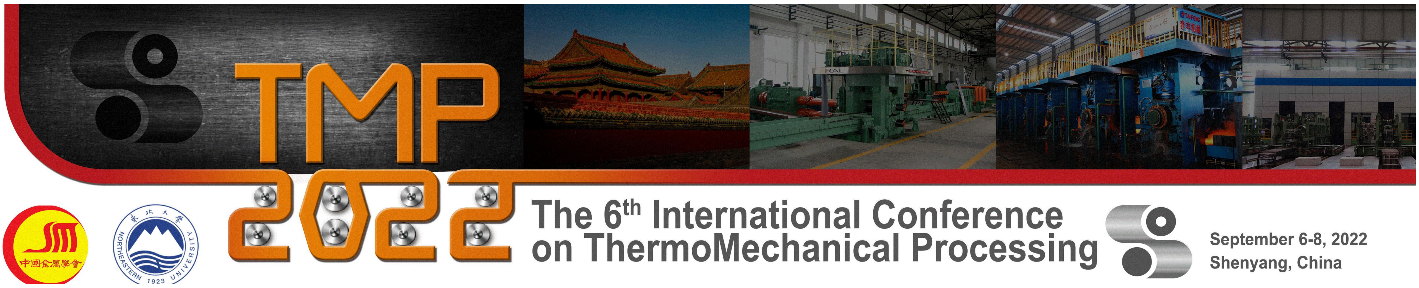

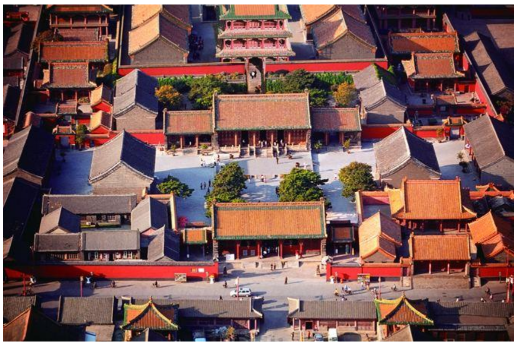

The 6th International Conference on ThermoMechanical Processing

September 6-8, 2022 Virtual Meeting

Technical Program

Organized by

The Chinese Society for Metals (CSM)

Northeastern University (NEU)

Co-organized by

The State Key Laboratory of Rolling and Automation (RAL)

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The Indian Institute of Metals (IIM), India

The Iron and Steel Institute of Japan (ISIJ), Japan

The Korean Institute of Metals and Materials (KIM), Korea

The Nonferrous Metals Society of China (Nfsoc), China

Conference Website: www.tmp2020.com

Technical Program Timetable

TUESDAY, 6 SEPTEMBER 2022, GMT+8 (Beijing)

Room A, Zoom Link:				
13:40-18:30 **Plenary Session I**				
Room B, Zoom Link:	**Room C, Zoom Link:**	**Room D, Zoom Link:**	**Room E, Zoom Link:**	**Room F, Zoom Link:**
B1 (19:30-20:55) **Flat Product and Processing - Silicon Steel** *Chair: Yong Tian* B2 (21:10-22:30) **Flat Product and Processing - Processing Technology I** *Chair: Qian Xie*	C1 (19:30-22:25) **Microstructure and Properties of Steels - Microalloyed Steel** *Chairs: Minghui Cai; Xiangdong Huo*	D1 (19:30-22:15) **Service Performance of Metallic Materials - Service Behavior** *Chair: Tao Zhang*	E1 (19:30-22:00) **Non-ferrous Alloys and Processing - Magnesium alloys, Titanium Alloys and Nickel Alloys I** *Chairs: Hua Ding; Gaowu Qin*	F1 (19:30-21:15) **Digitalization and Intelligent Manufacturing - Process Optimization** *Chair: Weigang Li*

WEDNESDAY, 7 SEPTEMBER 2022, GMT+8 (Beijing)

Room A, Zoom Link:				
14:00-18:00 **Plenary Session II**				
Room B, Zoom Link:	**Room C, Zoom Link:**	**Room D, Zoom Link:**	**Room E, Zoom Link:**	**Room F, Zoom Link:**
B3 (19:00-20:30) **Long Product and Processing - Microstructure and Properties of High Speed Wire** *Chair: Yi Luo* B4 (20:45-22:00) **Long Product and Processing –Section Steel Rolling / Process and Control of Wire and Rod** *Chair: Wenzhen Xia*	C2 (19:00-22:35) **Microstructure and Properties of Steels - High-alloy Steel** *Chairs: Zhongwu Zhang; Zhangwei Wang*	D2 (19:00-21:10) **Service Performance of Metallic Materials - Corrosion Behavior** *Chair: Linlin Li* D3 (21:10-21:55) **Service Performance of Metallic Materials – Mechanical Behavior and Fatigue Performance I** *Chair: Linlin Li*	E2 (19:00-20:30) **Non-ferrous Alloys and Processing - Magnesium Alloys, Titanium Alloys and Nickel Alloys II** *Chair: Yong Li* E3 (20:45-21:45) **Non-ferrous Alloys and Processing – Aluminum Alloys** *Chair: Hucheng Pan*	F2 (19:00-21:35) **Digitalization and Intelligent Manufacturing - Intelligent Manufacturing I** *Chair: Wei Guo*

THURSDAY, 8 SEPTEMBER 2022, GMT+8 (Beijing)

Room B, Zoom Link:	Room C, Zoom Link:	Room D, Zoom Link:	Room E, Zoom Link:	Room F, Zoom Link:
B5 (14:00-15:20) **Flat Product and Processing - Pipeline Steel and Marine Steel** *Chair: Yongqing Zhang*	C3 (13:30-18:15) **Microstructure and Properties of Steels - Automobile Steel** *Chairs: Lijia Zhao; Binhan Sun*	D4 (14:00-16:40) **Service Performance of Metallic Materials - Oxidation Behavior** *Chair: Hong Luo*	E4 (14:00-17:55) **Non-ferrous Alloys and Processing - Aluminum Alloys** *Chairs: Zhihao Zhao; Xiu Song*	F3 (14:00-16:00) **Digitalization and Intelligent Manufacturing - Intelligent Manufacturing II** *Chair: Shaowen Huang*
B6 (15: 20-17: 55) **Flat Product and Processing - Processing Technology II** *Chair: Feng Fang*		D5 (16:40-18:00) **Service Performance of Metallic Materials - Mechanical Behavior and Fatigue Performance II** *Chair: Hong Luo*		F4 (16:15-18:15) **Modelling and Simulation of Metallic Materials - High Temeprature Process and Texture** *Chair: Minghui Cai*
B7 (19:00-20:20) **Long Product and Processing - Microstructure and Properties of Tube and Pipes** *Chair: Guo Yuan*	C4 (19:00-22:20) **Microstructure and Properties of Steels - Special Steel** *Chairs: Dongsheng Liu; Zhinan Yang*	D6 (19:00-21:05) **Service Performance of Metallic Materials - Mechanical Behavior and Fatigue Performance III** *Chair: Guangming Cao*	E5 (19:00-20:00) **Non-ferrous Alloys and Processing - Aluminum Alloys, Zirconium Alloys and Other Alloys** *Chairs: Ni Tian; Qingfeng Zhu*	F5 (19:00-20:20) **Modelling and Simulation of Metallic Materials - Advanced High Strength Steels** *Chair: Chi Zhang*
B8 (20:45-21:25) **Long Product and Processing - Process and Control of Wire and Rod** *Chair: Jin Li*				F6 (20:35-22:10) **Modelling and Simulation of Metallic Materials – Phase Transformation** *Chair: Wenwen Song*

TECHNICAL PROGRAM

TUESDAY, 6 SEPTEMBER 2022, GMT+8 (Beijing)

Room A, Zoom Link:

13:40-14:30 Opening Ceremony and Group Photo

Plenary Session I

Chairs: Fusheng Pan, Chongqing University

Zhiling Tian, The Chinese Society for Metals

14:30-15:15 Plenary

High Plasticity Magnesium Alloys and their Processing Technologies

Fusheng Pan; Chongqing University, China

In the metal structural materials, the proportion of plastic processed products accounts for more than 70%. Various lightweight and functional parts of magnesium alloys processed and prepared by plastic forming process have the characteristics of good material comprehensive performance, high utilization rate, good product appearance and internal quality, which can be widely used in transportation, information, energy, aerospace, medical treatment, high-end equipment and other fields. However, due to its dense hexagonal crystal structure, magnesium alloy has poor plastic deformation ability, and its room temperature plasticity of magnesium alloys can not meet the requirements in many occasions. In addition, the base texture of magnesium alloy is easy to form after plastic deformation, which leads to further reduction of the plasticity of the alloy, aggravation of anisotropy and further reduction of the formability of the alloys. In order to promote the wide application of magnesium alloys, it is urgent to develop high plasticity magnesium alloys and high formability manufacturing technologies of magnesium alloy products. This report mainly introduces the new theory of high plasticity magnesium alloy design and the new asymmetric high formability processing technologies proposed by Chongqing University in the past decade. Many high plasticity magnesium alloys developed have been approved to enter national and international standards. Some new magnesium alloy materials with high performance and new processing technologies with high formability ability have been industrialized.

15:15-16:00 Plenary

Thermomechanical Processing for Fabricating Ultrafine Grained Steels

Nobuhiro Tsuji; Kyoto University, Japan

Nowadays various kinds of thermomechanical processing, such as severe plastic deformation followed by annealing, dynamic transformation, dynamic recrystallization, etc. are available for fabricating ultrafine grained steels having average grain sizes smaller than 1 μm. In this extended abstract, such processes are overviewed and possibilities to manage both high strength and large ductility/toughness in ultrafine grained steels are discussed.

16:00-16:45 Plenary

Digital Innovation Infrastructure Establishes for Steel Enterprises to Accelerate the Construction of Digital Steel

Guodong Wang; Northeastern University, China

The historical experience of the development shows that every major change in economic form often generates and relies on new production factors. As human society enters the digital age, data is gradually becoming a new key factor of production which is driving economic and social development, and data analysis becomes the most effective method to solve uncertainty problems. The steel industry is the industry closest to "digitization", whose process is extremely complex, with the multi-variable, strong coupling, nonlinear and large lagging characteristics. The steel industry must integrate with the digital economy and digital technology, and take advantage of the application scenarios and data resources of the steel industry. With the industrial Internet as the carrier, the data perception and precise execution of the underlying production line as the basis, the digital twins and CPS of the edge process setting model as the core, and the digital-driven cloud platform as the support, to establish digital innovation infrastructure for steel enterprises, accelerate the construction of digital steel. Give play to the amplification, superposition and multiplication of digital technology in the steel industry, reduce the research and production costs, improve the efficiency and progress, and accelerate the development of stranglehold iron and steel materials, thus to achieve digital transformation and high-quality development of the steel industry.

16:45-17:00 Coffee Break

17:00-17:45 Plenary

Strength of Undeformed Pearlite

H.K.D.H. Bhadeshia; Cambridge University, United Kingdom

The dependence of the proof strength of undeformed pearlite on its interlamellar spacing is examined in detail, with a view to resolving the plethora of relationships that exist in the research literature. It is found by the analysis of published data that the Hall-Petch equation is best suited to explain the strength, not simply on the basis of empirical fit, but even when examined in a Bayesian framework. Furthermore, it is the only relationship that gives a physically meaningful value to the friction stress. The reasons why previous analyses have failed to resolve this issue are examined and explained. It is discovered that ferrite in interstitial-free iron is, at an identical length scale, stronger in yield than the ferrite within pearlite.

17:45-18:30 Plenary

Dynamic Recrystallisation of Austenitic Stainless Steels During Conventional and Novel Thermomechanical Processing

Peter Hodgson; Daniel Fabijanic; Matthew Barnett; Hossein Beladi; Deakin University, Australia

Thermomechanical Processing of steels and many alloys involves grain refinement through dynamic recrystallization. For austenitic stainless steels this is typically through a discontinuous recrystallization process where new strain free grains are nucleated during deformation followed by growth both through deformation and after deformation (the latter typically referred to as metadynamic recrystallization). However, there is also evidence that continuous (or geometric) recrystallization can occur under some deformation conditions; typically higher strain rates and lower temperatures (ie higher Zener Hollomon conditions). This talk will review the extensive work related to grain refinement and the transition between the two mechanisms under conventional hot working conditions.

More recently, novel Thermomechanical processing routes have been developed. In particular, we have examined the Additive Friction Stir Deposition (AFSD) technique developed by MELD. For austenitic stainless steels we have shown that this can lead to extensive grain refinement. The mechanisms for this refinement will be discussed.

Room B, Zoom Link:

Flat Product and Processing (Chief Organizer: Yong Tian, Northeastern University)

Silicon Steel (Chair: Yong Tian, Northeastern University)

19:30-20:00 Keynote

Recent Development of Grain-Oriented Silicon steel in Shougang

Jian Gong; Maolin Sun; Jiaji Ma; Beijing Shougang Co., Ltd., China

Shougang has been seeking for low iron loss and high permeability technologies of grain oriented electrical steel. The metallurgical problems associated with the manufacture of grain oriented steel was discussed. The factors that affect primary recrystallization and secondary recrystallization were investigated. The evolution of microstructure and inhibitor in metallurgical process and texture developing selectively during the final annealing stage are described. The low iron loss grain oriented electrical steel was developed and the thin gauge 0.18mm-20mm grain oriented electrical steel has been recently developed to meet the demand of new chinese national standard of energy efficiency grades for power transformers.

20:00-20:30 Keynote

Microstructure Evolution and Strengthening Mechanism in Non-oriented Silicon Steel with High Strength

Feng Fang; Shangfeng Che; Yuanxiang Zhang; Yang Wang; Xiaoming Zhang; Guo Yuan; Northeastern University, China

Non-oriented silicon steel with high magnetic induction, low iron loss and high strength is urgently needed to meet the requirements of high-speed motor in electric vehicle in recent years. However, it is generally believed that the methods for improving mechanical properties may often damage the magnetic properties of non-oriented silicon steel. In this study, different strengthening methods involving solid solution strengthening, precipitation strengthening and composite strengthening are adopted to investigate the effect of strengthening mechanism on microstructure evolution and properties in non-oriented silicon steel. The results indicated that the solution strengthening with Ni addition was beneficial to improve texture and magnetic properties, while provided limited strengthen increment. Nano-size precipitation strengthening significantly improved the yield strength about 100 MPa, but resulting in a certain degree of deterioration. Composite strengthening with Ni and Cu addition was an excellent route towards obtaining good balance between magnetic properties and mechanical properties. And the optimum magnetic induction B50 was as high as 1.72 T, and the high-frequency iron loss P1.0/400 was as low as 13.6 W/kg, and the highest yield strength of 627.3 MPa was achieved in 0.20 mm non-oriented silicon steel.

20:30-20:55 Invited

Effect of Rolling Process on Recrystallization Microstructure and Texture of Ultra-Thin Grain-Oriented Silicon Steels

Shengdong Hu[1]; Xianwei Zhang[2]; Song Zhang[1]; *Jinlong Liu*[1]; Yuhui Sha[1]; Liang Zuo[1]; [1]Northeastern University, China; [2]Liaoning Wuhuan Special Materials and Intelligent Equipment Industry Technology Research Institute Co., Ltd., China

Ultra-thin grain-oriented silicon steel (UTGO) with thickness less than 0.15mm has been more and more used in medium and high frequency equipment. The cold rolling process of UTGO can use one-stage cold rolling (OSCR) or two-stage cold rolling (TSCR) with intermediate annealing. The magnetic properties of UTGO are very sensitive to its recrystallization texture. However, the effects of rolling process on the evolution of primary recrystallization microstructure and texture of UTGO have not been clarified in detail. In this study, UTGO was fabricated by OSCR and TSCR respectively, and the microstructure and texture evolution during cold rolling and recrystallization were analyzed by XRD and EBSD. The study found that a strong {111}<112> texture is formed in OSCR after cold rolling with 77% reduction due to the sharp Goss ({110}<001>) texture in the raw materials, in contrast, under the process of TSCR, it is difficult to form sharp deformation texture after the second stage cold rolling due to disappear of strong texture after intermediate annealing. After recrystallization annealing, weak texture was formed in TSCR samples, but strong η texture was obtained in OSCR samples, which can be attributed to the improved microstructure of a large number of {111}<112> deformed matrix with abundant shear bands developed in the cold rolling OSCR sample.

20:55-21:10 Coffee break

Processing Technology I (Chair: Qian Xie, Anhui University of Technology)

21:10-21:40 Keynote

Modelling Evolution of Microstructure and Flow Stress During Hot Rolling of Microalloyed Steels

Zhanli Guo; Sente Software Ltd., United Kingdom

Thermomechanical controlled process (TMCP) has become a general practice in the production of microalloyed steels, where processing parameters have direct impacts on the quality of the steels produced. TMCP is a rather complex process. On one hand, the rolling may finish in the austenite and ferrite region. On the other hand, accelerated cooling may be applied to allow the austenite to ferrite transformation to take place in a controlled fashion. Many physical and metallurgical phenomena take place during this process, including: precipitation of MX type carbides, nitrides or carbonitrides, recrystallisation and grain growth, and phase transformation from austenite to ferrite, pearlite, bainite and/or martensite. These processes interact with each other, which makes the design of the multi-pass rolling schedule a difficult task.

Extensive experimental studies have been carried out to study these processes. However, there are so many variables involved, such as steel composition, initial grain size, and deformation conditions (temperature, strain, strain rate and interpass time), which makes it difficult to make a meaningful comparison of all the experimental results and shed light on the directions for improvement. Thus, extensive modelling has been carried out in recent years, providing a better understanding on deformation-induced-precipitation kinetics, recrystallization kinetics and grain refinement, and phase transformation kinetics. All these models, together with our model developed previously for the calculation of flow stress curve as a function of strain, strain rate and temperature, have been incorporated in the current model and implemented inside JMatPro®. This integrated model considers the following metallurgical phenomena as well as their interactions:

- Precipitation of MX type carbides, nitrides or carbonitrides.
- Interactions between precipitation and recrystallisation and their effects on grain refinement.
- Effect of grain size and cooling rate on transformations from austenite to ferrite, pearlite, bainite and martensite.
- Effect of rolling parameters, recrystallisation and microstructure on rolling stress.

The model predicts the evolution of microstructural features such as precipitate size and amount, recrystallisation fraction, grain size, and austenite decomposition, as well as the evolution of rolling stress during hot rolling. It has been applied to various types of microalloyed steels and demonstrated good agreement with experimental observations. Therefore, it has the great potential to be implemented in a production line to help optimise the rolling schedule for both C-Mn and microalloyed steels.

21:40-22:10 Keynote

Evolution Mechanism of Nanoprecipitates and Mechanical Properties of NiAlCoCu-Containing Ultrahigh-Strength Stainless Steel

Qiang Yu[1]; Chaofang Dong[2]; [1]Lianyuan Iron and Steel Co., Ltd., China; [2]University of Science and Technology Beijing, China

The constituent content, structure, size and number density of nanoprecipitates are critical factors for determining the mechanical properties of ultrahigh-strength stainless steel. Understanding the evolution mechanism of nanoprecipitates during thermal aging has been a topic of significant interest. However, changes in these key parameters affect their mechanical property. Here we elucidate the nucleation mechanism, composition evolution and strengthening effects of the multicomponent nanophase in NiAlCoCu containing ultra-high-strength stainless steel by combined atom probe tomography together with first-principles calculation and Thermo-Calc software. Our study provides compelling experimental evidence that these consist of Co multicomponent nanoprecipitates by occupied in bcc core or corner partially replacement in a B2-NiAl phase formation stabilized structure. These tiny multicomponent NiAlCoCu nanoprecipitates provide a large interaction force to block dislocation movement between martensite matrix and NiAlCoCu particles interphases, resulting in high yield strength combined slight sacrifice ductility.

22:10-22:30 Contributed

The Mechanical Parameters Modeling of Heavy Steel Plate Snake/Gradient Temperature Rolling with the Same Roll Diameters

Lianyun Jiang; Taiyuan University of Science and Technology, China

The grains in the center of the thick steel plate can be refined by snake/gradient temperature rolling, and the deformation penetration, the microstructure and properties of the steel plate will be improved. The present rolling mechanical model is not suitable for the snake/gradient temperature rolling, so it is necessary to establish the mechanical parameter model of the snake/gradient temperature rolling to instruct production. The yield criterion of rolled material was modified based on the idea of equivalent flow stress. The elements stress analyses were carried out based on the uniform normal stress and non-uniform shear stress in the vertical sides of each slab. And then the equilibrium equation of the unit pressure based on slab method was established at this basis. The deformation region was divided into three layers (top layers, bottom layers and the central layers) and maximum four zones (back slip zone, front slip zone, cross shear zone and reverse deflection zone) according to the temperature distribution and position of the neutral point, and then the twelve zones were formed during snake/gradient temperature rolling. The boundary conditions of existence of the back slip zone, front slip zone and cross shear zone were established according to the relationship between threading angle and neutral angle. The accurate mechanical parameter models of the rolling force and rolling torque of the snake/gradient temperature rolling with the same roll diameters were set up on this basis. The Ansys software has been used in the rolling process simulation by many scholars, and the calculating precision has been verified. So the rolling processes were simulated by Ansys software to validate the model precision. The results show that the maximum relative deviation of the model is less than 7% compared with the numerical method. So the model can accurately predict the rolling force and rolling torque during the snake/gradient temperature rolling with the same roll diameters.

