gliwice, Poland

Microstructure evolution and dilatometric study of Al-alloyed medium-manganese steel manufactured by double-step intercritical annealing process

Medium-Mn Transformation Induced Plasticity (TRIP) steels have received much attention due to their potential application as modern automotive sheets. These steels are ideally suited for lightweight automotive applications due to the combination of excellent mechanical properties and good formability, which are attributed to the transformation of metastable retained austenite into strain-induced martensite during forming. Typically, medium manganese steels are subjected to one-step intercritical annealing process leading to multiphase microstructures containing ultrafine-grained ferrite-austenite mixtures. Carbon and manganese partition into the austenite during intercritical annealing and as a result, a significant fraction of austenite is stabilized at room temperature (20-40 vol.%).

In the present study, the additional annealing step was applied in order to further increase mechanical properties of Al-alloyed medium-manganese sheet steels. The alloy containing 5% Mn was subjected to the double-step heat treatment performed in a dilatometer. The microstructure analysis of obtained samples was performed by means of light and scanning electron microscopy. The applied heat treatment allowed to replace some fraction of ferrite by athermal martensite, while a significant fraction of austenite was retained in the final microstructure. Experimental results showed, that the temperature of second soaking affects the final microstructure of investigated steel.

Wednesday, 22 September 2021 11:35 – 11:50

Adam Skowronek[1], Adam Grajcar[1], Aleksandra Kozłowska[1], Mateusz Morawiec[2]

1 Silesian University of Technology, Faculty of Mechanical Engineering, Department of Engineering Materials and Biomaterials, 18a Konarskiego Street, 44-100 Gliwice, Poland
2 Silesian University of Technology, Faculty of Mechanical Engineering, Materials Research Laboratory, 18a Konarskiego Street, 44-100 Gliwice, Poland

Influence of intercritical annealing time on the microstructure and retained austenite fraction in 5%Mn lean medium-Mn steel

The development of new-generations AHSS steels requires detailed processes of their heat-treatment optimizations. The properties of medium-Mn steels produced mainly by intercritical annealing depend on few crucial parameters. The main of them are: annealing time and temperature, cooling and heating rates, initial microstructure.

The present research concerns the effect of increasing intercritical annealing time (from 1 min to 300 min) on the microstructure evolution and retained austenite (RA) fraction. The selected temperature for the tests was 700 °C as the one providing the highest fraction of RA. The works aims to indicate whether short times of intercritical are enough to stabilize austenite sufficiently basing only on carbon and initially localized manganese or it is necessary to hold material for longer times enabling redistribution of manganese from ferritic grains.

The physical simulations of intercritical annealing were performed in terms of dilatometry using DIL805 device. The samples were subsequently subjected to XRD investigations as the optimal method for the determination of retained austenite in the microstructure. Scanning electron microscopy was performed to show microstructural features in detail. Light microscopy after nital and Klemm’s etching was performed to show the overall microstructure. The use of Klemm’s reagent enabled to distinguish the specific phases.

The microstructure analysis indicated a significant increase of retained austenite lath thickness with increasing the annealing time. The RA fraction at the beginning of the annealing increases due to the redistribution of chemical elements and establishment of thermodynamic equilibrium but at the longest times it starts to deteriorate.

Keywords: medium-Mn steel, intercritical annealing, dilatometry, retained austenite

Acknowledgments

Financed under the project POWR.03.05.00-00-Z305 implemented as part of the Operational Program Knowledge, Education and Development, co-financed by the European Union under the European Social Fund.

Wednesday, 22 September 2021 11:50 – 12:05

Marcin Szczygieł, Grzegorz Łukaszewicz, Emilia Skołek, Krzysztof Wasiak, Monika Węsierska – Hinca, Krzysztof Chmielarz

Warsaw University of Technology, Faculty of Materials Science and Engineering, ul. Wołoska 141, 02-507 Warsaw

Analysis of the possibility of creating a fine-crystalline multiphase microstructure consisting of martensite, bainite and austenite in X38CrMoV5-1 steel bainitised below Ms

This presentation focuses on the design process of heat treatment of X38CrMoV5-1 steel (known as W300), which belongs to the group of hot work tool steels and is commercially available. The purpose of the heat treatment is to obtain a multiphase microstructure containing martensitic and bainitic ferrite together with stable retained austenite. Experiments have been conducted to determine mechanical properties such as: hardness, impact strength, tensile strength, yield strength, total and uniform elongation. Values of mechanical properties were compared with the results obtained for the reference samples, which were subjected to the conventional heat treatment proposed by the steel manufacturer, consisting of quenching and triple tempering.

Keywords: bainitisation below Ms, X38CrMoV5-1 steel, nanobainite, prior martensite, mechanical properties

Wednesday, 22 September 2021 12:05 – 12:20

Łukasz Szczepanek, Krzysztof Wasiak, Monika Węsierska – Hinca, Emilia Skołek

Warsaw University of Technology, Faculty of Materials Science and Engineering, ul. Wołoska 141, 02-507 Warsaw

Effect of austempering treatment on the microstructure and mechanical properties of K360 tool steel

The aim of this work was to achieve acicular microstructure consisting of nanobainite, residual austenite and undissolved alloy carbides in K360 tool steel as a result of austempering heat treatment. The parameters of austempering heat treatment were chosen on the basis of phase transformation studies with the use of computer simulations and dilatometric tests. The morphology and phase composition of the microstructure were examined by LM, SEM, TEM and XRD analysis. Microscopic observations showed that austempering heat treatments of K360 tool steel lead to the formation of acicular microstructure composed of bainitic ferrite and retained austenite which is the matrix of carbides. In order to determine mechanical and performance properties of this microstructure the hardness, impact toughness and wear resistance tests were conducted. The results of the investigations were compared with results obtained after conventional quenching and tempering heat treatment.

Keywords: K360, nanobainite, tool steel, acicular ferrite

Wednesday, 22 September 2021 13:40– 14:15

M. Górny[1], Ł. Gondek[2], G. Angella[3], E. Tyrała[1], M. Kawalec[1]

1 AGH University of Science and Technology, Faculty of Foundry Engineering, Department of Cast Alloys and Composites Engineering, Reymonta St. 23, 30-065 Krakow, Poland
2 AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Department of Solid State Physics, Mickiewicza Av. 30, 30-059 Krakow, Poland
3 Research Institute CNR-ICMATE, via R. Cozzi 53, 20125, Milano, Italy

Shaping the Structure and Properties of Austempered Ductile Iron

This work deals with the influence of copper and nickel alloying and also heat treatment conditions on microstructure and mechanical properties of ADI (Austempered Ductile Iron) castings. Different techniques, namely OM, SEM, dilatometry, tensile properties, hardness as well as impact strength were used for investigations. In addition to that, XRD tests were carried out within a temperature range of up to +500°C, which provided information related to the phase participation, lattice parameters, internal stresses as well as with an expansion of the crystal lattice. Experiments were carried out for castings with a 25-mm-walled thickness and under different heat treatment conditions. It has been concluded that in order to attain a good combination of static and dynamic tensile properties of ADI, an optimum heat treatment conditions and amount of copper and nickel should be selected. This work also provide insight into the role of the microstructure and its homogeneity on the stability of ADI castings.

Acknowledgments

This work was supported by the Directorate General Cultural and Economic Promotion and Innovation, Italian Department of Foreign Affairs (Italy), and the Polish National Agency for Academic Exchange (PPN/BIL/2018/2/00106/U/00001).

Wednesday, 22 September 2021 14:15 – 14:40

Dawid Myszka

Warsaw University of Technology, Faculty of Mechanical and Industrial Engineering, ul. Narbutta 85, 02-524 Warsaw

Surface properties of austempered ductile iron

Austenite in austempered ductile iron is a crystalline phase which for years has attracted interest of researchers around the world. It can have both positive and negative effects on the properties of cast iron. On the one hand, austenite is identified with high plastic properties that it confers to cast iron, while on the other hand, it causes great problems with the machining of castings. An answer to the question what isa the real impact of this phase on the properties of austempered ductile iron should be looked for in the post-casting chemical and morphological heterogeneity of the microstructure and in the deformation-induced transformation of austenite. In this study, the analysis included the results of the work carried out in a number of research centres regarding mechanically unstable austenite and its transformation to martensite under the influence of various impacts like stress or strain. It is of particular importance in the technological processes to which the austempered ductile iron is subjected, including, for example, machining, the process of abrasion or shot peening. Then, in the ausferritic cast iron matrix, the phenomenon occurs which involves partial austenite transformation to martensite, called deformation-induced martensite. Its result is hardening of the material and changing of the cast iron magnetic properties. Numerous experimental results obtained by the author of the study confirmed those features and allowed an assessment of the impact of austenite on the properties of austempered ductile iron and the development of a technological method to determine the estimated share of mechanically unstable austenite in microstructure of this material.