Room C, Zoom Link:

Microstructure and Properties of Steels (Chief Organizer: Liqing Chen, Northeastern University)

Microalloyed Steel (Chairs: Minghui Cai, Northeastern University; Xiangdong Huo, Jiangsu University)

19:30-20:00 Keynote

Interphase Precipitation and Resultant Strengthening in V-Ti and V-Nb Multiple Microalloyed Low-Carbon Steels

Yongjie Zhang; Goro Miyamoto; Tadashi Furuhara; Tohoku University, Japan

Ferritic steels strengthened by interphase precipitation of nano-sized alloy carbide formed during austenite-to-ferrite transformation by have been widely used in industry for its high strength with excellent formability. In this study, interphase precipitation behavior and its resultant strengthening in V-Ti and V-Nb microalloyed low-carbon steels were systematically investigated, to obtain a better understanding in multiple added alloy systems. A series of Fe-0.1C-1.5Mn-0.05Si (mass%)-based alloys with 0.1V-0.1Nb and 0.1V-0.05/0.1Ti multiple additions were mainly used, with their corresponding single additions as well for comparison. After austenitization, all the alloys were isothermally transformed at 963K and 923K for various times, followed by water quenching. Afterwards, the dispersion of alloy carbide in terms of number density and size were quantitatively analyzed by using three-dimensional atom probe (3DAP), while its precipitation strengthening was evaluated by the increment in ferrite hardness. The experimental results revealed that regardless of the transformation temperature, V, Nb and Ti atoms are precipitated simultaneously by interphase precipitation. Compared at the same total amount of alloy addition, the multiple added alloys represented a moderate dispersion of alloy carbide as well as the resultant hardness, falling between those of the single added counterparts. The advantage of multiple addition can be summarized as the fine dispersion of precipitates controlled by relatively stronger carbide-forming elements, accompanied by larger volume fraction contributed by relatively weaker carbide-forming elements without increasing the solution temperature of alloy carbide.

20:00-20:30 Keynote

The Non-recrystallization Temperature in Nb-based Steels: From the Laboratory to Industrial Conditions

Jose M. Rodriguez-Ibabe; Beatriz Pereda; *Beatriz Lopez*; Pello Uranga; Ceit-BRTA, Spain

The non-recrystallization temperature (T_{nr}) is a tool that is used in many plants for the design of controlled rolling schedules, as it determines the temperature below which strain is accumulated in the austenite. Initially, several empirical expressions were proposed to quantify it, depending only on the chemical composition of the steel and based on laboratory multipass tests. Among them, the most popular are those published by Boratto et al. and Bai et al. In some reported equations, the T_{nr} temperature was considered to be a characteristic of the processed steel. Later, it was observed that mill configurations and process parameters, such as per pass reduction, rolling speed or interpass time, were also affecting the definition of T_{nr}. In summary, the quantification of T_{nr} became significantly more complex than initially assumed. The T_{nr} temperature can be easily determined in laboratory conditions. For example, using multipass torsion tests and calculating the evolution of the mean flow stress pass after pass. Nevertheless, the transfer of these laboratory results to industrial conditions is, in practice, a complex issue. Based on these difficulties, Jonas proposed to consider the industrial data from the roll mill to calculate the T_{nr} for a specific chemical composition and rolling schedule. This approach is based on Sims roll force equations to determine the mean flow stress. Similarly, other authors have proposed to calculate the T_{nr} pass by pass considering the static recrystallization incubation time and comparing it with the interpass time. Finally, another approach is to work with the RLT (recrystallization limit) and RST (recrystallization stop) temperatures, both calculated with the help of microstructural models that consider industrial rolling schedules. The advantage of this approach is that with these two temperatures it is possible to identify the interval where there will be a heterogeneous microstructure formed by recrystallized and non-recrystallized austenite grains. This manuscript will analyze the practical relevance of these different approaches in the case of Nb-based microalloyed grades, considering hot rolling strategies representative of industrial conditions.

20:30-20:55 Invited

New Research Progress of Titanium Micro-alloyed High Strength Steel

Liejun Li[1]; *Xiangdong Huo[2];* Jixiang Gao[3]; Zhengwu Peng[1]; Songjun Chen[1]; *[1]South China University of Technology, China; [2]Jiangsu University, China; [3]Guangdong Polytechnic Normal University, China*

With the recent progresses of chemical metallurgical and TMCP, the problems in the production of titanium microalloyed steels have gradually been solved. It can be of remarkable economic value and social benefit. In recent years, titanium microalloyed high strength steel have attracted more and more attention for notable precipitation hardening of nano-meter carbides in steel. From 2004, in Zhujiang Steel, single titanium microalloying technology was successfully applied in compact strip production (CSP) process, and the yield strength of titanium microalloyed strip was over700 MPa. Our research progress will be introduced here for about seventeen years, for example, strength mechanism of ZJ700W produced by Zhujiang Steel, effect of TMCP schedule on property， microstructure and precipitation of titanium steel, isothermal precipitation kinetics of titanium carbides ,the relationship between isothermal transformation and precipitation or between isothermal precipitation and strain induced precipitation, effect of molybdenum on $\gamma \rightarrow \alpha$ transformation and nanometer carbides, and so on. A new method for isothermal precipitation kinetics of carbides was proposed through hardness and strength measurement with a Gleeble 3800® Thermo-Mechanical Simulator. Many experimental methods, such as SEM/TEM/HRTEM/APT, were used to study nanometer carbides in steel. Precipitation change model during isothermal transformation was established. The interaction mechanism between nanometer carbides precipitation and physical metallurgical behaviors such as austenite recrystallization, phase transformation and steel strengthening was revealed, which provided theory basis for titanium microalloyed high strength steel produced by through hot rolling, cold rolling. In short, the future development of titanium microalloyed high strength steel should focus on connecting experimental research in the laboratory and the real production in the field, so research results can be applied to develop new products in different applications and processes.

20:55-21:10 Coffee break

21:10-21:40 Keynote

Effect of Reheating Temperature on TMP in Nb Based Microalloyed Steels

Jose M. Rodriguez-Ibabe; Pello Uranga; *Beatriz Pereda;* Beatriz Lopez; *Ceit-BRTA, Spain*

Conventional thermomechanical processing (TMP) begins with a reheating stage that, in addition to soaking of the slab at the temperature required for rolling, defines the characteristics of the austenite grain size distribution and the state of the microalloying elements (precipitated, dissolved…). This microstructure will be the input that, with an adequate design of the TMP strategy, will provide a homogeneous and fine final microstructure after rolling. Thermomechanical processes of hot strip mill (HSM) and plate mill (PM) show some important differences. This paper analyzes how the austenite microstructure after reheating may affect the evolution of the microstructure during the TMP in the case of Nb microalloyed grades. The analysis will consider different situations in relation to the initial austenite grain size distribution and the amount of Nb in solution, in order to identify the conditions where the reheating temperature exerts a metallurgical role in the TMP. To do this, the study will take into account the situation of the austenite grain size distribution before strain accumulation starts. Similarly, the possible effects of different amounts of Nb in solution (before rolling) in the total amount of accumulated strain in austenite will be evaluated.

21:40-22:05 Invited

Warm Forming of Medium Mn Steel: Role Mechanism of Nb-Mo Multi-Microalloying

Minghui Cai; Chaoqun Zhao; Yuan Liu; Xin Zhong; Litao Ma; Yu Zhang; Hua Ding; Northeastern University, China

To improve the overall mechanical properties of medium-Mn steels, an addition of microalloying elements has been recently aroused. For this purpose, a comparison was made among the medium Mn steels with no microalloying addition, a single Nb addition and multi-additions of Nb-Mo. In particular, precipitation behavior and austenite stability of the warm-rolled medium-Mn steels with different Nb/Mo additions annealed at different temperatures were investigated. The Nb or Nb-Mo additions decrease the volume fraction of retained austenite, but increase its mechanical stability. The Mo addition to the Nb-bearing medium Mn steels can lead to a higher density and smaller mean size of the precipitates because of the decreased interfacial energy and enhanced precipitation kinetics. The optimal precipitation temperature of the designed steels is about 600 °C. The warm-rolled Nb-Mo multi-microalloyed medium Mn steels exhibit a mixture of equiaxed and lamellar grain morphologies, and exceptional mechanical properties, i.e. the average products of ultimate tensile strength and total elongation (PSE) values of approximately 62.0 GPa·%. An increase in yield strength of 300 MPa can result from grain refinement and precipitation hardening by Nb-Mo multi-microalloying.

22:05-22:25 Contributed

InTRAP: A Technique to Mimic the Downstream Thermo-Mechanical Processing of Steel

Santosh Kumar[1]; Cameron Pleydell-Pearce[1]; Didier Farrugia[2]; Mazher Yar[1]; Nicholas Lavery[1]; [1]Swansea University, United Kingdom; [2]Tata Steel, India

In the current work an accelerated process of alloy development that inherently connects a range of different production scales is presented; from laboratory route (20g cast) to pilot line (50kg cast) to industrially processed material. Recently optimized 20g Rapid Alloy Prototyping (RAP) casts been successfully produced with the potential to support development of hundreds of steel chemistries in a short timeframe. However, there is a challenge to reproduce industrially valid downstream processes like hot rolling, cold rolling and controlled heat treatment cycle due to the size limitations (particularly in relations to thermal control). In the present work, an Innovative Technique for Rapid Alloy Prototyping (InTRAP) is presented that has been developed to permit more representative processing of very small-scale casts. Given its sensitivity to processing parameters and hence amplified process-property dependence, a dual phase steel (DP800) was selected as the case study. In this technique, the 20g cast RAP steel samples of industrially produced DP800 steel are re-melted using the small-scale induction melting and cast to different dimensions. These casts are implanted into partially hot rolled strip material (transfer bar) which acts as carrier block (and a direct industrial reference). Subsequent thermomechanical processing are carried out on the small casts through to downstream processing. The RAP casts along with transfer bars are soaked in furnace and hot rolled using the pilot line hot reversing mill under multiple passes followed by water cooling on laboratory scale run out-tables and simulated coil conditions. Further these were cold rolled and annealed using a hot dip simulator. Finally, previously validated inhouse developed, mini tensile design of gauge 10mm were extracted from the embedded samples to determine the structure- property relationship. These results are compared with traditional industrial processing of identical dual phase steel under the same targeted processing conditions. The ferrite and martensite microstructure with mechanical properties of UTS>800MPa was achieved and with good agreement to industrially produced material in respect of mechanical properties, phase volume fraction and grain size. The InTRAP process was therefore found to provide a new method by which rapidly produced gram scale casts can be processed under industrially representative conditions.

This enabled the potential of representative and accelerated understanding of composition / thermomechanical interdependencies in downstream processing of steel when compared against conventional product development routes.

Room D, Zoom Link:

Service Performance of Metallic Materials (Chief Organizer: Zhenyu Liu, Northeastern University)

Service Behavior (Chair: Tao Zhang, Northeastern University)

19:30-20:00 Keynote

Revisit TWIP and TRIP Effects on Strain Hardening of High-Strength Steels

Mingxin Huang; University of Hong Kong, China

High strength steels are widely used in various industries. Understanding the strain hardening mechanism of high strength steel plays a key role on the development of new class of high strength steel. The first part of the present work revisit the twinning-induced plasticity (TWIP) effect on the strain hardening mechanism of TWIP steel. It is found that TWIP effect has trivial effect on the strain hardening of TWIP steel. Instead, carbon-induced high dislocation in TWIP steel is the major mechanism responsible for the high strain hardening of TWIP steels. The second part revisit the TRIP effect on strain hardening of TRIP-assisted steels at high-strain-rate deformation. During high-strain-rate deformation, martensitic transformation does occur, but the strain hardening rate is still low, indicating that TRIP effect does not provide strain hardening behaviour at high-strain rate. Further investigation indicates that the reason for this abnormal TRIP effect at high strain rate could be attribute to the critical role of interstitial carbon played in the TRIP effect.

20:00-20:30 Keynote

Effective Use of High Strength S690 Steel in Construction and Associated Welding Technology

Kwok Fai Chung; The Hong Kong Polytechnic University, China

Applications of high strength S690 steel to buildings and bridges are very attractive owing to their high strength to self-weight ratios which often provide significant savings in costs and time. However, there are concerns on deterioration in mechanical properties of the S690 steel after welding as a result of changes in microstructures. This presentation reports latest research findings and engineering applications of high strength S690 welded steels. Attempts are also made to address some practical issues likely to be encountered among design and construction engineers during adoption of these high strength steel.

20:30-20:45 Coffee break

20:45-21:15 Keynote

Stability and Regulation of TGO Interface of Thermal Barrier Coating for Aeroengine Single Crystal Blade

Zebin Bao; Institute of Metal Research, Chinese Academy of Sciences, China

With the increasing inlet temperature of aero-engine turbine, Ni-based single crystal superalloy has been widely used as turbine blades. The development of thermal barrier coating system for single crystal and the evaluation of its high-temperature service behavior have become a research hotspot. The stability of the three interfaces between "environment-ceramic layer-bonding layer-single crystal" directly determines and affects the high-temperature service performance, reliability and life of the whole thermal barrier coating system. This paper mainly focuses on the heterogeneous interface of "ceramic insulation layer-bonding layer", takes platinum modified aluminide coating as the main research object, reveals its surface TGO growth behavior and evolution law, and regulates TGO growth behavior through active element doping and low oxygen partial pressure pretreatment, to achieve the purpose of improving the stability of "ceramic-metal" interface.

21:15-21:35 Contributed

Towards Understanding the Origin of Grain Refined Tribolayer in Metals

Wenzhen Xia[1,2]; Zhenyi Huang[1]; Gerhard Dehm[2]; Steffen Brinckmann[3]; [1]Anhui University of Technology, China; [2]Max-Planck-Institut für Eisenforschung GmbH, Germany; [3]Microstructure and Properties of Materials, Forschungszentrum Jülich, Germany

The tribology induced plastic deformation dominates the final tribological property during sliding metal contacts. Yet the complex collective interaction of contacts limits the better physical understanding of the microstructure – tribological property relationship. Single asperity sliding wear tests allow to separate the microcontacts and to study the origins of plastic evolution during the initial stages of tribology. However, the elemental mechanism of grain refined tribolayer formation during tribology are still unclear. In this work, we designed a new microscratch wear test, i.e. a microwall scratch test, in order to solve the problem of observation limit from the conventional in-situ SEM testing and simultaneously pose the ability of direction inspection underneath the surface which was before restricted to in-situ TEM. Additionally, this new test design further simplifies the stress state in the contact zone. In preliminary experiments, the microwalls were fabricated in an austenitic stainless steel. Microwalls with a width of ~1.7 μm, a length of 20 μm and a depth of ~12 μm were focused ion beam (FIB) milled into several individual grains and across-grains containing a twin boundary(TB). The preliminary post inspection and analysis reveal that: 1) The formation and growth of horizontal dislocation wall (DW) depends on the wear orientation (grain orientation plus microwall direction), 2) DW formation obstructs the downward dislocation motion, 3) Fine grain forms at the DW and 4) TB strongly affects DW behavior and alters plasticity locally.

21:35-21:55 Contributed

Predicting the Temperature-Dependent Forming Limit Diagrams (FLD) for Sheet Metal Alloys

Jianan Hu[1]; Zhanli Guo[1]; Nigel Saunders[2]; Jean-Philippe Schille[1]; [1]Sente Software Ltd., United Kingdom; [2]Thermotech Ltd., United Kingdom

Forming limit diagrams (FLD) have been extensively used in the analysis of sheet metal forming to define the deformation limit or formability of materials without necking or fracture, in particular for aluminium and steel alloy sheets. The formability of alloy sheets has been understood to be enhanced when subject to warm/hot forming process, during which the strain rate may also play a pivotal role. However, despite this general understanding, determining FLD experimentally at warm/hot forming conditions is still challenging, time-consuming and costly, thus limited attention has been paid to FLD at these conditions compared with the room temperature counterparts. Further, common FLD models may have difficulty in dealing with the flow softening effect that can occur at elevated temperatures, making the FLD evaluation process more complex for industrial application. This study examines the application of a ductile fracture criterion to predict the effect of temperature on the formability of sheet metals, combined with the high temperature flow stress-strain curve calculation capability in JMatPro®. Case studies are presented on a range of aluminium and steel alloys at various temperatures and strain rates. The comparison between calculated and experimental results show promising agreement, demonstrating the effectiveness of the proposed analytical approach. It can further aid the formability evaluation of other sheet metals and also benefit the materials selection in industry.

21:55-22:15 Contributed

On the Development of 3-D Printed Mg-Based Interpenetrating-Phase Composites with Bioinspired Structures

Zengqian Liu; *Mingyang Zhang*; Zhefeng Zhang; Institute of Metal Research, Chinese Academy of Sciences, China

Bioinspired structures are effective in enhancing the mechanical properties of materials, yet are difficult to construct in metallic systems. Here, we present a multi-design strategy for developing Mg-based bicontinuous interpenetrating-phase composites with bioinspired structures through infiltration of Mg melt into 3-D printed porous scaffolds of reinforcements. The resulting Mg-NiTi composites achieve a unique combination of high strengths at ambient to elevated temperatures, remarkable damage tolerance, good damping capacities and high energy absorption efficiency. Their shape and strength can even be largely recovered after deformation by heat treatment. Additionally, bioinspired brick-and-mortar, Bouligand, and crossed-lamellar structures are further constructed in the Mg-based composites for optimizing their mechanical properties. These structures promote effective stress transfer, delocalize damage and arrest cracking, thereby bestowing improved strength and ductility. Additionally, they activate a series of extrinsic toughening mechanisms, including crack deflection/twist and uncracked-ligament bridging, which enable crack-tip shielding from the applied stress and lead to "Γ"-shaped rising fracture resistance R-curves. Quantitative relationships are established for the stiffness and strengths of the composites by incorporating their structural characteristics. The bioinspired Mg-based composites may have the potential for structural and biomedical applications. The notable strengthening and toughening efficiencies of the bioinspired structures may be further exploited for developing new bioinspired metallic materials.

Room E, Zoom Link:

Non-ferrous Alloys and Processing (Chief Organizer: Yong Li, Northeastern University)

Magnesium alloys, Titanium Alloys and Nickel Alloys I (Chairs: Hua Ding, Northeastern University; Gaowu Qin, Northeastern University)

19:30-20:00 Keynote

R&D of New High Titanium Alloys in China

Yongqing Zhao; Northwest Institute for Nonferrous Metal Research, China

High strength Ti-alloy is of one the important branch of Ti-alloys. Ti-alloys with strength over 1100MPa are paid great attentions. This paper reviews the R & D of new high strength Ti-alloys in China, including high strength (over 1100MPa) high toughness TC21 alloy with damage tolerance, high strength (over 1200MPa) high toughness Ti-5321 alloy, high strength (over 1250MPa) high corrosion resistant Ti-B19 and Ti-26 alloys, super high strength (over 1350MPa) high toughness Ti-1300 alloy, super high strength (over 1400MPa) high toughness Ti-1455 alloy, super high strength (over 1500MPa) Ti-1500 and Ti-1600 alloys, and also the high strength Ti-12LC alloy with low cost. Among the new alloys, TC21 has become the mainstay Ti-alloy for aircrafts; Ti-1300, Ti-26 and Ti-12LC alloys were used for aviation, aerospace and weapons. Ti-5321, Ti-1455, Ti-1500 and Ti-1600 alloys were just researched, and they are still in Lab. scale.

20:00-20:30 Keynote

Grain Boundary Segregation Engineering of Wrought Magnesium Alloys

Gaowu Qin; Northeastern University, China

Lightweight design of various equipments is aligning with the development of energy-saving society now and in the future. As the lightest metal structural materials, magnesium alloys have great development potential in the equipments lightweight in the fields of automobile, high-speed railway, aerospace and so on. However, the problems of low absolute strength of magnesium alloys and their trade-off of strength-ductility have always been challenging. This report summarizes the development of wrought magnesium alloys in the world in recent years, mainly focusing on the segregation effect of alloying elements at the grain boundaries which we developed five years ago, and their theoretical clarification of segregation mechanism. The ultra-fine crystallization, on the submicron scale, of a series of wrought magnesium alloys has been thus realized, together with high strength and good ductility. We give also an example to promote the application in new energy vehicles. Finally, the report addresses the prospect on the future development of grain boundary segregation engineering of wrought magnesium alloys.

20:30-20:45 Coffee break

20:45-21:15 Keynote

Microstructure Control and Strengthening Mechanism of GH4720Li Nickel-based Superalloy during Thermo-mechanical Processing

Hongkai Zhang; *Ke Huang;* Xi'an Jiaotong University

As an ideal material intended for turbine disk, it is desirable to have fine γ grains and multimodal distribution of γ' strengthening phase for GH4720Li nickel-based superalloy. In this study, through appropriate thermomechanical processing design, dynamic recrystallization was used to refine grains while avoiding strain localization and post-dynamic recrystallization. Meanwhile, the modulation of the nanoscale secondary and tertiary γ'; precipitates during hot deformation and heat treatment was achieved by a novel two-step integration method and controlling the undercooling, respectively. The evolution mechanism of these two types of nanoscale γ'; precipitates and the relationship between the precipitate size distribution and mechanical properties were investigated. In addition, the combination of TEM and molecular dynamics revealed the deformation mechanisms of the primary γ'; precipitate, for the first time. This provides a new understanding for the microstructure control and quantitative strength optimization of nickel-based superalloys containing multimodal γ' precipitates.

21:15-21:40 Invited

Improvement in Microstructure and Mechanical Properties of Pure Titanium by Thermo-mechanical Processing

Xiu Song; Jiaxin Jin; Lei Wang; Yang Liu; Northeastern University, China

The development and comparison of enhanced strength-ductility of pure titanium with various thermo-mechanical processes by severe plastic pressing via annealing were investigated in the present work. The effect of plastic pressing and annealing on the microstructure and mechanical properties of pure titanium were discussed. The results show that the good match of tensile strength and elongation of pure titanium sheet can be obtained through optimized thermo-mechanical processes by groove pressing and annealing among different pressing passes. The tensile strength of pure titanium by groove pressing followed with one intermediate annealing after first pressing pass is higher than those with annealing after second pass or among each pass, which is increased by approximately 50% compared with that of pure titanium. And for that kind of thermo-mechanical process, the tensile strength firstly increases and then decreases, as the intermediate annealing temperature increases form 673K to 873K. The dislocation slip and twinning are the main deformation mechanism in pure titanium during the thermo-mechanical processes with the intermediate annealing temperature below 773K.

21:40-22:00 Contributed

Comparison of Hot Deformation Behaviour and Microstructural Evolution for Ti-5Al-5V-5Mo-3Cr Alloys Prepared by Powder Metallurgy and Ingot Metallurgy Approaches

Qinyang Zhao; Chang'an University, China

To realize the systematic comparison of the hot workability and guide the further hot-processing of powder metallurgy (PM) and ingot metallurgy (IM) Ti-5Al-5V-5Mo-3Cr (Ti-5553) alloys, the hot deformation behaviour and microstructural evolution of the two alloys were investigated at a wide temperature range of 700 °C-1100 °C and strain rate of 0.001 s^{-1}-10 s^{-1}. The activation energy maps and processing maps for both PM and IM alloys were constructed, as well as the specific deformation mechanisms were identified for each processing region. The results showed that PM alloy has lower deformation resistance, smaller activation energy and larger optimal processing windows than those of IM alloy. The dynamic α precipitation mechanisms in PM alloy were diffusional globularization and coarsening, rather than diffusionless shearing and fracturing in IM alloy. The extensive dynamic recrystallization (DRX) happened at 900 °C-1050 °C for PM alloy and at 1000 °C-1100 °C for IM alloy. The DRX process was dominated by discontinuous dynamic recrystallization (DDRX) for PM alloy while continuous dynamic recrystallization (CDRX) for IM alloy. Furthermore, PM alloy had smaller flow instability region than IM counterpart in the hot processing map. The schematic deformation mechanism maps were eventually developed for both PM and IM Ti-5553 alloys.

Room F, Zoom Link:

Digitalization and Intelligent Manufacturing (Chief Organizers: Dianhua Zhang, Northeastern University; Jie Sun, Northeastern University)

Process Optimization (Chair: Weigang Li, Wuhan University of Science and Technology)

19:30-20:00 Keynote

PIDAS-A Practice on Digital Transformation of Process Manufacturing

Sihai Jiao; Bo Yan; Jianhua Ding; Ye Liu; Central Research Institute, Baoshan Iron & Steel Co., Ltd., China

The Process Intelligent Data Application System (PIDAS) has been developed in-house in Baosteel for the Heavy Plate Mill by a joint team of both metallurgists and ICT specialists, driven by the unceasing requirement on increasing production efficiency and effectiveness, product quality. The practices both on developing and applying the PIDAS shows that some characteristics of digital transformation of process manufacturing. By introducing the development and application of the PIDAS, the concepts, ideas, and development experience of the digital transformation of the process manufacturing are summarized. Moreover, the core issues worthy of attention are pointed out. Finally, a feasible route for the digital transformation of the process manufacturing is proposed. It could be summarized as follows: planning a long-term vision, initiating action by utilizing the legacy system, developing with the joint team, associating to actual manufacturing scenarios, and spiraling upward following new demands. The route is supposed to be one of the effective examples of digital transformation for the process manufacturing.

20:00-20:30 Keynote

Methodology for Alloy Design of Steel Using Prediction Model and Optimization

Jin You Kim; Ju-Seok Kang; Jae-Hwa Lee; POSCO, Korea

Methods such as trial & error and knowledge of experts are commonly used for alloy design of steel. But these needs repetitive experiments and required time and cost consuming. In this study, we propose methodology for alloy design of commercial steel including material properties prediction, machine learning and optimization of alloy compositions. The alloy design system are applicable in both cases. One is when an existing model can be used, and the other is when model development is needed. We demonstrate an application of commercial alloy design of steel in each cases. The developed alloy design system is combined with optimization algorithm to automatically design an optimized alloying composition for obtaining multiple material property objects such as strength, corrosion resistance, phase fraction and alloy cost. The developed system has shown that new alloys with the desired properties can be designed very quickly and effectively. The alloy composition derived from the example of STS alloys using Thermo-calc SW has shown similar trends with the optimal composition developed from the skilled researchers, and the development period could be reduced by about 80%. In the case of the application to API commercial alloys, the machine learning prediction model was developed from the material property data of the commercial product. And the combination of the optimization and the developed prediction model, we can obtain optimization of the alloy composition which is yielded the optimal alloy cost while satisfying the target yield ratio. Our results show new possibility of developing a new alloy satisfying the multiple targeted properties.

20:30-20:45 Coffee break

20:45-21:15 Keynote

Data Driven-based Prediction and Analysis of Effective Length of Steel Plates

Zishuo Dong; *Xu Li*; Dianhua Zhang; Northeastern University, China

With the increasing industrial productivity and production scale, how to use information technology-related means and intelligent computing methods to gradually improve production efficiency has become a trend in the development of traditional manufacturing industries. The prediction of the effective length of the medium thick plate is essential to assist in the design of sub plates and slabs to improve the yield. However, the defect in the head and tail of the plate after rolling make accurate prediction of the effective length difficult. In this paper, a data-driven method for effective length prediction of steel plates is proposed. Machine vision technology is used as a measurement method for the size of steel plates. Through image processing technology, an accurate plane contour of the steel plate is obtained, and the effective length of the steel plate is calculated by removing the irregular parts of the head and tail of the steel plate. The effective length of medium thick plate prediction performance of a support vector regression (SVM), neural-network-based method (ANN), and random forest method (RF) were evaluated. During model parameters setting, mean error (MAE), root mean square error (RMSE), mean absolute percentage error (MAPE), and correlation coefficient (R) are used as the evaluation indexes. The comparison results show that the ANN model with multiple hidden layers has higher prediction accuracy. On the basis of ANN, the WOA-ANN prediction model is proposed. The whale optimization algorithm (WOA) was used to optimize the ANN weights and threshold initialization process. The results show that the WOA-ANN algorithm further improves the prediction accuracy. At the same time, the correlation analysis shows

that the model proposed in this paper is in high agreement with the actual physical laws. Therefore, the model proposed in this paper can be flexibly applied to the actual rolling site as a supplement to the physical model to improve the prediction accuracy of the effective length of the medium-thick plate, reduce the design cost, and thus improve the yield.

WEDNESDAY, 7 SEPTEMBER 2022, GMT+8 (Beijing)

Room A, Zoom Link:

Plenary Session II

Chairs: Matthias Militzer, The University of British Columbia, Canada

Dierk Raabe, Max-Planck-Institut fuer Eisenforschung GmbH, Germany

14:00-14:45 Plenary

Computational Design of High Performance Steels

Ayush Suhane; *Matthias Militzer;* The University of British Columbia, Canada

Computational tools have aided manufacturing of high-quality steels for decades. For example, the concept of microstructure engineering has been successfully applied to hot rolling of steels. Recent advances in computational materials science have enabled multi-scale process modelling. The status of these modelling strategies is analyzed with an emphasis on hot-rolled high-performance low carbon steels. In particular, an interface-based steel design approach is illustrated with austenite grain growth simulations.

14:45-15:30 Plenary

Innovative Steelworks with Digital Transformation

Sedon Choo; POSCO, Korea

We are implementing a smart production system that collects field data with IoT technology, analyzes and predicts processes based on big data, and automatically controls processes using artificial intelligence technology. POSCO keep innovating with the goal of building an eco-friendly steel mill, creating a safe workplace, and growing together with customers beyond improving its own productivity. In addition, based on the achievements of smart technology development for unit processes and facilities, we are expanding smartization throughout the value chain. We was chosen by the World Economic Forum to be the first Korean "Lighthouse Factory" manufacture in July 2019, in recognition of its successful implementation of the smart factory.

15:30-16:15 Plenary

Reform and Challenge of Al Hot Working Under Emission Peak and Carbon Neutrality

Zuo Xu[1,2]; [1]CITIC Group, China; [2]CITIC Dicastal Co., Ltd., China

Electricity-drive is the most effective means for the automotive industry to face emission peaking and carbon neutrality challenges. The main characteristics in the electricity-drive time are the fast iterative products and digital application. Based on the above reforms, the new requirements including management, production and operation are put forward to the aluminum auto parts enterprises, and the most important challenges are low carbon emission production and intelligent manufacture, and operation modes. Although it is still one of the most important lightweight materials, the main barrier to further expands Al application is high carbon emission in the raw material process caused by the usage of fossil electricity. How to establish the business modes to fit fast iterative products, and meet the requirement of multiple species & medium batch and mass-customized batch, how to make digitalization and intelligent manufacture transformation in traditional enterprise need to be solved urgently. Combine to the real cases, the reform caused by low-carbon production, business innovation, and intelligent manufacture are discussed in this paper. The future trends including resource recycling, agile manufacturing and digital transformation are also put forward, and will introduce significant changes to organization.

16:15-16:30 Coffee Break

16:30-17:15 Plenary

Advanced Thermomechanical Process Simulations under Consideration of Microstructure, Texture and Damage using DAMASK

D. Raabe[1]; M. Diehl[1,2]; V. Shah[1]; K. Traka[1,3]; K. Sedighiani[1,3]; S. Vakili[1]; P. Shanthraj[4]; J. R. Mianroodi[1]; F. Roters[1]; [1]Max-Planck-Institut für Eisenforschung, Germany; [2]KU Leuven, Belgium; [3]Delft University of Technology, The Netherlands; [4]The University of Manchester, UK

The lecture presents a unified multi-physics, multi-mechanism, chemo-mechanical crystal plasticity and recrystallization theory and modeling package together with several applications to engineering alloys subjected to thermomechanical processing. The solution of such complex continuum mechanical boundary value problems requires constitutive laws that are based on material physics (considering effects such as microstructure, texture, chemistry, recrystallization, and damage) and that connect deformation and stress at each material point. This task has been implemented in the free software package DAMASK on the basis of the crystal plasticity method using a variety of constitutive laws and homogenization approaches. It is shown that a purely mechanics-based approach is no longer sufficient to study current advanced metallic materials. In these materials the elasto-plastic deformation via shear carriers such as dislocations, TRIP and TWIP effects is strongly coupled to recrystallization, phase transformation, dissipative sample heating, and damage evolution. Therefore, our theory has recently been extended to treat such chemo-mechanical multi-physics and multi-field phenomena.

17:15-18:00 Plenary

Different Roles of Nb in TMP of Steels: from Classic Austenite Pancake to More Complex Interactions with the Microstructure

Jose M. Rodriguez-Ibabe[1,2]; [1]Ceit-Basque Research and Technology Alliance (BRTA), Spain; [2]Universidad de Navarra-Tecnun, Spain

TMP covers a wide range of processing conditions to meet the requirements defined by the steel grade, final geometry and available layout of the rolling mill. In this scenario, Nb can perform other functions complementary to those initially associated with strain induced precipitation and austenite pancaking. In addition, strain induced precipitation behavior can be substantially affected depending on the grade/geometry/layout combinations and this will intervene in other metallurgical functions that Nb can perform. Based on this, some general considerations about the metallurgical characteristic of Nb in TMP will be detailed including several examples.

Room B, Zoom Link:

Long Product and Processing (Chief Organizer: Xianming Zhao, Northeastern University)

Microstructure and Properties of High Speed Wire (Chair: Yi Luo, CITIC Metal Group Ltd.)

19:00-19:30 Keynote

Investigation of the Factors of Quenched and Tempered 55SiCr Steel Wire Tensile Area Reduction Ratio and Industrial Optimization Trial

Jianjun Qi; Zhenye Chen; Hesteel Group Company Limited, China

In order to improve the tensile area shrinkage rate of 55SiCr wire products, this research systemically characterized and analysed quenched and tempered (QT) 55SiCr steel wires with different manufacturers' high and low area reduction ratios. The relationship between the segregation band width and the tensile area reduction ratio of QT 55SiCr wires was presented and manifested by tensile results after the high-temperature homogenization heat treatment for different durations. Furthermore, the origin of the segregation bands was investigated by QT heat treatment of the whole billet cross-section slice and optical microscopy observation. Finally, continuous casting process optimization was conducted to narrow the segregation bands through a continuous casting heat transfer and CAFÉ numerical modelling. An industrial optimization trial proves that the optimized continuous casting process results in the narrowed segregation bands and improves tensile area reduction ratios. The results of this study provide valuable guidance for the performance optimization of 55SiCr wire products.

19:30-20:00 Keynote

Effect of TMP on Precipitation of Grain Boundary Cementite of Wire Rod for Super and Ultra High Strength Steel Cords

Dayong Guo; Yang Pan; Hang Gao; Bingxi Wang; Bo Zhang; Liguo Ma; Anshan Iron and Steel Group Corporation, China

There is a strong demand for hypereutectoid steel wire rod to produce super high and ultra high strength steel cords to reduce automobile weight and improve fuel efficiency. Microstructure plays an important role in determination of the performance of the hypereutectoid steel wire rod during steel cord production. Grain boundary cementite (GBC), which forms at the prior austenite grain boundaries during the cooling of hypereutectoid steel wire rod, is detrimental to the drawing and bunching performances of the wire rod. Hence the prohibition of the formation of GBC is crucial to the quality control of the wire rod. This paper presents the effect of thermomechanical processing (TMP) on the precipitation of GBC in the wire rod for super high and ultra high strength steel cords. The study was carried out on the samples of hypereutectoid steel, which were melted in a vacuum furnace. The ingots were then reheated and hot-rolled into plates. The samples in this study were fabricated from the plates and treated by TMP using thermal-mechanical simulator. It was found that TMP has a marked effect on the mitigation of GBC precipitation. The sample treated under the condition of strain of 60% and strain rate of $0.1s^{-1}$ exhibits prominent GBC rings. Increases both in strain and strain rate during TMP reduce the grain size of the samples. Smaller grain size provides more sites for nucleation and growth of GBC, allow the carbides precipitate homogeneously along grain boundaries and make the GBC precipitation less obvious. The morphology of GBC changes from networks to discontinuous rings and lines, decreasing the harmful effect of the GBC on the drawing and bunching performances of the hypereutectoid steel wire rod. The recovery and recrystallization behaviors of the high carbon steel during TMP were also studied. The current results provide important guidelines for the control of GBC precipitation in the industrial production of wire rods for steel cords.

20:00-20:30 Keynote

Towards Revealing Indentation-induced Plastic Flow in FCC metals

Wenzhen Xia; Anhui University of Technology, China

The indentation-induced plastic flow and roughness have been intensively studied in the last decades. However, the elemental mechanisms of how plastic flow leads to pile-up formation are still not fully clear, although this is one of the initial steps causing surface roughening in tribological contacts at low loads. In this work, {001}, {101}

and {111}- grain orientations in Fe40Co20Cr20Mn10Ni10 (at. %) high entropy alloy with medium stacking faults energy are indented with varying load forces. Through the evolution analysis of slip-step and martensite transformation, we verify: (1) the activation sequence of slip-plane and (2) the slip-plane inclination determines the plastic flow, and further reveal: (1) the influence of martensite transformation on the plastic flow and (2) the mechanism of plastic flow induced martensite transformation.

20:30-20:45 Coffee break

Section Steel Rolling / Process and Control of Wire and Rod (Chair: Wenzhen Xia, Anhui University of Technology)

20:45-21:15 Keynote

Improvement of the Rolling Contact Fatigue Behavior on High-speed Railway Steel by Using Laminar Plasma Quenching Technology

Qingsong Zhang[1,2]; *Isaac Toda-Caraballo*[2]; Zongli Feng[1]; Shuang Li[2]; Qiuze Li[3]; Deping Yu[4]; [1]Southwest Jiaotong University, China; [2]Materalia Group, National Centre for Metallurgical Research, Spain; [3]CRRC Changchun Railway Vehicles Co., Ltd., China; [4]Sichuan University, China

In this work, the surfaces of CRH3 wheel steel (ER8) and rail steel (U71MnG) were treated using Laminar Plasma Technology by scanning and dispersed spot quenching methods. A combination of microstructural analysis, surface temperature evolution during the laminar plasma processing by finite element modelling (FEM), as well as the stress distribution on the heat affected zone (HAZ) during service is performed to provide a deep insight on the materials behavior and rolling contact fatigue (RCF) damage. Results show that the microstructure of the HAZ consists of martensite, retained austenite and undissolved cementite, showing a significant increase of microhardness which made possible that no plastic deformation occurred during service in the hardened layer. The simulations performed showed clearly the different stress distribution due to the treatments, which together with the experimental analysis explained the significant increase of fatigue life is observed. In conclusion, the laminar plasma quenching technology can effectively increase the service performance of wheel steel.

21:15-21:40 Invited

Understanding the Thermomechanical Processing Mechanism of the HRB400E Rebars with Nb Microalloyed

Yi Luo; Yongqing Zhang; CITIC Metal Group Ltd., China

The physical metallurgy of thermomechanical processing(TMP) on the Nb-bearing low carbon steel plates has become much better understood and led to improve their properties and production. In view of the wide application of TMP on Nb-bearing low carbon steel plates, for which Nb has been regarded as the most effective TMP microalloy element. Rebars with Nb microalloyed have been also researched and developed more and more nowadays, and the physical metallurgical mechanism of which is gradually clear. At present, the development and mass production of Nb-bearing hot rolled rebars, along with V bearing ones, can save iron and steel consumption and reduce carbon emission, and jointly promote the healthy development of construction industry in China. CITIC Microalloying Technology Center together with scientific research institutions and domestic leading rebars makers, after years of exploring the physical metallurgy mechanism of Nb microalloyed steel, and R&D of Nb-bearing aseismic rebars, has clarified the role of Nb in rebars. Combined with development and upgrading of the bar rolling lines, the TMP mechanism of the HRB400E rebars with Nb microalloyed is introduced in this paper.

21:40-22:00 Contributed

Improving Rebar Quality Reducing Alloy Elements by DANIELI Ultra-Fine-Grain Technology

Simone Ferrarese; Maicol Cimolino; Danieli & C. Officine Meccaniche S.p.A., Italy

In the years 2018 - 2020, Chinese market rebar demand grew to over 260 Mty, thanks to new buildings and infrastructure developments. This growing demand was followed by a slight descent (-6% in 2021), with some more percentage points per year reduction forecasts for the years 2022 and 2023. The rebar market boost in the years 2018 – 2020 was accompanied by a fundamental change which took place in rebar production, concerning the types of rebar used, and developed following the latest Chinese standard GB/T 1499-2018. Until 2007 the Chinese market was mainly oriented toward grades with a low yield strength, but later on was discussed a reconsideration of the use of lower strength and poor-quality rebar. Thanks also to the GB/T 1499-2018 which was issued in late 2018, the Ultra - Fine Grain steel grades (designated HRBF) with ferrite/perlite structure and a specific grain size (less than 9) were introduced.

In addition, with the latest standard release some new grades, such as HRB600, were added; and was excluded the presence in the microstructure of any tempered martensitic structure. The common way to achieve the latest requirements mentioned above, is to add alloying elements such as Niobium (Nb), Vanadium (V) and Titanium (Ti), inevitably, with a consequent significant increase in production costs. Instead, in order to meet the new standards requirements and the challenging targets set by steel producers, Danieli developed and installed in several plants the inline UFG (Ultra-Fine-Grain) process for straight bars and wire rod, which allows a drastic reduction in the expense of the alloy elements. Thanks to the regulation of the material cooling stages and the proper control of the deformation process will be possible to compensate the effect of the strengthening mechanism generally given by alloying elements. Here are presented some of the latest projects and the tangible results obtained by some Chinese steelmakers who applied the Danieli high-tech equipment and process mastership ensuring the tight standard requirements at lower production costs.

Room C, Zoom Link:

Microstructure and Properties of Steels (Chief Organizer: Liqing Chen, Northeastern University)

High-alloy Steel (Chairs: Zhongwu Zhang, Harbin Engineering University; Zhangwei Wang, Central South University)

19:00-19:30 Keynote

Design of High-strength and Ductile Compositionally Complex Steels

Zhangwei Wang; Central South University, China

We have developed a new class of compositionally complex (CCSs) by taking the advantage of the previously proposed high-entropy alloy (HEA) design concept. These newly designed CCSs contain five major components, in which Fe has the highest atomic fraction and the minimal content of each component is above 5 at. %. This approach allows us to use the high solid solution strengthening and shift the alloys' compositions into previously unattainable phase regions where both nanosized shearable-carbides and non-shearable B2 particles are simultaneously formed. We investigated the nanoprecipitation behavior of carbides and B2 phases in these novel CCSs by means of high resolution scanning transmission electron microscopy (STEM) and atom probe tomography (APT) at atomic scales. Upon uniaxial tensile testing, our CCSs show excellent specific strength and ductility, outperforming both the previous HEAs and the advanced lightweight steels. We further systematically investigated the interactions between dislocations and second phases including carbides and B2 particles to explain the outstanding specific strength and ductility in the CCSs. Our study thus provides a number of new insights into the design of high-performance novel structural materials.