Keywords: austempered ductile iron, austenite, transformation, deformation-induced martensite, surface engineering

Wednesday, 22 September 2021 14:40 – 15:05

Janusz Krawczyk

AGH University of Science and Technology, Faculty of Metals Engineering and Industrial Computer Science Department of Physical and Powder Metallurgy Leader of the Structural and Operational Analyzes Research Group Av. Mickiewicza 30, 30-059 Kraków, Poland

Qualitative and quantitative analysis of the microstructure of stepped steel castings

The qualitative and quantitative analysis of stepped castings of eight cast steels: G40MnSiCr7-6, G50MnSi6-6, G30NiCrMo13-5-3, G35MnSiNiMo8-6-4-3, G75SiMnNiMo8-7-4-4, GX20Cr15, GX3CrNiMnSiMo18-8, GX2CrNiMoMnSi18-11-2. These castings were characterized by the domination of the following structures: pearlitic (G40MnSiCr7-6, G50MnSi6-6), bainitic (G30NiCrMo13-5-3, G35MnSiNiMo8-6-4-3), martensitic (G75SiMnNiMo8-7-4r15, GX20Cr-415) and GX20Cr415. (GX3CrNiMnSiMo18-8, GX2CrNiMoMnSi18-11-2). The analysis concerned the influence of the casting wall thickness on the volume fraction of interdendritic spaces, dendrite morphology, grain size, crystallite size, the volume fraction of structural components, porosity and the volume fraction of non-metallic inclusions. The roles of the chemical composition and the casting process in the stepped molds in the obtained results are also presented. The microstructural differences of interdendritic spaces and areas (cores) of dendrites were characterized. The scope of the correlation between the various structural parameters of castings was indicated.

Keywords: cast steel, microstructure, dendrite, stepped castings, porosity

Wednesday, 22 September 2021 15:05 – 15:20

Piotr Nawrocki[1,2], Emilia Skołek[3], Dawid Myszka[2]

1 Łukasiewicz Research Network - Institute of Precision Mechanics, ul. Duchnicka 3, 01-796 Warsaw
2 Warsaw University of Technology, Faculty of Mechanical and Industrial Engineering, ul. Narbutta 85, 02-524 Warsaw
3 Warsaw University of Technology, Faculty of Materials Science and Engineering, ul. Wołoska 141, 02-507 Warsaw

Shaping the fine-grained microstructure of ductile iron in isothermal hardening processes

Austempered ductile iron has been an important engineering material in recent years due to its excellent combination of high mechanical properties, toughness and wear resistance. These combinations of properties are achieved thanks to the microstructure of lamellar ferrite and high carbon austenite. Refining of the ausferritic microstructure improves the mechanical properties of ADI, and the presence of austenite in the microstructure significantly increases the ductility of the material. The work focuses on the development of a ferritic-austenitic matrix with carbides (bainite) or without carbides precipitates (ausferrite) with a minimum grain size, ensuring good ductile and strength properties. Relations between microstructure and properties were determined. The research was carried out on cast iron with a designed chemical composition. Characteristic temperatures for cast iron were determined during dilatometric tests and with the use of JMatPro software (TTT diagrams). The obtained data made it possible to design the parameters of the heat treatment processes, in particular multi-step heat treatment. Ductile iron was subjected to a detailed microscopic analysis (LM, SEM, TEM) with image analysis (determination of the primary austenite grain size). The strength properties (Rm, R0,2, A5, HBW) were also determined. The obtained results indicate that the value of the intercritical heat treatment temperature and isothermal holding causes the refining of the matrix structure of the tested cast iron, even to the nanometric grain size. The differentiation of intercritical heat treatment temperatures causes changes in the mechanical properties of the tested cast iron. As a result of the research, it was found that the higher the intercritical temperature, the finer the microstructure was. By appropriate selection of heat treatment parameters, it is possible to shape the microstructure and the degree of its refinement, as well as the mechanical properties of ductile iron resulting from the differentiation of the microstructure in order to achieve the properties required for specific applications. The use of bainitic transformation and intercritical heat treatment allows for the refinement of the microstructure to the nanometric level and obtaining very good strength and ductile properties of the tested cast iron. Cast iron with such shaped microstructure can be a material intended for use in highly loaded elements of machine parts, e.g. gear wheels.

Keywords: ductile iron, microstructure, austempered ductile iron (ADI), strength properties, intercritical heat treatment, bainitic transformation.