19:30-20:00 Keynote

Development of New Lightweight Stainless Steels with Excellent Tensile Property

Chang-Hoon Lee[1]; Kyeong-Won Kim[1]; Heon-Young Ha[1]; Seong-Jun Kim[1]; Sung-Dae Kim[1]; Jae Hoon Jang[1]; Tae-Ho Lee[1]; Joonoh Moon[2]; Hyun-Uk Hong[2]; [1]Korea Institute of Materials Science, Korea; [2]Changwon National

University, Korea

To develop Fe-Mn-Al-C austenitic lightweight steels with enhanced corrosion properties, namely lightweight stainless steels, the effect of Cr addition on microstructures and tensile properties of Fe-20Mn-12Al-1.5C lightweight steels was investigated in this work. Microstructural phases were thoroughly identified through scanning electron microscopy (SEM), transmission electron microscopy (TEM), electron backscatter diffraction (EBSD), and x-ray diffraction (XRD), and corrosion test was carried out. There is a drastic change in microstructures of Fe-Mn-Al-C lightweight steels with Cr content. Fe-20Mn-12Al-1.5C lightweight steel without Cr consisted of austenite with fine intragranular κ-carbides, coarse intergranular κ-carbides, and a small amount of ferrite. As Cr content increased to 5 wt.%, coarse κ-carbides around grain boundaries disappeared and the fraction of ferrite slightly decreased, while the fraction of austenite slightly increased, leading to a homogenized microstructure consisting of mostly austenite with fine intragranular κ-carbides and a very small amount of ferrite and ordered phase DO_3. It results from that Cr, a strong carbide former, prevents precipitation of κ-carbides and thereby soluble C in austenite matrix increases. At 6 ~ 8 wt.% of Cr, Cr-rich M_7C_3 carbides precipitated and the fraction of ordered phase DO_3 increased drastically with increasing Cr contents since Cr acts as a carbide former as well as a ferrite stabilizer. The yield strength (YS) and ultimate tensile strength (UTS) decreased and elongation increased significantly with Cr contents up to 5 wt.%. Over 6 wt.% of Cr, strengths increased, but elongation decreased drastically due to the precipitation of brittle M_7C_3 carbides. Fe-20Mn-12Al-1.5C lightweight steel shows the best combination of strengths and elongation at 5 wt.% of Cr as well as excellent corrosion property due to less heterogeneity of microstructures with austenite and κ-carbide inside austenite and very small amount of ordered phase DO_3. Therefore, we developed Fe-Mn-Al-C-Cr lightweight stainless steel by optimizing Cr content with the potential to replace commercial stainless steels as it has much higher strength at similar formability, 17% lower mass density, and excellent corrosion resistance.

20:00-20:25 Invited

Engineering the High-Mn TRIP Steel via Heavy Ausforming

Qingquan Lai; Nanjing Tech University, China

This study explores the effect of heavy ausforming on the microstructure and mechanical properties of a high-Mn TRIP steel. The coarse-grained microstructure, consisting of 65vol.% of ε-martensite, presents limited mechanical properties as well as a brittle fracture behavior. By means of heavy ausforming, an ultrafine-grained microstructure is produced, associating with a fully austenitic microstructure at room temperature. Under mechanical loading, the transformation-induced plasticity leads to a high combination of strength and resistance to plastic localization. A ductile fracture mode in the ultrafine-grained microstructure also contrasts with the coarse-grained counterpart. The outstanding mechanical performance of the heavily-ausformed microstructure is attributed to the transformation-induced ultrafine-grained ε-martensite, in which non-basal <c+a> slip is dominant in the plastic deformation instead of mechanical twinning. A micromechanical model is also developed to probe the partitioning of stress and strain between phase constituents.

20:25-20:45 Contributed

Study of Grain Boundary Engineering of Austenitic Steels for Nuclear Reactors

Tingguang Liu; University of Science and Technology Beijing, China

Austenitic steels are widely used as component materials facing high-temperature and high-pressure water in nuclear power plants, such as 316L stainless steel and Ni-based alloy 600. They are susceptible to intergranular corrosion (IGC) and intergranular stress corrosion cracking (IGSCC) due to the synergistic action of stress and corrosive environment during their service life. Grain boundary engineering (GBE) is believed an impressing technology that can effectively inhibit intergranular attacking. In this work, the gran boundary character distributions of several austenitic steels after different thermomechanical processing in terms of GBE were investigated. The mechanism to strengthening the IGSCC resistance of austenitic steels by using GBE was studied. The grain boundary characteristics along the SCC path were characterized. Results shows that the low-Σ coincidence site lattice (CSL) boundaries perform high resistance to intergranular cracking. The microstructure of large grain-clusters is the direct reason for the improvement of IGSCC of the steels after GBE treatment. The distribution of twin boundaries in quadruple junctions and its effects to intergranular cracking were investigated by using 3D-EBSD characterization, showing that both the quantity and distribution of CSL boundaries in gran boundary network determine the strengthening effect of GBE on intergranular cracking. Advanced GBE technique via thermomechanical processing to realize the interrupted random grain boundary network could make materials immune to intergranular SCC.

20:45-21:00 Coffee break

21:00-21:30 Keynote

Improving the Creep Strength of 9Cr Ferritic/Martensitic Steels via MX Precipitation Optimization

David San-Martin[1]; Javier Vivas[1,6]; Eberhard Altstadt[2]; Mario Houska[2]; Marta Serrano[3]; David De-Castro[1]; Jonathan D. Poplawsky[4]; Wei Xu[5]; Carlos Capdevila[1]; [1]CENIM-CSIC, Spain; [2]Helmholtz-Zentrum Dresden-Rossendorf, Germany; [3]CIEMAT, Spain; [4]Oak Ridge National Laboratory, USA; [5]Northeastern University, China; [6]Ordizia, Spain

There is a need to increase the operation temperature of 9Cr ferritic/martensitic steels to improve the efficiency of future power plants. The key is to improve the thermal stability of the microstructure above 600-650 ºC. The microstructure of 9Cr steels, in normalized condition, consists of lath-like martensite with a high dislocation density and some precipitates. During tempering, dislocation structures recover and the laths evolve into subgrains. Large Cr-rich $M_{23}C_6$ carbides also precipitate mainly on lath boundaries and on prior austenite grain boundaries. Finer MX carbonitrides have been observed within the matrix, but in a lower amount than $M_{23}C_6$. At elevated temperatures, during the recovery/recrystallization processes, $M_{23}C_6$ carbides stabilize the subgrain boundaries and the MX precipitates pin the dislocations, leading to grain refinement of the microstructure. The distribution and size of MX nanoprecipitates presented in these steels have been demonstrated to be key factors for improving microstructural stability during creep. To improve the creep strength and raise the operation temperature of these type of steels, this investigation has been focused on exploring two different strategies; both aimed at refining the size of MX precipitates and increasing its number density and thermal stability. The first approach introduces an ausforming step prior to quenching and tempering to increase the dislocation density compared to the conventional processing route. In the second approach three different heat resistant steels (so-called HDSN in this work) have been designed based on the thermodynamic calculations to a have higher number density of MX nanoprecipitates than commercial 9Cr ferritic/martensitic steels. The microstructures of these steels have been investigated by SEM, TEM, APT and EBSD. Small Punch Creep Tests (SPCT) have demonstrated that by means of these two strategies, the creep strength can be improved as compared with a current commercial 9Cr ferritic/martensitic steel (G91). However, the implementation of an ausforming step seems to deteriorate the ductility and this should be further investigated and overcome.

21:30-22:00 Keynote

Enhanced Strength via Nanoprecipitate in a Maraging Stainless Steel

Junpeng Li; *Zhongwu Zhang;* Songsong Xu; Hao Guo; Harbin Engineering University, China

The microstructures and mechanical properties of Fe12Cr7Co9Ni2Cu1.5Mo0.6Ti0.4Al maraging stainless steel were studied. The tensile properties of Fe12Cr7Co9Ni2Cu1.5Mo0.6Ti0.4Al maraging stainless steel were evaluated from the specimens subjected to various aging time. The hardness result shows that with the increase in aging time, maraging stainless steel possesses a remarkable precipitation strengthening response. The developed maraging stainless steel has a yield strength of 1250 MPa and an elongation of 25%. Yield strength shows a substantial increase by ~450 MPa, together with increase elongation-to-failure, from 18% to 25%. Precipitation strengthening provides an large increment in strength without scarifying the ductility.

22:00-22:20 Contributed

Multiple Mechanisms in Non-equiatomic FeMnCoCr High-entropy Alloys under Cryogenic Deformation and Dynamic Loading

Zhufeng He; Nan Jia; Northeastern University, China

The relationships between deformation mechanisms which mainly affected by stacking fault energy (SFE) and mechanical properties, microstructure evolution of two typical non-equiatomic high entropy alloys (HEAs) have been studied in this work. Firstly, a non-equiatomic Fe40Mn40Co10Cr10 HEA which shows a single face-centered cubic (fcc) structure in the undeformed state, has been systematically investigated at room and cryogenic temperatures. Both strength and ductility increase significantly when reducing the probing temperature from 293 K to 77 K. During tensile deformation at 293 K, dislocation slip and mechanical twinning prevail. At 77 K athermal martensitic transformation prevail in addition to dislocation slip and twinning. The reduction in the mean free path for dislocation slip through the fine martensite bundles and deformation twins leads to the further increased strength. The joint activation of transformation and twinning under cryogenic conditions is attribute to the decreased SFE and enhanced flow stress of the fcc matrix with decreasing temperature. These mechanisms lead to an evaluated strain hardening capacity and enhanced strength-ductility combination. Secondly, the relationship between mechanical properties and microstructures of a metastable dual-phase high entropy alloy Fe50Mn30Co10Cr10 under uniaxial tensile testing at different strain rates (10^{-3} s^{-1}~10^{3} s^{-1}) has been studied systematically. As the strain rate increases, yield strength, ultimate tensile strength and uniform elongation decrease first and then increase. As dynamic deformation is affected by the adiabatic heating, the stacking fault energy of the alloy is increased by ~13 $mJ\cdot m^{-2}$ at a strain rate of 10^{3} s^{-1} compared with that in the quasi-static condition. Under quasi-static loading, martensitic transformation is the dominant deformation mechanism. Under dynamic loading, when the strain is low the deformation induced phase transformation dominates the deformation, whereas as the loading proceeds mechanical twinning becomes the dominant deformation mode. At the same time, the adiabatic temperature rise under dynamic tests also causes a reverse transformation from ε-martensite to austenite. Accordingly, the release of internal stress and the formation of soft and ductile austenite jointly contribute to the elevated uniform elongation of the material. Both mechanical twinning and martensitic reverse transformation promote the microstructure to be dynamically refined, so that the alloy shows the good plasticity while maintaining the high ultimate tensile strength at dynamic strain rates. The low SFE of FeMnCoCr HEAs are realized by relaxing the equiatomic HEA constraints towards reduced Ni and increased Mn contents. The insight that excellent mechanical properties obtained by change of SFE is important for designing strong and ductile Ni-saving HEAs.

22:20-22:35 Contributed

Springback Reduction of 301L Stainless Steel Arc-bending under Impact Hydroforming

Hao Li[1,2]; Shi-Hong Zhang[1]; Yong Xu[1]; Shuai-Feng Chen[1]; Hong-Wu Song[1]; [1]Institute of Metal Research, Chinese Academy of Sciences; [2]University of Science and Technology of China

In this paper, the springback behavior of 301L stainless steel sheet after arc-bending at high strain rate was tested by impact hydroforming (IHF) experiments. It was discovered that the springback of arc-bent 301L sheet is significantly reduced with an impact velocity of 33.54 m/s. To reveal the mechanism of springback reduction, solid-liquid coupling finite element model was established to analyze the effect of the high-speed loading liquid on material flow and springback behavior. To establish accurate material's model in simulation, constitutive equation describing dynamic mechanical behavior of 301L stainless steel was established based on simplified Johnson-Cook (J-C) model. The necessary parameter value in J-C model was derived from uni-axial tensile tests within different strain rates (1×10^{-4} s^{-1} ~ 3×10^{3} s^{-1}). By comparing with the simulation and experimental results, it indicates that the predicted profiles of bent sheet after springback show good agreement with the experimental results. Specially, as compared with conventional bending, the special material flow behavior induced by high speed liquid changes the deformation path of sheet during IHF, resulting in notable different distribution of strain/stress during forming process, and thus obviously reduces springback. Further, IHF promotes the development of plastic strain around the arc region, which is another critical factor for springback reduction.

Room D, Zoom Link:

Service Performance of Metallic Materials (Chief Organizer: Zhenyu Liu, Northeastern University)

Corrosion Behavior (Chair: Linlin Li, Northeastern University)

19:00-19:30 Keynote

Present Situation and Development of Protective Coatings

Fuhui Wang; Northeastern University, China

19:30-20:00 Keynote

Environmental Induced Degradation Behavior of Multi-principal High-Entropy Alloys

Hong Luo; Zhimin Pan; Xiaogang Li; University of Science and Technology Beijing, China

High-entropy alloys (HEAs), consisting of multi-principal elements, have been attracting extensive attention as

promising candidates for structural applications beyond those of conventional metallic materials. HEAs are receiving increasing attention and attention from materials researchers due to their various excellent properties. In the face of increasingly harsh service environment, whether such new materials can obtain certain applications, we need to conduct in-depth research and discussion. This paper focuses on the failure behavior and mechanisms of various multi-principal face-centered cubic high-entropy alloys in acidic, alkaline, neutral, and hydrogen environments. Through the research in this paper, we reveal the composition and structure of the passive film on the surface of high-entropy alloys and the mechanism of environmental corrosion resistance. Meanwhile, the mechanical damage behavior and failure mechanism of high-entropy alloys in hydrogen environment are proposed. The research results lay the foundation for further enhancing the service safety of multi-principal high-entropy alloy materials in multiple environments.

20:00-20:30 Keynote

Prediction for the Corrosion Lifetime of HP-13Cr Stainless Steel in the Ultradeep Well Environment

Tao Zhang; Yang Zhao; Wenlong Qi; Jidong Wang; Fuhui Wang; Northeastern University, China

A multi-degree of freedom mechanistic-chemometrics model for predicting the pitting damage of HP-13Cr stainless steel is developed by combining the mechanistic models and chemometrics method. The mechanistic model is reconstructed by considering the effect of single factors, such as high temperature, high CO2 pressure, flow rates and complex stress distribution. The single mechanistic models are combined together considering the weight coefficients of variable interaction using the chemometrics method. Finally, the predicted results are validated by six-year-served field data, which indicates that the newly developed mechanistic-chemometrics model is accurate and highly reliable.

20:30-20:45 Coffee break

20:45-21:10 Invited

A Comparative Study of Corrosion Behavior of Martensitic and Duplex Stainless Steels in Arduous Environments Containing CO_2/H_2S Relevant to Deep-Geothermal Energy Production

Yong Hua; Zhejiang JIULI Hi-Tech Metals Co. Ltd., China

This paper focused on the corrosion behaviour of S13Cr and 2205 DSS in the deep geological environment. The relationship between the corrosion products and general/localised corrosion behaviour of various materials under different CO_2/H_2S concentrations at 150 °C was systematically investigated. For all the materials, the adsorption of HS^- and S^{2-} promotes the defects within the passive films and decreases the stability of the passive films on the surface. The results also indicate that high H_2S partial pressure of 33.1 bar promoted the general/localised corrosion via precipitation of the S-rich products. No S-containing crystals were detected through XRD measurements, suggesting that this FeS/FeS_2 layer might be too thin and XRD cannot detect them under low H_2S partial pressure. For S13Cr, the presence of high H_2S partial pressure promoted the corrosion kinetics, the composition of the corrosion products was mainly FeS, FeS_2 and they coexisted with undissolved Cr_2O_3 and $Cr(OH)_3$ at 33.1 bar of H_2S partial pressure, and the thickness of the corrosion scales was non-uniformly distributed on the surface. For 2205 DSS, the introduction of H_2S resulted in the formation of two different morphologies on the surface, for the bright region, Cr_2O_3 and $Cr(OH)_3$ were the main components. The corrosion products in the black region were mainly comprised of FeS, FeS_2 and NiS. It should be noted that the presence of H_2S plays a leading role in localized corrosion kinetics. A low p_{H2S} contributes to the formation of small pits, however, high p_{H2S} induces severe localized corrosion with preferential dissolution at phase boundary/ferrite phases. As the increase in H_2S partial pressure up to 33.1 bar, the localsied corrosion rate of 2205 DSS increased significantly than that of S13Cr under the current study. The characterisation of the corrosion products is combined with thermodynamics calculations.

Mechanical Behavior and Fatigue Performance I (Chair: Linlin Li, Northeastern University)

21:10-21:35 Invited

The Effect of Carbon on Mechanical Performance of a Non-equiatomic High-Entropy Steel and the Comprehensive Strengthening Mechanism

Xiaolin Li[1]; Qian Li[1]; Xiaoxiao Hao[1]; Xiangtao Deng[2]; Zhaodong Wang[2]; [1]Northwestern Polytechnical University, China; [2]Northeastern University, China

The deformation mechanism of a C-doped interstitial high-entropy steel with a nominal composition of Fe49.5Mn29.7Co9.9Cr9.9C1 (at.%) were investigated. An excellent combination of strength and ductility was obtained by cold rolling and annealing. The structure of the alloy consists of an FCC matrix and randomly distributed Cr23C6. For gaining a better understanding of the deformation mechanism, EBSD and TEM were conducted to characterize the microstructure of tensile specimens interrupted at different strains. At low strain (2%), deformation is dominated by dislocations and their partial slip. With the strain increasing to 20%, deformation-driven athermal phase transformation and dislocations slip are the main deformation mechanism. While at a high strain of 35% before necking, deformation twins have been observed besides the HCP phase. The simultaneous effect of phase transformation (TRIP effect) and mechanical twins (TWIP effect) delay the shrinkage, and improve the tensile strength and plasticity. What's more, compared with the HEA without C addition, the yield strength of the C-doped iHEA has been improved, which can be attributed to the grain refinement strengthening and precipitation hardening. Together with the lattice friction and solid solution strengthening, the theoretically calculated values of yield strength match well with the experimental results.

21:35-21:55 Contributed

Achieving Low Young's Modulus and High Ductility in a Compositionally Complex Alloy via Metastable Engineering

Bingnan Qian; Jikui Liu; Junhua Hou; Tianming Sun; Sihao Zou; Fengchao An; Wenjun Lu; Southern University of Science and Technology, China

In refectory alloys, the body centered cubic (BCC) structure is known as a common phase limiting the deformability of such alloys due to their embrittlement at room temperature. Here, we developed a novel strategy (compositionally complex alloy (CCA) design) to benefit from metastable engineering while preventing their embrittlement in BCC refectory alloys. The non-equiatomic compositions of the CCAs lead to a stress-induced martensitic (SIM) transformation, i.e., BCC→hexagonal close packed (HCP) phases due to the instability of the BCC matrix. After careful study of the deformation behaviors, it is obvious that the SIM plays a key role in influencing the mechanical properties of the CCAs. At the elastic region of tensile loading, the SIM can effectively reduce Young's modulus of the CCA (45 GPa) because of the elastic softening effect caused by the SIM transformation. Then the BCC phase totally transforms into HCP martensite, whereas offers a twinning transformation (i.e., $\{10\bar{1}1\}<10\bar{1}\bar{2}>$ and $\{10\bar{1}2\}<10\bar{1}\bar{1}>$ HCP twins) at the plastic stage of tensile tests. These transformations further contribute to a double yield effect. As a result, a high work hardening (9 GPa) and a decent ductility (20%) with a low level of apparent yield stress (300MPa) and a high ultimate tensile strength (824 MPa) are achieved in the CCAs. The results provide a new alloy-design strategy using the SIM for developing ductile CCAs with low Young's modulus.

Room E, Zoom Link:

Non-ferrous Alloys and Processing (Chief Organizer: Yong Li, Northeastern University)

Magnesium Alloys, Titanium Alloys and Nickel Alloys II (Chair: Yong Li, Northeastern University)

19:00-19:30 Keynote

Mechanistic Investigation of the Novel Low-cost Mg-Ca Based Extrusion Alloy with High Strength-ductility

Synergy

Hucheng Pan; Hongbo Xie; Yuping Ren; Gaowu Qin; Northeastern University, China

In recent years, it becomes more and more urgent for industry to develop low-cost and rare earth-free magnesium alloys, and the yield strength higher than 350 MPa is usually necessary. Recently, we have discovered a new grain refinement mechanism in conventional extruded Mg-Ca based RE-free Mg alloys. Adding a small amount of Ca can induce the segregation of Ca at the grain boundary and the dynamic precipitation of nano-Mg_2Ca phases, and finally obtain the refined a-Mg matrix down to submicron size (~0.32 μm), which is normally difficult to achieve by conventional extrusion. Consequently, this Ca-containing Mg alloy exhibits an excellent mechanical property (yield strength ~ 443 MPa). In particular, this alloy can display ultra-high strength at a low solute content of ~ 4 wt.%, e.g., the high-strength low-alloying magnesium materials. However, the plasticity of this alloy is low (~1.2%), which severely limits its wider practical applications. Fortunately, we have recently designed a novel micro-alloyed Mg-Ca-Al-Zn-Mn alloy (total alloy content <2.4 wt.%), which exhibits excellent combination of strength and plasticity, yield strength ~ 425 MPa, tensile strength ~ 442 MPa, and elongation ~ 11%. The microstructure analysis shows that the matrix of this ductile alloy contains high density low angle grain boundaries (LAGBs) and the thickness of the subgrain lamella is 200-500 nm. Further TEM analysis confirmed that the <c+a> dislocations formed during deformation of this ductile alloy are intrinsically less prone to dissociate. Instead, the mobile dislocations interact intensively with the high-density LAGBs, which thereby ensured the multiplication of dislocations and improved the strength and plasticity of present Mg alloy.

19:30-20:00 Keynote

Shear Band in AZ91 Magnesium Alloy Produced by Warm Compression

Dongxiao Wang; Ben Yu; Yi Jing; *Jianping Li*; Northeastern University, China

The shear band produced by magnesium alloy during warm deformation is one of the main factors leading to cracks. The shear band produced by warm temperature compression is studied in this paper, some characteristics of AZ91 compressed at 200 ℃ were observed by optical microscope (OM), electron probe microanalysis (EPMA), electron backscatter diffraction (EBSD) and transmission electron microscopy (TEM). The results show that the deformation mechanism is mainly sliding and twinning in the warm temperature compression. The twin modes of coordinated deformation are mainly 86.3 °$\{10\bar{1}2\} < 11\bar{2}0 >$ extension twins, 37.55 °$\{10\bar{1}2\}$ - $\{10\bar{1}2\} < 11\bar{1}0 >$ secondary twins and 29.69 °{10-13} - $\{10\bar{1}2\} < 1\bar{1}\bar{2}0 >$ secondary twins. Due to the slow speed of twin-slip coordination deformation a large number of dislocations gather and produce shear bands at a slightly faster compression speed, which is one of the sources of crack initiation in the deformation process. Besides, a large number of β-$Mg_{17}Al^{12}$ phases precipitated at the shear band, and the uneven distribution of the precipitated phases in the α-Mg matrix also leads to the cracks.

20:00-20:30 Keynote

Numerical Modeling of Unmixed Zone and Macrosegregation Distribution during MIG Welding of an AA6063 Alloy with an ER5183 Filler Metal

Yu Chen[1]; *Qingyu Zhang[1]*; Shule Xia[2]; Xiaonan Wang[1]; [1]Soochow University, China; [2]CITIC Dicastal Co., Ltd., China

A lattice Boltzmann (LB) model is applied for the simulations of unmixed zone and macrosegregation distribution during MIG welding of a 6063 aluminum alloy sheets with an ER5183 filler metal. The multi-phase flow and solute transports are calculated by multi-relaxation-time (MRT) and the lattice Bhatnagar-Gross-Krook (LBGK) schemes, respectively. The LB simulations indicate that the impact effects of the filler metal droplets with vertical direction result in downward and upward flows in the weld pool, leading to that the high-concentration area of solute Mg presents a layered morphology, while the high-concentration of solue Si zones symmetrically distribute in left and right sides of the molten pool. As a result, the unmixed zones are formed in the weld pool, denoting the area of the solute macrosegregation in the weld joint. The numerical simulations of the droplet impacting the molten pool with random directions are simulated. The processes of liquid mixing and evolution of solute distribution become more complicated, and the solute Mg heterogeneity in the weld pool can be greatly reduced, while the solute Si accumulates at the bottom of the molten pool. The quantitative data obtained from the LB simulations show that the solute distributions in the weld pool become more uniform with the increase of droplet velocity and by applying an alternating flight direction.

20:30-20:45 Coffee break

Aluminum Alloys (Chair: Hucheng Pan, Northeastern University)

20:45-21:15 Keynote

Quantitative Relationship between Microstructure and Tensile Properties of Al-Zn-Mg-Cu Alloys with Various Alloying Degrees

Yanan Li[1,2,3]; *Zhihui Li[1,2,3]*; Ruishuai Gao[1,2,3]; Xiwu Li[1,2,3]; Kai Wen[1,2,3]; Yongan Zhang[1,2,3]; Baiqing Xiong[1,2,3]; [1]State Key Laboratory of Nonferrous Metals and Processes, GRINM Group Co., Ltd., China; [2]GRIMAT Engineering Institute Co., Ltd., China; [3]General Research Institute for Nonferrous Metals, China

Quantitative relationship between microstructure and tensile properties of Al-Zn-Mg-Cu alloys with various alloying degrees was investigated in this study. Three kinds of high strength Al-Zn-Mg-Cu alloys with little strength difference were used for the microstructural characteristic and statistical analysis. A strength model with high accuracy was established through the systematical calculation of strengthening theories, which was validated by the microstructure and UTS of a testing sample. The model gives the precise ratio of the contribution of precipitation hardening and even the component that achieved from the bypass mechanism. Moreover, guidance on the regulation of precipitation phases was proposed from the strength model. It can be disclosed that the alloys will show the best strength when the precipitates of 7xxx series Al alloy are distributed near the right of critical radius, which is identified as 2.5 nm in this model.

21:15-21:45 Keynote

Role of Mn-dispersoids on the Tensile Properties and Recrystallization Resistance in an Al3Mg0.8Mn Rolled Alloy

Kun Liu; University of Quebec at Chicoutimi, Canada

In the present study, the role of Mn-dispersoids on the tensile properties and recrystallization resistance in an Al3Mg0.8Mn rolled alloy was investigated. During heat treatment, the modified low-temperature three-step heat treatment (275 ℃ / 12h + 375 ℃ / 48 h + 425 ℃ / 12h) generated a higher number density of Mn-bearing dispersoids with finer size compared to the high-temperature industrial heat treatment, leading to the remarkable improved mechanical properties after both hot and cold rolling. The yield strength (YS) reached 196 MPa and 233 MPa after hot/cold rolling and annealing, respectively, showing an improvement of 30% over the samples with the industrial heat treatment. In addition, the modified three-step heat treatment showed a stronger recrystallization resistance after hot and cold rolling, owing to the higher number density of Mn-dispersoids and the lower fraction of dispersoid free zone (DFZ) compared to the base heat treatment. The YS contributions of various strengthening mechanisms after hot and cold rolling were quantitatively analyzed using the constitutive equations. The predicted YSs were in good agreement with the experimentally measured values.

Room F, Zoom Link:

Digitalization and Intelligent Manufacturing (Chief Organizers: Dianhua Zhang, Northeastern University; Jie Sun, Northeastern University)

Intelligent Manufacturing I (Chair: Wei Guo, Shougang Research Institute of Technology)

19:00-19:30 Keynote

Research and Application of Intelligent Optimization Technology in Baosteel Manufacturing and Supply Chain

Shujin Jia; *Jing Wen;* Baosteel Central Research Institutes, China

The development trend of intelligent manufacturing technology is from automation, information to intelligence. Until now, steel industry management information system is basically completed, which mainly relies on manual work to conduct optimization and decision making. The intelligent technology in steel manufacturing is still in the automation and information level. To achieve the transformation and upgrading of steel industry, intelligent technology, especially the intelligent optimization and decision support technology is the key to high-quality development of steel industry. This report briefly introduced the research and application of intelligent optimization techniques in Baosteel manufacturing and supply chain: (1)Alloy intelligent procurement system is an effective tool for alloy cost management and alloy production management. This system achieves the cooperation between production and purchase with technologies including big data, metallurgy, optimization and control. After the application of this system, inventory and order cycle are reduced by 20% and 50% respectively. (2)Steel-making and hot-rolling intelligent scheduling concerns order selection, steel-making plan and hot-rolling plan. Baosteel adopts intelligent scheduling models to describe these problems and then proposes customized algorithms to obtain the optimal or approximate optimal solutions to these scheduling problems.

19:30-20:00 Keynote

Machine Learning Modelling for Thermomechanical Control of Advanced Steels: A Case Study to Predict Deformation Induced Martensite Formation

Wangzhong Mu[1]; Joakim Odqvist[1,2]; Peter Hedström[1,2]; [1]KTH Royal Institute of Technology, Sweden; [2]Ferritico AB, Sweden

To date, machine learning (ML) a branch of artificial intelligence (AI) started to be utilized for multiple applications in thermomechanical process control and microstructure evolution in advanced steels. This method has gained interest in multiple applications for microstructure prediction and process control in advanced steels. Deformation-induced martensite (DIM) is a key microstructure in metastable austenitic stainless steels, generating the TRIP effect. In this work we attempt to predict DIM utilizing an integrated approach of ML and a physical model. The database of experimental data is physically modelled using the Olson-Cohen model to expand the database, and subsequently different ensemble learning ML methods are applied. Finally, the model performance is validated using unseen data from different austenitic stainless steel grades. Besides, other examples e.g. mechanical property evolution in duplex stainless steels is also briefly mentioned. This work aims to foresee further implementation of ML more broadly in steels research of large benefits for the industrial community.

20:00-20:30 Keynote

AIM: Collaborative Analysis of Laboratory Small Sample Data and Industrial Big Data

Huwei Li; Wei Xu; *Chenchong Wang*; Northeastern University, China

With the advent of the era of big data, machine learning (ML) is widely used in big data analysis. At present, various artificial intelligence analysis methods have been accumulated for the analysis of industrial data. However, limited by the extensibility of one regression strategy, it is difficult to obtain a generic property prediction model for multi-type steels. At the same time, the mechanism information formed in the small sample data of the laboratory is also difficult to provide guidance for the analysis of industrial big data. To solve this problem, ML classification and regression models combined with physical metallurgy (PM) variables are developed to be a novel industrial big data analysis system in this work. Firstly, the database of different types of steels are obtained from the industrial production lines and carefully preprocessed. Then the data classification is realized based on K-nearest neighbor (KNN) algorithm. According to the classification results, different ML algorithms are selected for each category to maximize the prediction accuracy. Considering the role of PM variables in improving the accuracy of the models, some relevant PM parameters (AC1 temperature, AC3 temperature and flow stress) are introduced to guide the ML process. Through the reasonable combination of different regression strategies, the results clearly shows that the scalability of the property prediction model based on data classification is significantly improved. As for data classification, the dataset is divided into five subsets so that the complexity of the original dataset is reduced. In addition, compared with the prediction model established directly using the original dataset, the proposed industrial analysis system has higher prediction accuracy and flexibility. For steels with sufficient samples and accurate classification, the MAEs are controlled in a small range and the effective ratios are more than 90%. For other steels, the predicted MAEs and effective ratios both have a significant improvement, and the interference caused by the steels with small samples was reduced. This study provides a feasible direction for the rapid transformation of laboratory prototype materials to industrial products (AIM).

20:30-20:45 Coffee break

20:45-21:15 Keynote

Research and Development of a New Generation Mathematical Model and Intelligent Analysis System for Process Control of Hot Strip Rolling

Weigang Li; Wuhan University of Science and Technology, China

The model and control technology during hot rolling process play an important role in the quality and rolling

stability of strip products, which is the key core technology of modern hot rolling production. So far, the technology level of hot rolling model has become mature from the perspective of the traditional function of process control. But in the actual production process of hot-rolled strip, the model and control technology still have some deficiencies and technical difficulties. Therefore, from the point of view of achieving high efficiency and stable production of strips, there is still a lot of meaningful work to be studied in the field of hot rolling model and control. This report shows our exploration work on the mathematical model and intelligent analysis system for hot rolling process control. The content includes: 1) A new generation mathematical model suitable for small batch and new steel during hot continuous rolling process; 2) Intelligent optimization control method for hot strip rolling process; 3) Strip product quality defect diagnosis and analysis tool; 4) Steel performance prediction model integrating big data and metallurgical mechanism; 5) On-line diagnosis system for functional accuracy of hot rolling mill equipment; 6) Hot rolled product manufacturability simulation analysis platform. Compared with the existing technology, the new model and control technology requires higher setting precision and intelligentization. The combination of automation and information technology is more closely; Replace human experience with model and reduce human intervention; Through industrial big data mining, the rolling rules are found and used for online control.

21:15-21:35 Contributed

Research and Application of Optimization Strategy Using Planar Contour Perception Online for Heavy Plate Shearing

Ping Zhou[1]; Xu Li[2]; Jianzhao Cao[3]; *Shaowen Huang[1]*; Jinguo Ding[2], Xiangqian Li[1]; [1]Research Institute of Shangang Group, China; [2]Northeastern University, China; [3]Shenyang Jianzhu University, China

Shearing steel plate in accordance with user's dimension requirement is an important process for heavy plates manufacture. However, due to the complicated shearing operation and high control accuracy requirements of the shearing process, workers often require to visually inspect and accumulate experience to judge the planar contour information of the length, width, camber and the plate ends' shape. It is difficult to determine the shearing strategy according to each steel plate with different contour in a short time. The production mode of depending on traditional artificial experience is inefficient and leads to large shearing errors frequently, which fails to meet the demand for product quality requirements during heavy plate production. There are many studies for planar contour detection, but the online shearing of steel plate is not carried out in combination with the information of order requirements' dimension and each plate's planar contour. Therefore, an optimization shearing approach based on planar contour perception feedback for heavy plate is proposed in this paper, where develops the

optimization of shearing system. The system consists of a dynamic planar counter detection model based on the binocular multigroup CCD cameras. By the preprocessing flow includes image enhancement, noise filtering, and the extraction algorithm which combines the Canny operator and the grayscale gradient interpolation subpixel edge contour, obtains the overall contour of the steel plate. The system establishes shear strategy online further according to the information of the order contract and feedback of planar contour, which can improve the utilization rate of plate after rolling. The application of optimization shearing technology from an industrial plant demonstrates that the presented approach can obtain the plate's planar contour information accurately, and the width detection accuracy is ± 2mm, the length detection error is less than 5‰, the camber detection accuracy is ± 5mm, and the plate ends irregular deformation area detection accuracy is ± 2mm. Shearing plate using the optimization of shearing system is significantly reduces shearing error and improves shearing efficiency, and the productivity of the shearing process is increased by 13%, the power consumption per ton of steel plate is reduced by 3.1 kW.h.

THURSDAY, 8 SEPTEMBER 2022, GMT+8 (Beijing)

Room B, Zoom Link:

Flat Product and Processing (Chief Organizer: Yong Tian, Northeastern University)

Pipeline Steel and Marine Steel (Chair: Yongqing Zhang, CITIC Metal Co., Ltd.)

14:00-14:30 Keynote

Understanding and Use of TMP Concept for Successful X80 Steels in China

Yongqing Zhang[1,2]; Jose Bacalhau[3]; Aimin Guo[2]; Marcos Stuart[3]; Rafael Mesquita[3]; [1]China Iron & Steel Research Institute Group, China; [2]CITIC Metal Co., Ltd., China; [3]Companhia Brasileiro de Metalurgia e Mineracao, Brazil

Since start, Nb microalloying and thermo-mechanical processing (TMP) have been closely linked together to achieve microstructural refinement for high-strength, low-alloy steels based on the theoretical foundation of structure-property relationships. It is well recognized that both the strength and the resistance to brittle fracture can be improved for virtually all steels through proper understanding and use of TMP. The principal role of Nb in steel is during austenite processing, where the Nb contents are firstly dissolved into the upper austenite region at reheating stage and then get reprecipitated with the decrease of rolling temperature, especially at finishing rolling stage. In the course of development of high-strength pipeline steels, physical metallurgy of TMP had been well established. Kozasu et al once concluded that niobium is the basic building block of metallurgical design for steels used for large-diameter and high working pressure. T. Tanka firstly proposed the total TMP concept, which involves almost all processing steps from metallurgical design, steelmaking, con-casting, reheating, controlled rolling, accelerated cooling, and even texture control for DWTT separation. Another one important event is the successful application of X80 steels with high-Nb metallurgical design for Cheyenne Plains pipeline, which make is possible to produce X80 grade under weak rolling mills.

In China, it was late, but quick for the development and application of high-strength pipeline steels, in particular X80 steels used for the second West-East line. For the development of X80 steels, high temperature processing (HTP) concept with low carbon and high niobium was firstly introduced by CBMM and CITIC Metal, which is regarded one of the key points to develop X80 steels in early stage. Through mass production practice, China's metallurgical workers have continued to optimize alloy design and production processing for the optimum balance of property, quality, productivity and costs. It is the first time that X80 spiral welded pipe made of hot rolled coil had been used on mass scale, which provided the chance to study the strengthening effects of Nb in hot continuous line. Up to now, more than 10 million tons X80 steels had been produced, accounting for about 68.0 percent of total X80 pipelines in the world. During this process, some new metallurgical phenomena had been observed and studied to advance the understanding of TMP. In the meanwhile, it was found girth welding has been one bottlenect to affect application of X80 and above grades such as X90 or X100. For this reason, it is essensial to include girth welding as one part into total TMP concept.

In this paper, China's pipeline construction and X80 development have been reviewed. At the same time, some metallurgical phenomema and studies centering about TMP and Nb microalloying have been presented.

14:30-15:00 Keynote

Research on the Grain Refinement Process and High-Temperature Mechanical Behavior of Superalloy Sheet/Foil

Xu Yang; Shunan Chen; *Bingxing Wang*; Northeastern University, China

The grain refinement process and high-temperature mechanical behavior of Inconel 718 sheet and foil are introduced to facilitate further aerospace applications of thin gauge superalloys. A multi-pass cold rolling and intermediate annealing process was designed to produce foils with a thickness of < 0.08 mm. Due to the better matching of fine-grain strengthening and size effect, the foil with a thickness of 0.067 mm achieves a yield strength of 929 MPa and an elongation of 8.75% at room temperature. Furthermore, cold rolling and two-stage annealing were developed to refine and homogenize the grains to improve the superplasticity of Inconel 718. Sheets with a thickness of 0.8 mm and a grain size of 1.21 μm provided great ductility (up to 657% elongation) at 950°C with a strain rate range of 6×10^{-4} s^{-1} to 1×10^{-2} s^{-1}. The sufficient pre-precipitation and subsequent uniform dispersion of δ phase achieve a significant grain refinement effect. To improve forming efficiency and reduces device dependency, the superplasticity of cold-rolled Inconel 718 sheet (0.8 mm thickness) at high strain rates has also been investigated. The ductility enhancement is attributed to the rapid atomic diffusion caused by dense dislocations and the grain refinement through recrystallization induced by cold rolling in the early deformation stage.

15:00-15:20 Contributed

Effect of Austenite Grain Refinement on Microstructure and Properties of Polar Marine Steel

Jiuxin Zhang; Hongtao Wang; Yong Tian; Northeastern University, China

The influence of refined austenite grains induced by the secondary austenitizing on the microstructures and mechanical properties of polar marine steel was elucidated using thermo-mechanical controlled processing. With the reheating temperature rising from 890 °C to 1050 °C, the austenite grain size increased from 14 μm to 28 μm causing the increased effective grain size from 3.6 μm to 4.8 μm, the decreased ferrite content from 45.0% to 3%, and the increased bainite content from 55% to 97%. With the coarsening of bainite lath, the M/A islands gradually change from small blocks to long strips with tips. The steel austenitized at 890 °C showed the best low-temperature toughness down to -100 °C with the impact absorbed energy of 241 J for the minimum effective grain size of 3.6 μm, and the highest high-angle grain boundaries proportion of 57.4%, and blocky M/A islands with small content. The extremely high effective interfacial area per unit volume of 269.0 mm-1 inheriting the small austenite grain of 14 μm before phase transformation was the key for the refined and uniform microstructures.

Processing Technology II (Chair: Feng Fang, Northeastern University)

15:20-15:50 Keynote

Study on Intelligent Prediction and Control Method of Mechanical Properties of Hot-Dip Galvanized High-Strength Steel Products

Zhenhua Bai[1]; Wei Wang[2]; [1]Yanshan University, China; [2]Fuzhou University, China

The fluctuation of chemical composition and process parameters of hot-dip galvanized high-strength steel coil makes the final mechanical properties fluctuate greatly. Mechanical property control is an important issue in production. For typical steel grades and specifications in production, a mathematical model corresponding to the skin-pass process parameters and coil properties is established, and a mechanical property prediction model based on neural network and an on-line feedback control system are developed. The mechanical property qualification rate of high strength steel coils is improved by successful utilization of prediction and on-line feedback control of mechanical properties.