Wednesday, 22 September 2021 15:35 – 15:50

Wojciech Pakieła

Department of Engineering Materials and Biomaterials, Silesian University of Technology, Konarskiego 18A, 44-100 Gliwice, Poland

Laser cladding of S235 steel with a mixture of carbide and tool steels powders to improve mechanical and tribological properties.

As a parent material, a popular steel S235 was used. It is a classic and relatively cheap structural steel used, among others, for elements of devices and machines such as bodies, shafts, gears and belt wheels, etc. However, due to the relatively low tribological resistance, its use is minimal. In this work, in order to improve the mechanical properties, laser surface cladding was used (LSC). LSC process was performed on fiber Ytterbium Laser System YLS-4000 with a wavelength of l = 1070nm. The maximum power of the laser beam was 4kW. The laser head was mounted on a 6-axis robot REIS RV30-26 coupled with a tilt-and-swivel positioning system. The process was conducted in a shielding gas atmosphere of argon. During cladding was applied the round laser spot with a diameter of 5mm and a power density of $12 \cdot 10^4$W/cm^2.

For cladding, a mixture of tool steel 1555-20 (TS) powder and boron carbide (B_4C) was used (a-1%; b-1.5%; c-2.5%). Results of powder mixing are presented in Fig 1. The powders were mixed in a planetary mill. A steel container and balls with a diameter of 10mm (15 pieces) were used during mixing.

The microstructure of the analyzed layer was examined by a light microscope Axio Observer Zeiss and a scanning electron microscope Zeiss Supra 35 (SE, BSE). Analysis of the chemical composition and phases occurring in the layer was carried out using a scattered X-ray detector and EBSD. Structures of the layers are shown in Fig. 2.

The surface hardness measurements were performed using a Rockwell test on HRC scale. Microhardness on the layer cross-section was measured by the Vickers microhardness test with a force of 100 gf. The wear resistance studies of the surface layer were performed using a ball-on-disk test. Test parameters are shown in Table 1. As a result of the LSC process, layers with a thickness of about 1500 μm were obtained. The hardness was respectively: TS – 45HRC; TS+1B_4C – 49HRC; TS+1.5%B_4C – 55HRC; TS+2.5%B_4C – 63HRC.

Table 1. The ball-on-disk wear test parameters

Load, N	Linear speed,	Distance, m	Radius, mm	Counter
15	15	1000	5	ball – ZrO_2

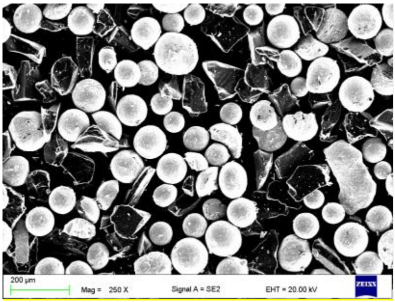


Fig. 1. The morphology of the powder used for LSC process (TS+2.5%B_4C)

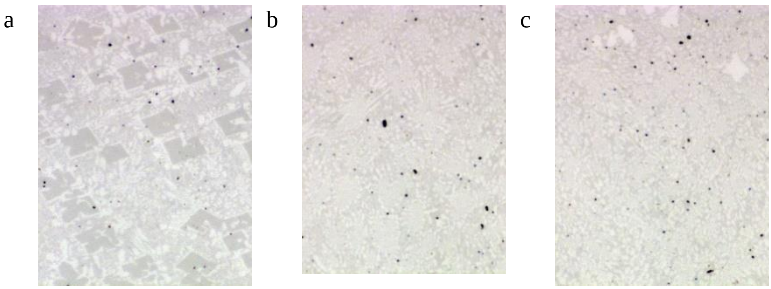


Fig. 2. Structures of the layers; a) TS+1B_4C; b) TS+1.5%B_4C; c) TS+2.5%B_4C

Wednesday, 22 September 2021 15:50 – 16:05

Marcin Staszuk

Investigations of nitride-oxide coatings obtained in the hybrid PVD/ALD process on 316L steel substrates