15:50-16:05 Coffee break

16:05-16:35 Keynote

Investigations on the Hot Ductility Behavior of a Continuously Cast Low Alloyed Steel

Marina Gontijo[1,2]; Christian Hoflehner[3]; Sergiu Ilie[3]; Jakob Six[3]; Christof Sommitsch[2]; [1]K1-MET GmbH, Austria; [2]Graz University of Technology, Austria; [3]Voestalpine Stahl GmbH, Austria

Investigations on the hot ductility behavior of a continuously cast low alloyed steel were done to evaluate its sensitivity to the formation of surface cracks along the thermal cycle during the casting process. The goal was not only to obtain the hot ductility curve, but also information on the transformation temperatures, fracture mechanisms, strain rate influence, microstructure aspects, and precipitation kinetics. Cylindrical tensile test specimens, machined in dog-bone shape, were used for the tests. In a BETA 250-5 thermomechanical simulator, under vacuum atmosphere, the specimens were first heated by an induction coil until the melting point and then they were controlled cooled to the desired testing temperatures, in the range of 600 °C to 1100 °C. First, at each testing temperature from the mentioned range, the samples were pulled until fracture at a strain rate of 10^{-3} s^{-1}. With the analysis and measurement of the reduction of area of each specimen, done with a stereo microscope, the critical temperature range could be identified between 900 and 750 °C. After the determination of these critical temperatures for the hot ductility, which define the second ductility minimum, hot tensile tests with different strain rates were done at 900, 850 and 750 °C. Once again, the reduction of area was measured for the evaluation of the ductility under the influence of the different strain rates applied, which were of 10^{-2} and 10^{-4} s^{-1}, in addition to the strain rate used in the initial tests, of 10^{-3} s^{-1}. The fracture surfaces from the samples tested were also observed with a scanning electron microscope (SEM), to correlate the temperatures and reduction of area to the associated type of fracture. The microstructure of all specimens was observed with a light optical microscope (LOM) for the evaluation of grain sizes, grain boundaries, phases, and initiation sites of cracks. Among other factors, the nucleation of precipitates is an event known to be detrimental to the hot ductility of low alloyed steels. Therefore, thermo-kinetic simulations were additionally performed for the temperatures and strain rates tested to obtain more information about the expected formation of precipitates and their influence during the process at different testing parameters.

16:35-17:05 Keynote

Yield Improving of Plate Rolling with Unconventional Technology

Shijun Liao; Nanjing Iron and Steel Co., Ltd., China

The difficulties and deficiencies in controlling the yield rate were briefly introduced. In the past two years, the head-end ruler quantity mathematical model has replaced the previous head-end ruler table. A performance prediction models replaced the actual sample testing. The development of angle rolling width function improved the billet weight with an optimized relevant functional modules of MES billet design. Eventually, the material yield rate has been improved significantly.

17:05-17:30 Invited

Behavior of Inclusions in Different Rolling Processes for Heavy Plate

Rensheng Chu; Zhanjun Li; Jingang Liu; Ning Hao; Shaopo Li; Haibo Li; Shougang Group Co., Ltd., China

The inclusions have an important influence on the properties of steel plates, and the behavior of different inclusions in the rolling process is also different. The production of steel plates is composed of the steelmaking process and the rolling process. Inclusions are generated during the steelmaking process, and deformation behavior is caused during the rolling process, which affects the final steel plate performance. In high-quality steels, there are strict requirements on the shape and length of inclusions. Therefore, it is particularly important to study the behavior of inclusions in the rolling process of steel plates and the effects of different rolling processes on inclusions. In this paper, the deformation behavior of the same type of inclusions in the same thickness of continuous casting slabs under different rolling processes is studied (Seven times for heavy reduction process and twelve times for smaller reduction process). Only two rolling processes, the number of reduction passes and the reduction ratios of different passes, were compared to study the behavior of inclusions in the rolling process of steel plates and the effects of different rolling processes on inclusions. The results show that: 1) The maximum lengths of inclusions in two rolling processes are significantly different. The maximum sizes of the corresponding steels with high and low pass reductions are 38.1 μm and 45.4 μm, respectively, and the aspect ratios are 2.88 and 3.61; 2) In terms of the number of inclusions, the number of large-sized inclusions with a smaller pass reduction ratio is larger than that of a large-sized inclusion with a larger pass reduction ratio. At the same time, the smaller the pass reduction ratio is, the larger the number of large-sized inclusions larger than 20μm is; 3) After the slab is rolled, the number of inclusions increases, especially for large-sized inclusions. Large reductions are beneficial to reduce the size and number of inclusions.

17:30-17:55 Invited

Online Prediction of Mechanical Properties of Hot Rolled Steel Plate Using Time Series Deep Neural Network

Qian Xie; Anhui University of Technology, China

In industrial hot rolled steel plate production, using process parameter to predict the mechanical properties of products is an important topic, which can effectively reduce the production cost and improve the product quality. At present, the research on the prediction of steel mechanical properties is mostly based on DNN, which finds the correlation between all parameters and mechanical properties from the perspective of statistics, but does not pay attention to the time-series correlation of steel production process. This work aimed to devise the deep learning model which is considering the time-series relationship between the process parameters to predict mechanical properties of industrial steel plate including yield strength (YS), ultimate tensile strength (UTS), elongation (EL). Two time-series neural networks based on LSTM and Transformer15 are established to predict the steel plate mechanical properties, Their performance under different hyper-parameters are tested and compared with three

classical algorithms(SVM, random forest, DNN), and LSTM had the best performance (compared with DNN, its mean squared error is reduced by 30%), the performance of transformer is similar to DNN and does not show obvious advantages. After sensitivity analysis, we found the parameters that have a greater impact on the subsequent process had a higher sensitivity in LSTM, which is more consistent with the real physical metallurgical process of hot-rolled steel plate. The results of this paper show that the time-series relationship between parameters is helpful to improve the prediction accuracy of mechanical properties, and the interpretation of the model is more helpful for people to understand the physical metallurgical process.

Long Product and Processing (Chief Organizer: Xianming Zhao, Northeastern University)

Microstructure and Properties of Tube and Pipes (Chair: Guo Yuan, Northeastern University)

19:00-19:30 Keynote

Hot Rolling Deformation Manufacturing Processes of Large Diameter 9Cr Heat Resistant Seamless Steel Pipes

Jin Li[1,2]; Li Xiong[2]; Guang Chen[1]; [1]Nanjing University of Science and Technology, China; [2]Yangzhou Chengde Steel Pipe Co., Ltd., China

9Cr steel is a key material for the main steam pipe and power generating units with larger diameter (up to 1000mm) and thick wall (up to1 20 mm) in ultra-supercritical (USC) power plant with 1000WM. Due to the high alloy Cr、Mo and W contents, the traditional manufacturing process was die-casting billet, forging, extrusion and machining, resulting in low material yield and production efficiency. In this study, hot rolling deformation manufacturing processed by large-diameter continuous casting round billet + hot rolling piercing is introduced to efficiently produce 9Cr large-diameter seamless steel pipe. The research on the possibility of unification of continuous casting billet and piercing for both decreasing and increasing the diameter of crude pipes was conducted. The technology of wide range of sizes from φ559~960mm pipe-rolling with φ600 or φ800 mm diameter continuous casting pipe production was developed to use Two -Roll Piercing mill by only one heating. With hot rolling product of 9Cr seamless pipe, microstructure analysis and creep rupture strength were examined after long time and pressure at high temperature.

19:30-19:55 Invited

Optimized API X70 Mechanical Property Performance with Optimized Nb Processing

Douglas Stalheim[1]; Xiangjiang Xiong[2]; Chunyong Hou[3]; David Han[4]; Yongqing Zhang[7]; Jose Bacalhau[5]; Aaron

Litschewski[6];[1]DGS Metallurgical Solutions, Inc., USA; [2]Xiangtan Steel, China; [3]Tubular Goods Research Institute, *China; [4]International Welding Technology Center, China; [5]CBMM Brazil; [6]CBMM North America; [7]CITIC Metal Co. Ltd., China*

Optimum API mechanical properties in both plate and pipe can be achieved by using an optimum Nb level along with processing the Nb during hot rolling in a metallurgically optimized approach. Metallurgically optimized processing can be evaluated through mean flow stress analysis of two key regions of the mean flow stress curve generated with each pass. Metallurgically optimized processing approach consists of two key points; 1. creating a fine and homogenous through thickness microstructure, 2. precipitating a significant volume fraction of the proper size distribution of Nb precipitates. By accomplishing both key points optimum ductility properties of lower transition temperatures and stability as measured by standard deviation can be achieved for Charpy V-notch, DWTT performance in both plate and pipe including pipe seam/girth weld HAZ performance. By creating a fine homogenous through thickness microstructure along with the proper size distribution (5-70 nm) of a significant volume fraction of Nb precipitates a finer more homogenous seam/girth weld HAZ performance can be realized resulting in higher Charpy averages, improved stability/standard deviations, and lower transition temperatures.

19:55-20:20 Invited

Development and Application of Microstructural Control Technology in the Whole Process of Hot-rolled Seamless Steel Pipe

Guo Yuan; Zhonghua Zhuang; Jian Kang; Zhenlei Li; Chao Wang; Guodong Wang; Northeastern University, China

In the conventional manufacturing process for the hot-rolled seamless steel pipe, the production process was restricted by the shape of steel pipe. And due to the absence of proper on-line microstructural control of the pipe, properties had to be controlled depending on addition of much more alloy elements and the subsequent heat treatment process. As an important means of on-line microstructural control of hot rolled steel, controlled rolling and controlled cooling were widely used in the field of plate and strip. However, there had been no effective breakthrough in the field of steel pipe for a long time, which seriously restricted the development of on-line microstructural control technology for steel pipes. In this paper, the heat transfer characteristics of steel pipe with annular cross-section were studied and the asymmetric cooling mechanism was proposed. And the method of introducing micro-nano second phase particles with high thermal stability was proposed to control the microstructure refinement of hot-rolled steel. Furthermore, the development progress of the existing successful controlled cooling technology for steel pipe was introduced, and the applications of improvement and control of histomorphology, temperature accuracy and cooling uniformity were summarized. The development of microstructural control technology for the whole process containing smelting − continuous casting − rolling − cooling was of great importance in short process green manufacturing for hot-rolled seamless steel pipe.

20:20-20:45 Coffee break

Process and Control of Wire and Rod (Chair: Jin Li, Nanjing University of Science and Technology)

20:45-21:05 Contributed

Control of Interlamellar Spacing of High Carbon Steel Wire Rod through ThermoMechanical Processing

Dayong Guo[1]; Bingxi Wang[1]; An Che[2]; Hang Gao[1]; Leigang Liu[2]; Haoxing Zhang[2]; Yang Pan[1]; [1]Ansteel Iron and Steel Research Institute, China; [2]Wire rod plant, Angang Steel Company, China

Interlamellar spacing has a crucial effect on mechanical properties and drawability of high carbon steel wire rod. With the development of automobile industry, the demand for the super high strength steel cord increases dramatically. The breakage in the course of drawing of the wire rod for the fabrication of super high strength steel cord is highly sensitive to the interlamellar spacing. Therefore, it is important to investigate the relationship between the interlamellar spacing and hot rolling parameters in order to make the microstructure feature meet the requirement of wire rod drawing. This paper presents the effects of finishing rolling temperature, laying head temperature and cooling rate on the interlamellar spacing of 0.9% C hypereutectoid steel wire rod. The wire rod considered in this study had been rolled from industrial billet. It was found that lower finishing rolling temperature leads to larger interlamellar spacing. Lower deformation temperature gives rise to strong work hardening, produces higher accumulation of strain before austenite decomposition and increases the number of nucleation sites for the austenite-eutectoid transformation, leading to the increase in the transformation temperature and larger interlamellar spacing. The interlamellar spacing is less sensitive to laying head temperature. The cooling rate of wire rod on the conveyor after hot rolling also strongly affects interlamellar spacing. Fast cooling rate makes the austenite-eutectoid transformation occur at lower temperature and decreases the interlamellar spacing of the wire rod. The results provide guidelines for the precisely industrial control of microstructure of wire rod for steel cord.

21:05-21:25 Contributed

Research on Temperature Adaptive Control Method of Bar Cooling Process

Chunyu He; Northeastern University, China

The temperature control in the hot rolling process of the bar is very important. The temperature is a key parameter for the microstructure evolution, such as recrystallization, phase transformation and precipitation, and the control accuracy of the temperature determines the microstructure and mechanical of the finished product. In this study, a temperature feedforward adaptive control method was developed to meet the temperature uniformity control requirements of the bar. As the temperature measured and the position of the rolling piece in front of the cooling equipment are finely tracked, a queue for the temperature information is established. Based on a high-precision temperature model, fast regulation of the water flow in the bar during cooling is achieved. The temperature difference in the length direction of the bar before the phase transition reaches a minimum value, which is important to control of the property uniformity of the cooled product.

Room C, Zoom Link:

Microstructure and Properties of Steels (Chief Organizer: Liqing Chen, Northeastern University)

Automobile Steel (Chairs: Lijia Zhao, Northeastern University; Binhan Sun, East China University of Science and Technology)

13:30-14:00 Keynote

Carbon Enrichment at Coating/Substrate Interface and its Effect on Bendability of Al-Si Coated Press Hardening Steel

Linlin Zeng[1]; Dapeng Yang[1]; Shu Zhou[2]; *Hongliang Yi[1,2];* [1]Northeastern University, China; [2]Easyforming Materials Technology Co., Ltd., China

Al-Si coated press hardening steel (PHS) is widely applied on carbody due to its high strength, the tensile strength usually exceeds 1500MPa. In addition to strength, the fracture strain of PHS in bending deformation characterized by the bending angle in tests of VDA238 standard is critical for the crash performance of carbody. The Al-Si coating transforms into Fe-Al intermetallics during austenitization heating in the hot stamping process, and therefore prevents severe oxidation of the sheet surface. However, the Al-Si coating was found to seriously deteriorate the fracture strain. In this research, the fracture process of a press-hardened Al-Si coated PHS during bending test was investigated. The Al-enriched alloying layers involving the intermetallic layers and the ferrite layer are not able to inhibit the crack propagation, but the cracks are then blunted by the hard martensite substrate. Finally, fracture happens by the shear band initiation and propagation from the surface of martensite. The carbon enrichment about several micrometers in martensite at the coating/substrate interface after press-hardening was found for the first time to deteriorate the bending fracture strain of Al-Si coated PHS. The coating/substrate interface migration during austenitization heating leads to the carbon diffusion into the austenite substrate because carbon has large solubility in austenite compared to the negligible solubility in Al-enriched alloying layers. A novel method of reducing the coating thickness was then invented to suppress the carbon enrichment by suppressing the coating/substrate interface migration. This invention will change the commercial practice of PHS by improving 20% of bending fracture strain and sacrificing neither of the other performances such as spot-weldabiltiy, paintability and corrosion resistance after e-coating. The thin coating has another advantage that the austenitization soaking period is reduced by 20%~30% due to the much less heat absorption of Al liquidation and the formation of Fe-Al intermetallics.

14:00-14:30 Keynote

Application of Chemical Heterogeneity for Microstructure Control in Advanced High Strength Steels

Dong-Woo Suh; Pohang University of Science and Technology, Korea

Quenching and partitioning (Q&P) processed steel is one of promising materials for automotive application. Stabilizing austenite is an important issue to improve mechanical properties of Q&P processed steel and the carbon partitioning plays a critical role in obtaining desired ones. In this study, different from the conventional Q&P process which stabilizes austenite by carbon partitioning only, we utilizes carbon and manganese partitioning to austenite by applying isothermal treatment prior to initial quenching. Intercritical isothermal annealing prior to full austenitization has a significant influence on the partitioning of carbon and manganese, which affects the austenite stability. The mechanical properties are remarkably improved by multiple-plasticity enhancing mechanisms; twinning-induced plasticity and transformation-induced plasticity.

14:30-15:00 Keynote

Engineering Segregations at Phase Boundaries through Thermomechanical Processing

Binhan Sun[1]; Yan Ma[2]; Xian-Cheng Zhang[1]; Shan-Tung Tu[1]; [1]East China University of Science and Technology, China; [2]Max-Planck-Institut für Eisenforschung, Germany

Inexpensive high-strength steels with enough ductility and formability are continuously sought after in the automotive industry, in order to meet the body-in-white weight reduction strategies for fuel economy and vehicle safety. Due to economic constraints and better recycling, most recent alloy design concepts avoid using expensive alloying elements or high alloying contents. Instead, compositionally lean alloys are targeted and thermomechanical treatments are used to produce multiphase microstructures with balanced phase stability and a high density of interfaces. This approach enables the utilization of a large variety of accessible phase constituents (e.g. ferrite, austenite, martensite, and bainite) in steels with the aim to utilize a mechanical composite effect for achieving a superior strength-ductility synergy. The recently emerged medium-Mn steels are excellent examples demonstrating the power of such multiphase mixture strategy. Due to the multiphase structure and the typically ultrafine grain scale, a high density of austenite-ferrite interphase boundaries exists in this type of materials, which has significant impacts on their mechanical responses. Here we show that a proper design of such interphase boundaries, through controlled thermomechanical processing that enables a pronounced phase boundary solute segregation, can affect the steels' mechanical properties in various aspects. Particularly, we found that the C segregation at the austenite-ferrite phase boundaries impeded interfacial dislocation emission, thus increasing the stress required to activate such dislocation nucleation process and initiate plastic deformation. As a result, the yield strength of the studied medium-Mn steels was increased by about 100–120 MPa. This segregation engineering of phase boundaries might provide some new insights on the thermomechanical processing design for the modern advanced high-strength steels.

15:00-15:25 Invited

Effect of Rolling Schedule on Mechanical Properties and Deformation Behavior of Medium Mn Steels

Yuming Zou; *Hua Ding;* Zhengyou Tang; Northeastern University, China

Enhancing the strength of automobile steel is the main way to realize the lightweight of automobile. In recent years, medium Mn steels have attracted widely attention owing to their excellent comprehensive mechanical properties. Hot rolling (HR) and cold rolling (CR) were the common methods for the manufacture of medium Mn steels, recently, in order to obtain better comprehensive mechanical properties, warm rolling (WR) has been used more and more wildly. In the present work, the influence of rolling schedule on the austenite stability, work hardening behavior and alloying elements distribution of the medium Mn steels was studied. The chemical composition of the experimental steels was Fe-0.28C-5.90Mn-0.90Al. The microstructural evolution was characterized by field-emission scanning electron microscope (FE-SEM), Transmission Electron Microscope (TEM), X-ray diffraction (XRD) and Electron Probe Microanalyzer (EPMA). The results revealed that different rolling schedule leading to different microstructure and mechanical properties after intercritically annealed (IA) for one and a half hours at 660 ℃. The duplex microstructures composed of ferrite and austenite are obtained in all samples, however, their morphologies are quite different. As the lath-shaped microstructure and granular microstructure were developed in the HR and CR samples, respectively, the WR sample exhibited ultrafine granular and lath-typed ferrite/austenite grains. Besides, the average products of ultimate tensile strength and total elongation (PSE) values of the HR and CR samples were 51.39 GPa% and 49.86 GPa%, respectively, when the PSE values of the WR sample could reach 57.76 GPa%. In general, martensite transformation (TRIP effect) would influence the mechanical properties of medium Mn steels, better comprehensive mechanical properties would obtain when larger amount of austenite transformed during deformation. However, the WR steel posessed the highest value of the PSE, while its transformation ratio of austenite after tensile testing was lower than ones in the HR steel and the CR steel. The results showed that except TRIP effect, the hetero-deformation induced (HDI) hardening played an important role in improving the comprehensive mechanical properties of the WR steel.

15:25-15:50 Invited

Microstructure and Mechanical Properties of Dual Phase Steels Produced by Laboratory Simulated Strip Casting

Zhiping Xiong; Beijing Institute of Technology, China

Instead of hot rolling and cold rolling followed by annealing, strip casting is a more economic and environmentally friendly way to produce ferrite-martensite dual phase (DP) steels. This presentation will show the results of successful trials to manufacture DP steels using a strip casting technology simulated in the laboratory. This technology included rapid solidification of a thin strip (around 1 mm) in a specially designed mould, followed by heat treatment in a dilatometer or thermo-mechanical processing in a Gleeble 3500 simulator. The effect of ferrite formation temperature and time, the amount of deformation and deformation temperature on microstructure evolution was systematically investigated. The resulting microstructures were typical for DP steels containing 10 - 60 % martensite imbedded in polygonal ferrite, however, together with a small amount of Widmanstätten ferrite probably due to a relative large prior austenite grain size. Interestingly, strain-induced ferrite formation was observed following austenite deformation (~0.41 reduction) in the 800~700 °C temperature range, leading to a ferrite grain refinement down to 3.1 ± 2.3 mm. The relationship between microstructures and tensile properties was analyzed via the analysis of strain hardening exponent and modified Crussard–Jaoul model, both exhibiting three strain hardening stages. The studied steels had comparable tensile properties with DP 600 manufactured in industry, indicating the feasibility to produce DP steels by strip casting.

15:50-16:00 Coffee break

16:00-16:30 Keynote

Practice and Exploration of the Multi-mode Continuous Casting & Rolling Plant

Haiwei Xu[1]; Jiangtao Liang[2]; Baoliang Xiao[2]; Kun Liu[2]; Xun Zhou[1]; Xiaolin Li[2]; Bo Lv[2]; Meng Yu[2]; Chengliang Miao[1]; Haoyu Wang[1]; Jixin Li[1]; Shaofeng Lin[1]; Chunzheng Yang[1]; [1]Shougang Jingtang Iron and Steel United Co., Ltd., China; [2]Technology Research Institute of Shougang Group Co., Ltd., China

This study reports a ultra-strong hot stamping steel produced on the continuous casting and rolling line. The microstructure of the parts after hot stamping process is martensite, and the decarburization layer on surface is about 25 μm, and the microhardness is greater than 420 HV (HV10). After hot stamping process, the yield strength is 1053 MPa, the ultimate tensile strength is 1562 MPa, and the total elongation is 8.66 %, which meets the GB/T 34566-2017 (Hot stamping steel sheet and strip for automobile). The ultimate tensile strength of the tested steel under high strain rate is maintained at 1500 MPa, which changes little at different strain rates (from 10 s^{-1} to 500 s^{-1}), and the total elongation is between 10.0 % to 20.0 %. The part maintains high strength and elongation at high strain rates, indicating the experimental steel exhibits high safety in simulating crash scenarios. The ultimate cold bending angle of the tested steel is 66.1°, showing good anti-intrusion performance. After hot stamping, the microstructure and mechanical properties meet the requirements of the automobile manufacturers. Compared with traditional cold-rolled and annealed sheet, the hot stamping steel produced by continuous casting and rolling lines has lower carbon emissions among the production process.

16:30-17:00 Keynote

Ultra Grain Refinement of Steels with Superior Properties

Lijia Zhao[1]; Nobuhiro Tsuji[2]; John Speer[3]; Qiang Wang[1]; [1]Northeastern University, China; [2]Kyoto University, Japan; [3]Colorado School of Mines, USA

Grain refinement is an effective method to simultaneously improve the strength and toughness of steels. For centuries, metallurgists are endeavoring to find ways to fabricate ultrafine grained (UFG) steels (with grain size smaller than a few microns) having simple chemical compositions, which can improve the strength-to-weight ratio for lightweight engineering. The present study summarized our work on fabricating UFG steels with single body-centered cubic (BCC), face-centered cubic (FCC) or multiphase structures through thermomechanical processing (TMP) and advanced heat treatment approaches. Deformation-induced phase transformation and recrystallization were combined for grain refinement, which was further enhanced by deformation-induced carbon redistribution. A new strategy was proposed for realizing homogeneous UFG structures with grain sizes down to 350 nanometers. Furthermore, ultrafine-metastable-multiphase (UMM) structures were achieved through microalloying and quenching and partitioning (Q&P) approaches. The UMM steels show high strength and both high universal (ductility) and local formability (bendability or hole expansion ratio). It is expected that the steels with UMM structures would have potentially wide applications in areas such as automotive industry, etc.

17:00-17:30 Keynote

Excellent Mechanical Properties of a Medium-Manganese Steel with Aluminum Added after a Short Intercritical-Annealing Time Period

Wei Ding; Guangying Zhang; Yan Li; Inner Mongolia University of Science and Technology, China

This work studied the microstructure and tensile properties of a medium-manganese steel with 1.0Al (mass %) addition after short intercritical annealing (IA) time with different IA temperatures by scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray diffractometry (XRD), and uniaxial tensile tests. The research results show that addition 1.0Al (mass %) can increasing retained austenite fraction and improving the mechanical properties of investigated steel when the IA time is short. The steel with a tensile strength above 1000 MPa, elongation above 35% and the strength times ductility above 35,000 MPa% when the IA temperature is 700 and IA time is 3min. Most of the retained austenite transforms to α'-martensite during the tensile test. Part of the retained austenite transforms to α'-martensite in the early stage and contributes little plasticity. The other part of the retained austenite transforms in the middle or late tensile deformation stage and improves the mechanical properties.

17:30-17:55 Invited

Joint Investigation of Strain Partitioning and Chemical Partitioning in Ferrite-containing TRIP-assisted Steels

Xiaodong Tan[1]; Wenjun Lu[2]; Yunbo Xu[3]; Di Wu[3]; D. Ponge[4]; D. Raabe[4]; [1]Southwest University, China; [2]South University of Science and Technology, China; [3]Northeastern University, China; [4]Max-Planck-Institut für Eisenforschung GmbH, Germany

We applied two types of hot-rolling direct quenching and partitioning (HDQ&P) schemes to a low-C low-Si Al-added steel and obtained two ferrite-containing TRIP-assisted steels with different hard matrix structures, viz, martensite or bainite. Using quasi in-situ tensile tests combined with high-resolution electron back-scattered diffraction (EBSD) and microscopic digital image correlation (μ-DIC) analysis, we quantitatively investigated the TRIP effect and strain partitioning in the two steels and explored the influence of the strain partitioning between the soft and hard matrix structures on the TRIP effect. We also performed an atomic-scale analysis of the carbon partitioning among the different phases using atom probe tomography (APT). The results show that the strain mainly localizes in the ferrite in both types of materials. For the steel with a martensitic hard-matrix, a strong strain contrast exists between ferrite and martensite, with the local strain difference reaching up to about 75% at a global strain of 12.5%. Strain localization bands initiated in the ferrite rarely cross the ferrite/martensite interfaces. The low local strain (2%–10%) in the martensite regions leads to a slight TRIP effect with a transformation ratio of the retained austenite of about 7.5%. However, for the steel with bainitic matrix, the ferrite and bainite undergo more homogeneous strain partitioning, with an average local strain in ferrite and bainite of 15% and 8%, respectively, at a global strain of 12.5%. The strain localization bands originating in the ferrite can cross the ferrite/bainite (F/B) interfaces and increase the local strain in the bainite regions, resulting in an efficient TRIP effect. In that case the transformation ratio of the retained austenite is about 41%. The lower hardness difference between the ferrite and bainite of about 178 HV, compared with that between the ferrite and martensite of about 256 HV, leads to a lower strain contrast at the ferrite/bainite interfaces, thus retarding interfacial fracture. Further microstructure design for TRIP effect optimization should particularly focus on adjusting the strength contrast among the matrix structures and tuning strain partitioning to enhance the local strain partitioning into the retained austenite.

17:55-18:15 Contributed

In-situ EBSD Study of Intercritical Annealing Quenching and Partitioning Steels with Equiaxed and Lamellar Microstructure

Pengfei Gao; Zhengzhi Zhao; Feng Li; Weijian Chen; Beijia Ning; University of Science and Technology Beijing, China

The relationship between microstructure morphology and mechanical properties of the low-carbon steel (Fe-0.20C-2.59Mn-2.13Si) treated by different intercritical annealing quenching and partitioning (Q&P) process was illuminated through interrupted tensile tests plus in-situ electron backscatter diffraction (EBSD) measurements. The composite effect that the hard and soft phases benefit the overall strength and plasticity, respectively, through an effective partitioning of stress/flow strain among the constituent phases during deformation was observed in these multiphase steels. The transformation of retained austenite (RA) in the test steel was studied in the aspect of mechanically induced martensite variant selection. Results show that the size, orientation (variant selection), and distribution of RA directly affect the order of transformation. Larger equiaxed and finer lamellar RA were observed. Meanwhile, the selection of mechanically induced martensite variants becomes stronger and is concentrated in one close-packed plane (CP) group with the reduction of RA grain size. Furthermore, the equiaxed RA tends to transform into a specific variant with a close orientation to adjacent ferrite. In this case, phase transformation in specific grains could occur earlier under stress, regardless of the grain size. Compared with traditional intercritical annealing Q&P steel with equiaxed structure, the Q&P steel with quenching pretreatment contains the uniform lamellar structure and the relatively lath-like/film-like type of RA, leading to the higher yield strength, tensile strength, and elongation. The product of tensile strength and elongation of the latter reaches 29 GPa·%. It was observed from the KAM maps that the transformation of equiaxed RA in the traditional intercritical annealing Q&P steel resulted in a significant increase in local dislocation density and stress concentration. Moreover, these brittle regions formed a nearly continuous network. However, no concentrated area with high dislocation density was observed in the Q&P steel with quenching pretreatment, due to its uniform lamellar structure and the relatively single type of RA.

Special Steel (Chairs: Dongsheng Liu, Jiangsu Shagang Group Co., Ltd.; Zhinan Yang, Yanshan University)

19:00-19:30 Keynote

Making Composite Steel with Higher Strength and Higher Ductility

Zhinan Yang; Feng Jiang; Fucheng Zhang; Yanshan University, China

Researchers have always aimed to break the trade-off relationship between strength and ductility. Combining high-strength metals with high-ductility ones and producing multilayered structures with alternating hard and soft layers are effective methods to improve the ductility of high-strength metals. However, the strength and ductility of composite steel always follow the “rule of averages”. In this study, a carbon diffusion strategy was designed and realized on low carbon martensite and high manganese austenite composite steel, via further holing the steel at 1150 ℃ for 2 min after hot rolling process. The martensite layer in composite steel is strengthened due to increased carbon content, with twin martensite being observed in the layer. Moreover, the austenite layer is also strengthened slightly, although some carbon and manganese atoms were lost. The transformation strain due to martensite transformation in the martensite layer directly caused a slightly compressive deformation on the adjacent austenite layer, introducing more dislocations in the austenite layer, which should be responsible for the increased hardness of austenite layer. Moreover, the strain hardening rate of austenite layer is kept, guaranteeing the coordination ability of Hadfield layer on the adjacent martensite layer. Finally, the strength and ductility of composite steel are improved by 9.5% and 40%, respectively, as compared with the monolithic martensite steel. The uniform ductility is notably improved by 190%. This process strengthens the martensite without losing the hardening ability of austenite constituents, which is critical for excellent mechanical properties. Moreover, the effect of thickness ratios between martensite layer and austenite layer was analysed in detail, with an optimum ratio of 2:1 being obtained. And the effect of diffusion amount of carbon atoms on the mechanical properties of composite steel was also discussed. The proposed strategy is a general conception for making high-strength and high-ductility materials.

19:30-20:00 Keynote

Hot Forming Mechanism of Spring Clip in the High-Speed Railway

Yao Lu[1]; Haibo Xie[1]; Hui Wu[1]; Jingtao Han[2]; Zhengyi Jiang[1]; [1]University of Wollongong, Australia; [2]University of Science and Technology Beijing, China

The spring fastener is one of the key parts of the rail track, which provides buckle pressure to keep track gauges. A high-performance spring fastener can greatly improve railway-running safety. In this investigation, on the premise of fully studying the processing process of spring fasteners, the static CCT curve of spring fasteners is determined using the thermal expansion method combined with metallographic microstructure observation and hardness test, and the post-heat-treatment process is comprehensively studied. An optimal heat treatment process (quenching temperature of 850 °C, holding time of 35 min, medium of 12% PAG aqueous solution, tempering temperature of 460 °C, and holding time of 60 min) was obtained. The metallographic microstructure and hardness of the samples obtained by the heat treatment process well meet the technical requirements of the high-speed railway spring fastener. The studies conducted in this investigation has a valuable guiding effect on the thermal processing technology of high-speed railway spring fasteners.

20:00-20:30 Keynote

Electric Current Induced Enhancement of Recrystallization Kinetics in Steel

Heung Nam Han[1]; Kyeongjae Jeong[1]; Sung-Tae Hong[2]; Moon-Jo Kim[3]; Sung-Woo Jin[1]; [1]Seoul National University, Korea; [2]University of Ulsan, Korea; [3]Korea Institute of Industrial Technology, Korea

The origin of electric current induced kinetic enhancement on microstructural and mechanical behavior had been elucidated based on numerical and experimental approaches. Ab-initio calculations showed that a charge imbalance near defects weakens drastically atomic bonding. Then, the weakening of atomic bonding was confirmed by measuring elastic modulus under electric current, which is inherently related to bond strength. As one of examples of this phenomenon, in this presentation, we investigate the athermal effect that occurs during recrystallization of an ultra-low carbon steel by single pulse treatment (SPT) of electric current, comparing with conventional furnace treatment (CFT). Recrystallization of the ultra-low carbon steel was achieved by SPT under various electric current densities/duration times, followed by microstructure and hardness analysis. To calculate the recrystallization kinetics, Johnson-Mehl-Avrami-Kolmogorov (JMAK) equation adopting the additivity rule was employed and relevant parameters were determined by genetic algorithm-based optimization. In the comparative experiment of SPT and CFT, a remarkably higher temperature was required in CFT for similar degree of recrystallization, which showed there is the athermal effect induced by electric current distinct from Joule heating. Moreover, the increase in the recrystallization fraction only due to the athermal effect was quantitatively

well captured using the JMAK equation. The recrystallization fraction of the specimen in SPT showed the V-shaped trends when it was plotted as a function of the applied electric current density. We could explain the V-shaped trends by the competition between the decrease in the thermal effect due to the heating rate increase and the increase in the athermal effect. A comparison of SPT and CFT clearly confirmed the existence of the athermal effect of electric current. The athermal effect with the variation of current density was well quantified as the form of recrystallization fraction using JMAK equation.

20:30-20:50 Contributed

Understanding the Role of Residual Element Cu on Hot Shortness Behaviour of the Free Cutting Steels

Mo Ji; Ishwar Kapoor; Zushu Li; Claire Davis; University of Warwick, United Kingdom

Steel scrap is crucial for modern steel industry, which takes about 35% of iron source globally. Residual elements, such as Cu, could affect the surface finish and processability of steel products significantly. Four levels of Cu concentration, 0-0.8 wt.% Cu, of free cutting steel grades have been VIM cast and oxidation tests have been carried out at 1100 °C between 5 mins and 60 mins to investigate the effect of Cu concentration on the hot shortness behaviour. It has been found that the Cu segregated to the inclusion/ matrix interface in the as- cast condition. When oxidation occurred at 1100 °C, S was released from MnS inclusions to form FeS. Cu was enriched within the FeS matte, which forms Cu_2S and Cu rich inclusions. The Cu concentration within the FeS matte region increased with increasing nominal Cu concentration in steels. Cu distribution within the matte was also heterogeneous. It suggests that Cu as a residual element in free cutting steel might lead to a wider range of hot shortness susceptible temperature.

20:50-21:00 Coffee break

21:00-21:30 Keynote

The Challenges of Ausforming Medium C Bainitic Steels

Carlos Garcia-Mateo[1]; Adriana Eres-Castellanos[1]; Pentti Kaikkonen[2]; Mahesh Somani[2]; David A. Porter[2]; Andreas Latz[3]; Arunim Ray[4]; Francisca G. Caballero[1]; [1]Spanish National Center for Metallurgical Research, Spain; [2]University of Oulu, Finland; [3]Thyssenkrupp Steel Europe AG, Germany; [4]ArcelorMittal Global R&D Ghent

By plastically deforming the austenite well below the recrystallization stop temperature, and close to the start of bainitic transformation, i.e., imposing low temperature ausforming, there is a possibility to enhance both the austenite strength as well as the driving force for bainite transformation. This, in principle, should lead to both a reduction of the scale of the bainitic ferrite plates as well as facilitation of an accelerated transformation process. With the ultimate aim of realizing this innovative concept on an industrial scale, an EU project was launched recently, wherein, on specifically designed medium C steels (0.4-0.5 wt.%), a thorough study has been performed encompassing various feasibility aspects and technological challenges, thus outlining the fundamental implications of such a process. This paper aims to present the most relevant results obtained in the study. The research is supported by the Research Fund for Coal and Steel under the Contract RFCS-2016-709607.

21:30-22:00 Keynote

Cleavage Fracture in Heavy Steel Plates with Brittle Crack Arrestability

Dongsheng Liu; Binggui Cheng; Mi Luo; Jinbo Qu; Institute of Research of Iron and Steel, Jiangsu Shagang Group Co., Ltd., China

Thermomechanical control process (TMCP) was successfully applied in industrial trials for producing heavy plates for shipbuilding using a microalloyed low carbon SiMnCrNiCuMo steel. Submerge arc welding technique was employed in a welding trial to evaluate to weldability of an ultra-thick plate (80 mm). Charpy V-notch (CVN) impact tests were then conducted to evaluate ductile-to-brittle transition temperatures (DBTTs) in the plates or in the coarse-grained heat affected zone (CGHAZ). Local cleavage fracture stresses (σ_f) were evaluated for the plate and the CGHAZ, respectively. Crack-initiation toughness (K_c) was evaluated in the plate and weld joint. Crack-arrest toughness (K_{ca}) of the ultra-thick plate was determined employing a double tension technique. Yield-strength greater than 500 MPa and DBTT lower than -78 ºC were achieved in all plates. Enhanced CVN impact toughness was attributed to high brittle crack arrestability. An increase in s_f led to a decrease in DBTT enhancing CVN toughness. Identical critical events were observed during the CVN testing and the double tension crack arrest testing, respectively. Under the as weld condition, K_c at the regions near the CGHAZ was lower than K_{ca} in the mother plate. Therefore, a brittle crack initiating in the CGHAZ could be arrested in the mother plate.

22:00-22:20 Contributed

Microstructural Variations and Mechanical Properties of AISI M35 High-speed Steel via Deep Cryogenic Treatment and Low-high-high Temperature Tempering

Guili Xu; Northeastern University, China

Deep cryogenic treatment and low-high-high temperature tempering applied in high-speed steel both yield promising results, and their cooperation can further improve the performance of high-speed steel. The deep cryogenic treated AISI M35 high-speed steel was first tempered at a low temperature of 320 ℃ and then tempered at different high temperatures. The microstructural variations (residual austenite, martensite, and carbides) and mechanical properties (Vickers hardness and impact toughness) of these samples were investigated. The samples treated with deep cryogenic treatment and low-high-high temperature tempering contained substantial amounts of tempered martensite and some slight austenite. The increase in the high-tempering temperature facilitated the precipitation of secondary carbides while the content of small secondary carbides decreased as the temperature was higher than 550 ℃. Moreover, secondary carcks mostly initiated in the primary carbides (including M_6C and MC), M_6C of secondary carbides exhibited broken and or cleavage fracture and MC of secondary carbides decohere at the interface. In addition, the specimen tempered at a high temperature of 550 ℃ exhibited the highest hardness of 870.7 HV1 due to the more homogeneous carbide precipitation. The impact toughness of the sample tempered at a high temperature of 575 ℃ was the best, namely 2.40 $MJ \cdot m^{-2}$, due to the reduction of alloying elements in the martensitic matrix.

Room D, Zoom Link:

Service Performance of Metallic Materials (Chief Organizer: Zhenyu Liu, Northeastern University)

Oxidation Behavior (Chair: Hong Luo, University of Science and Technology Beijing)

14:00-14:30 Keynote

Combination Effect of Si and P on Oxidation Characteristics of Steel

Lin Wang[1]; *Yang Yu*[1]; Chang Wang[1]; Xiaoli Gao[1]; Jiaqi Zhang[2]; Jin Chen[2]; [1]Shougang Research Institute of Technology, China; [2]Qian'an Iron and Steel Company of Shougang Co., Ltd., China

The effect of Si element on properties of the scale at high temperature has been adequately studied by predecessors. The microstructure of scale and surface quality of steel is strongly affected by alloying elements,such as Si and P which is widely used. In this paper, the combination effect of Si and P on oxidation characteristics of steel is studied. It has been found that Si and P elements are associated with enrichment at the interface between substrate and scale,and has opposite effects on the scale adhesion, which is greatly influenced by the Si/P content ratio. The SP defect and red scale defect could be eliminated by appropriately matching the content of Si element and P element. With the increase of Si/P content ratio, the low-temperature oxidation resistance of the samples increased, the temperature at which the peak value of oxidation weight gain rate appears gradually increased, the liquefaction temperature of the element rich layer at the interface of scale and substrate increased.

14:30-15:00 Keynote

Water Vapor Effect on Oxidation of Fe and Fe-Cr Alloys

Jiarui Chen[1]; Zhao Shen[2]; *Jianqiang Zhang*[1]; [1]The University of New South Wales, Australia; [2]Shanghai Jiao Tong University, China

Water vapor is widely present in some important industrial high temperature environments, e.g., steel hot rolling, heat exchangers in power plant. The presence of water vapor (wet air, wet oxygen or steam) can have a dramatic effect on stainless-steel oxidation behavior, inducing a rapid and catastrophic oxidation. This work provides further understanding of this effect on oxidation of Fe and Fe-Cr alloys by examining their oxidation kinetics and reaction products.

In this work, pure iron and binary Fe-Cr alloys containing 5-30wt% Cr were exposed to Ar-20O_2, Ar-20H_2O and Ar-20O_2-20H_2O (vol%) for 10, 100 and 300 h at 700°C. For pure iron, three typical oxides (Fe_2O_3, Fe_3O_4 and FeO) were formed in all gas conditions with a thick FeO layer beneath the thin Fe_3O_4 and Fe_2O_3 layers. The presence of water vapor led to a thicker FeO with an increased adherence with the metal surface. For Cr-containing alloys, the oxidation kinetics and oxide morphologies depended strongly on reaction condition (water vapor and pO_2) and alloy composition (Cr concentration). The water vapor was found to markedly accelerate the oxidation rate and increase the critical chromium concentration for protective chromia formation, from 10-20 wt% Cr in dry gas to more than 30 wt% Cr in wet gases. In addition, water vapor enhanced the oxygen inward diffusion and oxygen permeability, leading to the thicker inner layer and better scale adherence. By comparing results in H_2O-only and H_2O+O_2 gases, the change of oxygen partial pressure did not affect much on the oxidation rate, but affected the scale morphology by forming much less Fe_2O_3 on the top of oxide scale in H_2O-only gas. For high Cr alloys where a chromia scale can form, the co-existence of water vapor and oxygen led to chromia volatilization, reducing the stability of the chromia. These phenomena are understood based on the interaction of water vapour on diffusion processes and its effect on oxide formation and stability.