Titanium nitride TiN obtained by the PVD method is a coating material that has been used since the 1960s and is still widely used in industry to this day. TiN layers have high abrasion resistance, but corrosion resistance is limited due to the crystalline structure of the coatings, which is a characteristic feature of the PVD technique. The work aimed to investigate the effect of the parameters of obtaining a TiO2 layer using the ALD technique as a sealing layer for a TiN (PVD) coating in a hybrid PVD/ALD coating on a substrate made of austenitic 316L steel. TiO2 ALD layers deposited at a variable number of cycles in the range of 200-1000 cycles at a constant temperature of 200°C were tested. Structural studies were performed using SEM scanning electron microscopy and AFM atomic force microscopy. The analysis of the chemical composition in the micro-regions was performed using EDS spectroscopy. The study of electrochemical properties was performed with the use of potentiodynamic and electrochemical impedance spectroscopy (EIS) in a 3.5% NaCl solution. It was found that the best corrosion resistance is characteristic for hybrid TiN/TiO2 (PVD/ALD) coatings with titanium oxide deposited in 500 ALD cycles. The polarization resistance for this coating is Rpol=4,810 kΩ×cm2 and the corrosion current density icorr=825×10-12 A/cm2. For comparison, the corrosion resistance of single PVD (TiN) coatings is characterized by Rpol = 247 kΩ×cm2 and icorr=2,357×10-12 A/cm2, and the corrosion resistance of the uncoated substrate Rpol=338 kΩ×cm2 and icorr=2,853×10-12 A/cm2. The corrosion mechanisms were investigated based on the observation of the surface of the samples after corrosion tests in the SEM scanning electron microscope.

Wednesday, 22 September 2021 16:05 – 16:20

Monika Węsierska-Hinca, Krzysztof Wasiak, Emilia Skołek, Michał Tacikowski, Wiesław Świątnicki

Warsaw University of Technology, Faculty of Materials Science and Engineering, ul. Wołoska 141, 02-507 Warsaw

Modification of low-temperature bainite steel surface by nitriding process

Bainitic austempering has proven to provide superior properties of steels, such as enhanced toughness, fatigue resistance and strength and ductility synergy. While implementing to high carbon tool steel K360, it allows obtaining a new type of complex microstructure consisting of carbides in the nanocrystalline matrix. The presence of carbides prior to austempering step induced heterogeneous nucleation of bainitic ferrite plates and lead to the formation of acicular ferrite microstructure, that stands out due to its improved mechanical properties, especially fracture toughness.

However, for some applications the maximum surface properties possible to achieve in nanobainitic steels are not enough. Therefore the thermochemical surface treatments, that aim to augment hardness and wear resistance of steel are developed. In this study the nanostructured K360 steel was subjected to two types of the nitriding processes: plasma and gaseous nitriding at 4200C for 12h and 16h, respectively. It occurred that nitrogen-enriched samples show enhanced wear resistance by about 20%, whereas the surface microhardness exceeded 950 HV 0.05. The phase composition and morphology of phase constituents were determined by observations with the scanning electron microscope (SEM), accompanied by the XRD and magnetic measurements. The effect of the treatment temperature (4200C) on the microstructure and properties of the steel was studied as well.

Keywords: nitriding, nanobainite, surface treatment, wear

Thursday, 23 September 2021 9:30 – 10:05

M. Pellizzari[1], F. Deirmina[2], S. Amirabdollahian[1], P. Bosetti[1], A. Molinari[1]

1. University of Trento, Department of Industrial Engineering, Via Sommarive 9, 38123 Trento, Italy
2. Powder R&D, Sandvik Additive Manufacturing , Sandvik Machining Solutions AB, Mossvägen 10, 811 82, Sandviken, Sweden

Properties of tool steels fabricated by additive manufacturing

Tool steels can be efficiently produced by additive manufacturing techniques as Laser Powder Bed Fusion (LPBF) and Direct Energy Deposition (DED). The microstructure of as-built material is largely affected by rapid solidification: a very fine martensite is generally accompanied by a relatively larger amount of retained austenite, if compared to same steel grade fabricated by conventional methods. The microstructure keeps trace of additive manufacturing process even after heat treatment, which has to be properly designed to achieve the final desired properties. In this work the microstructure of H13 hot work tool steel produced by LPBF and DED will be discussed. The heat treatment behaviour will be investigated by means of dilatometric analysis, revealing the phase transformations during quenching and tempering. The thermal fatigue resistance of quenched and tempered steel will be compared to that after direct tempering. Some peculiar applications of tool steels in Functionally Graded Material (FGM) and in multi-materials structures fabricated by DED will be described.

Thursday, 23 September 2021 10:05– 10:20

Jacek Górka, Tomasz Kik, Marek Burda

Attempts to modify austenitic steel with carbon nanotubes

Abstract: In this work, research on influence of multiwalled carbon nanotubes (MWCNTs), produced in Catalic Chemical Carbon Vapor Deposition, NANOCYLTM NC7000CNTs on a structure and properties of AISI 301 steel remelted by TIG arc. In the assessment of influence a type of carbon on properties and structure of austenitic steel, as a carbon filler was use also carburizer. In the specimens (AISI 301 plates) with dimensions 155x60x7 [mm] were drilled holes with 1.3mm diameter and placed 0.5mm under specimen surface. Next, to the drilled holes was implemented CNTs, carburizer and mixture of these both powders. Prepared specimens were remelted by TIG method on the CASTOTIG 2200 power source with 2.4mm tungsten thoriated electrode with parameters sets for obtain 3.0mm penetration depth. Remelted specimens were cut into the half of the welds distance and prepared for metallographic examinations. Cross sections of the specimens were tested on classical metallography microscopes, hardness tests, SEM analyses (on JEOL 5800 LV SEM EDX equipment) and phase identification by X-ray phase analysis on Philips APD X'Pert PW 3020 diffractometer. Hardness analysis indicates about 25% increase of hardness in the remelted area when the CTNs are used. In the specimens with carburizer there is no significant changes. SEM analyses of remelted areas on AISI 301 specimens modificated with CNTs, indicates that dark areas, initially interpret as one of the phase (based on optical microscope) is finally densely packed bladders with dimensions from 50nm up to few μm. These bladders are not present in the specimens with carburizer filler. High resolution scanning microscopy allow to observe in the this area protruding, longitudinal particles with 100-300nm length. For identification of this phase, X-ray analysis was done. But very small dimensions of used CNTs (diameters about 9,5nm), random orientation and small weight amount can make difficult or impossible to CNTs detection during XRD tests. It means that it is not possible to clearly determine nature of particles filling the cavities, it is only possible to suppose that they are CNTs beams with nanoparticles comes from their disintegration. Results of the researches indicates, that fill in the weld pool with different form of carbon (CNTs and carburizer) it is possible to achieve remelted beads with different structure and hardness distribution. It confirms validity of the research continuation with CNTs as a modifier of steels and also other metals and theirs alloys.

Keywords: multiwalled carbon nanotubes, MWCNTs, carburizer, austenitic steel, TIG remelting, structure modification, hardness

Thursday, 23 September 2021 10:20 – 10:45

Magdalena B. Jabłońska, K. Kowalczyk, M. Tkocz, R. Chulist, K. Rodak, I. Bednarczyk

Ferritic Steel behaviour during SPD process

Thursday, 23 September 2021 10:45 – 11:10

Mateusz Morawiec[1], Aleksandra Kozłowska[2], Adam Grajcar[2]

1 Silesian University of Technology, Faculty of Mechanical Engineering, Materials Research Laboratory, 18a Konarskiego Street, 44-100 Gliwice, Poland
2 Silesian University of Technology, Faculty of Mechanical Engineering, Department of Engineering Materials and Biomaterials, 18a Konarskiego Street, 44-100 Gliwice, Poland

Dependence of manganese content on the kinetics of phase transformation in intercritically treated medium-Mn alloys

The study addresses the intercritical annealing process of multiphase medium-Mn sheet alloys for automotive industry. During the present work, monitoring a microstructure evolution including the retained austenite stability and resulting mechanical behavior after intercritically annealing of steels with different manganese contents of 3, 4 and 5% was conducted. The theoretical calculations and phase transformation simulations were carried out using JMatPro software to determine experimental parameters of heat treatment. The dilatometric analysis was made to determine critical temperatures of the steels and to investigate the austenite formation kinetics during the heat treatment process. Manganese, as the austenite stabilizer, influences the critical temperatures of the steel significantly. Microstructure analysis was performed using the light and scanning electron microscopy. The different heat treatments resulted in multiphase microstructures composed of lath-like ferrite, retained austenite and tempered martensite. Vickers hardness measurements were carried out to determine changes in mechanical responses of the materials.

Thursday, 23 September 2021 11:25 – 12:00

Aleksandra Królicka[1], Andrzej Żak[2], Roman Kuziak[3], Krzysztof Radwański[3], Andrzej Ambroziak[2]

1 Department of Metal Forming, Welding and Metrology, Wroclaw University of Science and Technology, Wybrzeże Wyspiańskiego 27, 50-370 Wroclaw, Poland
2 Electron Microscopy Laboratory, Faculty of Mechanical Engineering , Wroclaw University of Science and Technology, Wybrzeże Wyspiańskiego 27, 50-370 Wroclaw, Poland
3 Łukasiewicz Network Institute for Ferrous Metallurgy, K. Miarki 12-14, 44-100 Gliwice, Poland

Decomposition mechanisms of bainitic rail in the critical Heat-Affected Zone of a flash-butt welded joint

In recent years, the issue of the possibility of using bainitic steels in the railway industry is the subject of intensive research. Just in the past two years, many crucial investigations were published on the optimization of microstructure, wear resistance, contact and low-cycle fatigue performance, as well as analysis of welding processes. The mechanical properties of bainitic steels, compared to conventional ones, are promising and indicate the possibility of enhancing the durability of railway tracks, especially under heavy loads. However, some controversies and ambiguities in the evaluation of the advantage of bainitic rails over pearlitic rails have been noticeable.

The welding processes of bainitic rails are relatively poorly known. In the previous work, the authors analyzed the changes in the microstructure occurring in the flash-butt welded joint of low-carbon, continuous cooled bainitic steel. In this research, the mechanisms of austenite decomposition and bainite degradation occurring in the Low-Temperature Heat-Affected Zone (LTHAZ) of the welded joints of the bainitic rail were detailed determined. This zone was defined as critical in the context of the lowest hardness and adverse microstructure morphology. Moreover, the highest degree of microstructure degradation concerning the parent material was found. The LTHAZ is also called the softened zone which is the most crucial problem in the case of welded joints of high-strength steels. However, this research is focused on identifying complex degradation mechanisms and morphological changes using high-resolution transmission electron microscopy (HRTEM). New knowledge on microstructural changes in this zone may allow for future optimization of welding processes with the reduction of this adverse morphology. Due to the complex nature of decomposition mechanisms, this research will provide a better understanding of these processes and will complement previous considerations associated with bainite transformation.

Keywords: bainite, rails, HAZ, welding, retained austenite, austenite decomposition cementite, TEM study

Thursday, 23 September 2021 12:00 – 12:25

Krzysztof Kwieciński, Michał Urzynicok, Marek Węglowski

Electron Beam Welding of New Generation Martensitic Steel - THOR 115

Development of materials used in the power industry for ultra-supercritical (USC) boilers poses new challenges. The introduction of new alloying agents intended at obtaining the best possible mechanical properties, including creep resistance, affects the fabricability of new steel grades. Martensitic steels containing 9% Cr, used in the production of steam superheaters shall have good creep resistance and also high oxidation resistance at a temperature above 600°C. In turn, steels with a 12% Cr content, for example, VM12-SHC or X20CrMoV12-1 are characterized by significantly higher oxidation resistance but have lower strength at higher temperatures, which translates to their limited application in the production of modern USC and A-USC (advanced ultra-supercritical) boilers.

X20CrMoV12-1 was withdrawn from most of the power plants across Europe and VM12-SHC was supposed to replace it, but unfortunately, it failed in regards of creep properties. To fulfill the gap a new creep strength-enhanced ferritic steel for service in supercritical and ultra-supercritical boiler applications was developed by Tenaris and named Thor™115 (Tenaris High Oxidation Resistance). This publication covers the experience obtained during first steps of fabrication which includes cold bending and TIG welding of homogenous joints. The paper also presents the first results of welding Thor 115 steel using an electron beam. The results obtained suggest that this steel will perform well in future applications.

Thursday, 23 September 2021 13:40 – 14:15

Wangzhong Mu[1], Moshiour Rahaman[2], Felix L. Rios[2], Joakim Odqvist[1,2], and Peter Hedström[1,2]

1 Department of Materials Science and Engineering, KTH Royal Institute of Technology, Brinellvägen 23, SE-100 44 Stockholm, Sweden
2 Ferritico AB, Valhallavägen 79, SE-114 28 Stockholm, Sweden

Combination of machine learning and physical modelling to evaluate microstructure in steels: A case study to predict deformation induced martensite transformation in austenitic stainless steels

Abstract: It is known that computational materials design has made significant progress in recent years. Machine learning (ML), a sub-domain of artificial intelligence (AI), is the key enabling technology for the digitalization of the material science and industry. In this work, a case study of modelling of deformation-induced martensite transformation (DIMT) in austenitic stainless steels has been performed using a combinational approach of ML and physical modelling. A fully predictive model for DIMT is established here by utilizing an experimental dataset correlating DIMT with composition, temperature and strain. The dataset is firstly collected from the open literature. Subsequently, the classical method of Olson-Cohen model is used to expand the database to a larger final size relating the features and the target. Thereafter, state-of-the-art ensemble ML methods are applied to model the data and the final model is validated on a holdout dataset, including both austenitic and duplex stainless steels. It is seen that the final model provides accurate predictions of DIMT in a temperature range from -196 to 100 °C and from 0 to 1 in strain. Besides, the model can readily be extended to consider further factors such as strain rate and stress state. The implementation of this case study reveals the application of this combinational approach in a general engineering material science.

Keywords: machine learning; deformation-induced martensite; austenitic stainless steels; computational materials design

Thursday, 23 September 2021 14:15 – 14:40

Grzegorz Łukaszewicz

Warsaw University of Technology, Faculty of Materials Science and Engineering
Warsaw University of Technology, Doctoral School No 1

Machine learning meets steels - the latest trends

On the one hand, it is an intensively developing area of science, and on the other, a powerful tool supporting many scientific disciplines. The presentation introduces the latest examples of the use of machine learning by scientists from various centres. There are discussed cases of modelling phase transformations in steel and predicting mechanical properties of steel products. In addition, the idea of artificial neural networks is introduced, and tips are given on how to start your adventure with them.

Keywords: machine learning, artificial neural networks

Thursday, 23 September 2021 14:40 – 14:55

Anna Wojtacha[1], Mateusz Morawiec[2], Marek Opiela[1]

1 Silesian University of Technology, Faculty of Mechanical Engineering, Department of Engineering Materials and Biomaterials, Konarskiego 18a St., Gliwice 44-100, Poland
2 Silesian University of Technology, Faculty of Mechanical Engineering, Materials Research Laboratory, Konarskiego 18a St., Gliwice 44-100, Poland

Effect of plastic deformation on the shape of CCT-diagram of new-developed steel for drop forgings

The paper presents the results of research on the influence of plastic deformation on the phase transformation kinetic of supercooled austenite in the newly developed HSLA steel with Ti and V micro-additions. The BAHR 805 A/D dilatometer (BÄHR-Thermoanalyse GmbH) with an induction heating system and a vacuum chamber was used to determine the transformation curves of non-deformed supercooled austenite (CCT) and plastically deformed cooled austenite (DCCT). The samples were austenitized at 1000°C and then cooled at a rate ranging from 0.1°C/s to 60°C/s. In order to determine the influence of plastic deformation on the form of the DCCT diagram, the samples were deformed at the temperature of 1000°C using a 50% degree of compression at the deformation rate of 1s-1. The study of the steel structure was carried out using light microscopy and scanning electron microscopy. The microstructure is mainly ferritic with some fraction of granular bainite, and increasing the cooling rate led to formation of a higher fraction of bainitic ferrite. In plastically deformed austenite, there is an increased diffusion rate and a high density of sites suitable for heterogeneous nucleation of diffusion transformation products of this phase. In order to reveal the presence of retained austenite in the structure, etching in Klemm's reagent was used. The results show that the increase of cooling rate decreases the amount of retained austenite in the microstructure of the steel. Hardness measurements were also performed. It was found that the specimens plastically deformed prior to their controlled cooling show higher hardness values, which is the result of a finer structure.

Keywords: HSLA steel, dilatometry, phase transformation, CCT diagram, DCCT diagram

Thursday, 23 September 2021 14:55 – 15:10

Krzysztof Chmielarz, Grzegorz Łukaszewicz

Warsaw University of Technology, Faculty of Materials Science and Engineering, Woloska 141, 02-507 Warsaw, Poland

Evaluation of bainitic transformation kinetics models for different steels

There is a number of models dedicated to describing the kinetics of transformation. In this paper we decided to compare four of them: general kinetics models - JMAK, Austin-Rickett, Starink, and the autocatalytic model, dedicated to the bainite transformation. These models were fitted to a series of dilatometric curves describing the bainitic transformation using the least squares method. The aim of the study was to determine the model that offers the best fit to the bainite growth curves, as well as to determine the physical meaning of the model fit parameters and their usefulness in describing bainite transformations. Various approach to fitting parameters, especially to Avrami exponent “n” was conducted to show its physical meaning.

Keywords: bainite transformation, nanobainite, modelling, kinetics, JMAK, Starink, Austin-Rickett, Autocatalytic model

Authos Index