15:00-15:30 Keynote

Evolution and Application of Oxide Scale Control Technology for Hot-Rolled Steels

Zhenyu Liu; Northeastern University, China

During hot-rolling process, steel surface is oxidized at high temperatures, thereby forming thick oxide scales, which results in a loss of material and significant influence on the surface quality of final products. Based on the different formation stages of oxide scales in hot strip rolling, the types of oxide scales are classified as primary scale, secondary scale, and tertiary scale. The primary scales are formed during reheating, and they are removed by using a scale breaker with high-pressure water. Subsequently, the secondary scales grow during rough rolling at relative high temperatures, and they are also descaled by using the scale breaker. Finally, the tertiary scales formed during finish rolling and coiling are retained after the final descaling. The Fe-O phase diagram indicates that the tertiary scale on the hot strip surface is comprised of three typical Fe-oxides, including a thin outer hematite (Fe_2O_3) layer, an intermediate magnetite (Fe_3O_4) layer and a thick inner wüstite (FeO) layer. When the temperature is below 560 °C, FeO becomes unstable and gets subjected to a eutectoid transformation into magnetite/α-iron ($FeO \rightarrow Fe_3O_4 + \alpha$-Fe), which determines the pickling efficiency and surface quality of hot-rolled steel products. The "pickling free" and "easy pickling" steel grades have been developed for mass productions by careful controlling the thickness and structure of tertiary oxide scales during hot strip rolling.

Therefore, the thickness and phase composition of oxide scale on the surface of hot rolled steel have received significant attentions of the researchers. The difference of thickness and phase composition can affect the properties of oxide scale, such as tribological properties, spallation and adhesion model, mechanical descaling, pickling descaling, and gaseous reduction descaling. The influence factors including alloy elements, temperature, atmospheres and cooling rate have been extensively studied. The mechanism of thickness reduction and structure optimization of oxide scale is introduced in order to fine control.

At high temperature, the alloy elements play an important role in controlling the thickness and structure of oxide scale due to selective oxidation. Si, Cr, Al as main elements of oxidation resistance always is added to steel. They have good affinity with oxygen ions, which can take the lead in forming oxides on the substrate surface at the initial oxidation. The oxides layer of Si, Cr, Al after oxidation as chemical barrier to inhibit outward diffusion of iron ions, and then extend the oxidation rate and reduce the thickness of oxide scale.

In previous reports, the oxide scale is thermally grown in dry air. However, in view of typical industrial hot-strip rolling lines, it can be found that the entire production process, in fact, is exposed to a wet atmosphere caused by high-pressure descaling, work-roll cooling, in-stand cooling, laminar cooling after finish rolling and coiler cooling. The water vapor reacts with iron oxides and significantly affects the microstructure and ions transportation in oxide scales. Consequently, consideration of the effects of atmosphere that specimens exposed to on the scale structures is significantly important.

In the process of hot-rolled, the thickness of oxide scale can be reduced by controlling the finishing temperature. The thickness of oxide scale increases with the increase of finishing temperature when the rolling rate is same. However, at high finishing rolling temperature, the temperature oxidation time is also reduced because of the rapider rolling rate.

In the cooling stage of steel strip, the significant differences appear in the microstructure of oxide scale due to the different start cooling temperatures and cooling rates. It can be found that the eutectoid reaction is initiated by Fe nucleation from the saturation of Fe in FeO and the interaction of the FeO lattice with O. The saturation of Fe in FeO is an electron to transfer from a Fe^{2+} to a Fe^{3+}. On the same supercooling, the low cooling rate promotes the activation energy for the diffusion of Fe and O in FeO, and then provides sufficient driving force and time for the decomposition of FeO.

The thickness and structure of oxide scale and elements distribution at the oxide/substrate interface are important aspects of surface quality control. Through composition design and process optimization, the thickness and structure of oxide scale can be improved, and the fine control of oxide scale can be achieved. Meanwhile, it can be found that the fine control technology of oxide scale not only reduces the follow-up processing costs and improves manufacturing efficiency, but also provides a strong support for energy-saving and green manufacturing.

15:30-16:00 Keynote

New Insights into High-Temperature Oxidation of Steels by Atomic Scale Investigation

Gang Sha; Yi Zhang; Shenbao Jin; Nanjing University of Science and Technology, China

High-temperature oxidation is a well-known phenomenon often encountered in steel production and steel service in extreme conditions. A significant number of investigations have focused on the influence of temperature, cooling rate, and oxygen partial pressure on the structure of oxide scale on low-alloy steels. In contrast, the effect of alloying elements on the high-temperature oxide scale of low alloy steels remains to be explored in detail. High-temperature oxide scales on two low-alloy steels were carefully studied using atom probe tomography in combination with TEM and SEM etc. For the first time, the FeO inner scale on the steel with low Cr and Si contents is observed to incur a eutectoid reaction in a divorced mode during cooling, resulting into a bimodal Ni distribution near the scale/substrate interface. In contrast, a combination reaction of oxygen and FeO layer occurs on the steel with high Cr and Si contents where cracks in scales provide pathway for oxygen transport, and a fine-grained nanocomposite oxide band develops near the interface. Dealloying, partition and segregation during the scale formation are comprehensively addressed.

16:00-16:15 Coffee break

16:15-16:40 Invited

Effect Water Vapor of Ferritic Stainless Steel on Oxidation Behavior at 1100 ℃

Bin Sun; Shenglun Gao; Lei Cheng; Shenyang University, China

The high temperature oxidation behavior of 430 ferritic stainless steel under different water vapor was studied by thermogravimetric analysis. The morphology of oxide scales were observed by scanning electron microscope. The phase of the oxide scale were analyzed by X-ray diffraction. The results showed that oxidation kinetics curves of ferritic stainless steel in three different atmosphere are S-shape. It includes induction, acceleration and deceleration periods. The higher the water vapor content, the curve tends to shift upward and to the left. The higher the content of water vapor in the atmosphere, the shorter the transition time of oxidation behavior from one stage to another. Continuous and dense Cr_2O_3 layer was rapidly formed on the surface of the substrate in the initial stage of oxidation. The nodular oxide are formed on the substrate under 30% and 50% water vapor for 5min. When nodular oxide occurs on the surface of the substrate, the Cr_2O_3 protective layer failed. When the stainless steel was oxided in the air containing water vapor above 500℃, valatile oxides CrO_3 and $CrO_2(OH)_2$ were formed.

Mechanical Behavior and Fatigue Performance II (Chair: Hong Luo, University of Science and Technology Beijing)

16:40-17:10 Keynote

Quantitative Prediction and Optimization of Tensile Properties of Single-Phase Metal Materials

Zhenjun Zhang[1]; Zhan Qu[1,2]; Zhefeng Zhang[1,2]; [1]Institute of Metal Research, Chinese Academy of Sciences, China; [2]University of Science and Technology of China, China

A new dislocation annihilation model is proposed, and by considering the effects of initial microstructure and alloy composition on work hardening, a universal hardening model exponential hardening model for single-phase metal materials is established, based on which the quantitative relationship between tensile strength and uniform elongation of single-phase metal materials is derived for the first time. The model clarifies some important laws in the deformation process of single-phase metal materials: 1) the five stage work hardening law is unified with a parameter (n); 2) The relationships among ultimate strength, critical strength, true tensile strength, composition and deformation mechanism are revealed; 3) The quantitative relationship between "yield strength - tensile strength - uniform elongation" is derived for the first time; 4) It quantitatively reveals two basic principles of synchronous improvement of tensile strength and plasticity, namely, composition optimization (improving dislocation slip planarity) and microstructure optimization (reducing initial high-energy defects). 5) quantitative prediction of tensile strength, plasticity and tensile stress-strain curves of single-phase copper aluminum alloy is realized.

17:10-17:40 Keynote

A Novel Nanotwinned High-Entropy Alloy Fabricated by Reverse Transformation and Nano-precipitation

Wenjun Lu; Southern University of Science and Technology, China

Forming precipitates in a metallic matrix is a commonly employed approach in alloy design, including steels and advanced high-entropy alloys (HEAs). They usually serve to enhance strength by forcing dislocations to cut or bypass these secondary phases. Another strategy in HEAs with tunable stacking fault energy, for instance through non-equimolar composition adjustment, is to use twin boundaries as Hall-Petch-type strengthening elements. Coupling both mechanisms offers to realize a wide range of microstructures, increasing the degrees of freedom to enhance the mechanical properties of complex alloys.

In this work, we aim to understand two types of fundamental mechanisms. One is the role of reverse phase transformation (HCP to FCC) phenomena and the associated nano-twining and de-twinning effects and the second one is the unexpected formation of nano-precipitate evolution at twin boundaries in interstitial HEAs (e.g., FeMnCoCrNiC). Aberration-corrected high-resolution scanning transmission electron microscopy (STEM) coupled with in situ heating and energy dispersive X-ray spectroscopy (EDS) provides insights into (1) partial dislocation motion, (2) incoherent twin boundary formation and (3) the heterogeneous nano-precipitation pathways at nano-twins. These in situ observations of the dynamic of the microstructure evolution at the nanoscale help to establish guidelines to design advanced alloys with tunable nano-twinning and -precipitation to improve strength and microstructural stability.

17:40-18:00 Contributed

Developing a CPFEM Modelling Frame Work that Considers the TRIP Effects and Intergranular Failures for Medium Mn Steels

Yunzi Yan[1,2]; Jingsi Jiao[2]; Matthias Weiss[2]; Bernard Rolfe[2]; Yunbo Xu[1]; [1]Northeastern University, China; [2]Deakin University, Australia

The current presentation introduces the working progress for a joint NEU-DEAKIN PhD project. The project aims to establish the fundamental link between steel making processing/alloying parameters, macroscopic mechanical properties, and fracture mechanisms of Medium Mn Steels. The final objective is to develop a numerical material model that can be applied to optimise the material's forming limits in stamping without compromising strength. In the presentation, the research motivations and research gaps are presented at first and followed by the current working progress and preliminary remarks, then finalised with introducing future work plans. Emphasis of the presentation will be placed on the current working progress, where an extensive literature review has been performed. This is followed by the production of different Medium Mn Steels, and their microstructure and mechanical properties characterisations. Moreover, the modelling framework has been formulated and will be introduced.

Mechanical Behavior and Fatigue Performance III (Chair: Guangming Cao, Northeastern University)

19:00-19:25 Invited

Superior Strength-Ductility Balance in a Novel Texture Gradient Steel with Dual-Phase Lamella Structure

Qibin Ye; Institute of Research of Iron & Steel, Sha-Steel Co., Ltd., China

Simultaneous improvement of strength and ductility of steel can be hardly achieved by conventional methods, such as alloying or microstructure refinement. Here, we architected an ultrafine grained ferrite-martensite lamella structure, exploiting Mn micro-segregation bands, in a typical low-carbon low-alloy steel by a simple rolling process. Especially, large-area electron backscattered diffraction (LA-EBSD) shows a unique texture gradient from <110> // ND to <111> // ND and back to <110> // ND was developed along the plate thickness. The heterogeneous lamella structured steel (HL) with texture gradient demonstrated a superior combination of high strength and ductility due to hetero-deformation induced (HDI) stress. The HL steel has a yield strength 637.3 ± 8.4 MPa, 1.37 times higher than the conventional steel. At the same time, the elongation of HL specimen is 23.4 ± 2.4%, 3.8 times higher than the ultrafine grained steel. This work provides a new perspective for significantly improving mechanical properties by utilizing segregation of chemical composition in steels based on the current industrial rolling process.

19:25-19:50 Invited

Effects of Microstructure Inhomogeneity and Cast Pores on the Tensile and Fatigue Properties of A356-T6 Aluminum Alloy

Hongwu Song[1]; Baocheng Yang[1,2]; Shihong Zhang[1]; Haiping Chang[3]; Changhai Li[3]; [1]Institute of Metal Research, Chinese Academy of Sciences, China; [2]University of Science and Technology of China, China; [3]CITIC Dicastal Co., Ltd., China

A356 cast aluminum components have been widely employed in automobile industry, e.g., A356 alloy wheels are increasingly used to replace the traditionally stamped and welded steel wheels. However, manufacturing induced pores and inhomogeneous microstructures have critical influences on the monotonic or cyclic mechanical properties of A356-T6 aluminum alloy, which brings potential uncertainly to the service safety of castings. In this study, the distribution of microstructure and cast pores at different positions of a typical A356 die cast wheel is firstly characterized through experiments and simulation, and the effects of microstructure heterogeneity and casting pores on the tensile and high-cycle fatigue properties of A356-T6 alloy are then comprehensively investigated. The results show that microstructure coarsening is presented in the notably grown α-Al dendrites, which leads to the connection and thickening of eutectic regions accompanied by the aggregative distribution of eutectic Si particles. With the coarsening microstructure, microcrack is easier to initiate in those thick eutectic regions, due to the higher stress concentration caused by the aggregated eutectic silicon. In addition, it confirms that the casting pores have larger detrimental effects on the tensile and fatigue properties than the microstructure coarsening in the aspects of crack initiation. Moreover, a modified fatigue model considering the effects of casting pores and the microstructure difference is proposed to describe the fatigue performance of A356-T6 alloy.

19:50-20:10 Contributed

Brittle Precipitates Induced Nanotwins Breakthrough the Strength-Ductility Trade-Off in a CoNiV Compositionally Complex Alloy

Fengchao An; Jikui Liu; Junhua Hou; Bingnan Qian; Wenjun Lu; Southern University of Science and Technology, China

Strength-ductility trade-off is one of typical puzzles to evaluate the mechanical properties of engineering alloys. Here, we demonstrate a novel strengthening strategy to solve the strength-ductility dilemma by using brittle precipitates induced nanotwins. This strategy is realized in a reference compositionally complex alloy (CoNiV) via κ phase ((Co, Ni)3V) formation. The κ phase can stimulate the nanotwins to enhance the strength and ductility simultaneously during tensile loading. Firstly, the yield strength increment is mainly attributed to the coupling strengthening effects of grain refinement and precipitation. Next, the brittle κ phases exhibit a plastic deformability at high stresses, further enhancing the strength without sacrificing too much ductility. The improved strength reaches the critical stress for the onset of nanotwins, promoting the formation of the high stress twinning. These twin boundaries not only block the movements of dislocations, but also provide places to motivate the dislocation slips. As a result, a combination of yield strength (~1100 MPa), ultimate tensile strength (~1550 MPa) and ductility (~32%) can be achieved in this compositionally complex alloy. This new approach of brittle precipitates induced nanotwins provides a promising pathway on developing compositionally complex alloys.

20:10-20:25 Coffee break

20:25-20:45 Contributed

In-Situ Prepared M_2B Intergranular Precipitation Strengthening in a Compositionally Complex Composites via Selective Laser Melting

Junhua Hou; Sihao Zou; Wenjun Lu; Southern University of Science and Technology, China

Introducing uniformly dispersed nano-precipitations is a promising way to enhance the strength of metallic materials due to the reduction of the dislocation mobility. However, controlling the size and distribution of such precipitations is a challenge for conventional manufacturing processes (e.g., thermomechanical treatment). This is because that the thermomechanical process usually leads to a brittle intergranular fracture mode caused by a loss of interface cohesion. This cohesion is mainly attributed to the grain boundary precipitation and coarsening during heat treatments. To overcome this barrier, a combination of in-situ alloying and selective laser melting (SLM) is performed to effectively tune the size and distribution of nanoprecipitations via nucleation and growth of dendrites.The rapid solidification of SLM results in a formation of dendrite micro-segregation intergranular precipitates. In this study, a reference alloy (CoNiCr) is utilized as a matrix, while ceramic particles (B_4C) are employed as nucleation agent for the nanoprecipitations. During the manufacturing process, a high power of SLM is applied to dissolve the B4C particles and make them diffuse into the CoNiCr matrix. Subsequent heating effects from the SLM result in chemical segregation and sub-grain boundary precipitation (M_2B). As a result, a compositionally complex composite (CCC) is fabricated via M2B reinforced CoNiCr matrix. This composited structure increases the yield strength by ~30% with a decent ductility (17%). The results provide a new composite-design strategy using the nanoprecipitations and SLM for developing strong and ductile CCCs.

20:45-21:05 Contributed

Eutectoid Transformation Behavior in Oxide Scale of 960MPa High Strength Steel

Hao Wang; Guangming Cao; Yingjian Chen; Chenyang Wang; Zhenyu Liu; Northeastern University, China

The on eutectoid phase transformation behavior in oxide scale in 960QT was studied in this paper. Thermogravimetric analysis (TGA) was employed to investigate the eutectoid reaction in the oxide formed on pure Fe after being exposed to air at 1000 ℃ for 10 min. The oxidized specimens were held isothermally in Air from 1000 s to 10000 s in the temperature range from 300 to 600 ℃, and the morphologies in FeO were observed by EPMA. The experimental results show that after high temperature oxidation, the scale consists of the outermost layer of Fe_2O_3, the middle layer of Fe_3O_4, the inside of FeO and the alloy element enrichment layer near the substrate. With the isothermal process, proeutectoid Fe_3O_4 is formed in FeO, and a large number of long Fe_3O_4 strips perpendicular to the matrix are formed. With time extend, the content of proeutectoid Fe_3O_4 increases gradually, and eutectoid phase transition begins to take place in FeO, forming lamellar Fe+Fe_3O_4. According to the TTT curve the temperature range of isothermal eutectoid transformation of experimental steel grades is 400-550 ℃, and its isothermal structural transformation behavior conforms to the law of "C" curve, and the nose tip temperature is 450 ℃, which means that the time required to complete eutectoid transformation at this temperature is the shortest. The effects of alloying elements such as Mn, Cr and Si in 960QT on the eutectoid phase transformation of FeO were analyzed based on the experimental results. With the statistics of phase transition results of FeO at different isothermal temperature and time, the phase transition model of FeO in continuous cooling process is derived by combining the phase transition kinetic model and additive model. By using the experimental data of continuous cooling with variable temperature, the calculated phase transformation

model has achieved high calculation accuracy.

Room E, Zoom Link:

Non-ferrous Alloys and Processing (Chief Organizer: Yong Li, Northeastern University)

Aluminum Alloys (Chairs: Zhihao Zhao, Northeastern University; Xiu Song, Northeastern University)

14:00-14:30 Keynote

Investigations on Superplastic Deformation Mechanisms in a Al-Zn-Mg-Cu Alloy

Guangyu Li; *Hua Ding*; Jian Wang; Northeastern University, China

In the present work, the deformation mechanism of superplastic deformation in an Al-Zn-Mg-Cu alloy was investigated by both experimental and numerical methods. The material was achieved by solid solution, aging, rolling and annealing and the grain size was about 10 μm. Superplastic testing was carried out at temperatures ranging from 480℃ to 530℃ and strain rates ranging from $3\times10^{-4}s^{-1}$ to $3\times10^{-3}s^{-1}$ and it was found the optimal superplastic deformation condition was 530℃ and $3\times10^{-4}s^{-1}$. Constitutive equations were established according to the experimental results by BP neutral network and viscoplastic constitutive equation considering damage and grain size. The microstructural evolution was characterized by SEM quipped with EBSD and TEM and it was revealed that the deformation mechanism was grain boundary sliding accompanied by diffusion in the optimal superplastic deformation condition. The FIB technology, combined with in situ SEM observation was utilized to investigate the surface morphology evolution during superplastic deformation and the contributions of different deformation mechanisms to the total deformation were quantitatively assessed. Modeling of superplastic deformation of the investigated Al-Zn-Mg-Cu alloy was conducted by finite element model of crystal plasticity . The grain boundary sliding is coupled as an extra slip system and the microstructural evolution could be predicted in the superplastic deformation process. Meanwhile, the nucleation and growth of cavities during the superplastic deformation were also discussed.

14:30-15:00 Keynote

Research Progress on Horizontal Continuous Casting of Aluminum Alloy

Zhihao Zhao; Northeastern University, China

Direct-chill casting was invented in the 1930s and found its practical application as a means to produce aluminum alloy billets for further processing. The DC process has been classified into vertical direct chill (VDC) casting and horizontal continuous casting (HCC), and it is the VDC casting which has become the most used in aluminum alloys billets production. However, in recent years, the HCC has attracted the attention of the global aluminum industry. As compared to the VDC process, the HCC has many advantages such as lower investment cost, higher flexibility and so on. However, the HCC has some characteristic technical problems due to the gravity difference between the top and bottom surfaces in the horizontal portion, which, in turn, results in heterogenous microstructures in the ingot. The influences of low frequency electromagnetic field on the as-cast structure of horizontal continuous casting aluminum alloy ingots were studied. The results show that the interaction of the low-frequency electromagnetic field and the melt can generate an electromagnetically induced forced flow in the melt, which, in turn, changes flow pattern and temperature field in the mold. the as-cast structure of ingot can be greatly improved by the changes of flow pattern and temperature field. The results of experimental analysis show that the micro-structures of HCC under low frequency electromagnetic field are fine and uniform. Other research progress is also introduced in this report.

15:00-15:30 Keynote

An Idea of Improving Properties of Aluminum Alloy Combining Controllable Electromagnetic Energy (CEME) with Aging Process

Yonglin Ma; Chunlei Yan; Xinyu Bao; Shuqing Xing; Qiao Cheng; Inner Mongolia University of Science and Technology, China

High strength aluminum alloy is widely used in many fields, including spacing crafts, airplanes, automobiles and other key parts in structures. Many of these parts are suffered alternative loads, or, although the loads being not so high, but the action time being extremely long. In such applications, the fatigue properties are essential and many hypotheses and technology are brought up, and promote the aluminum alloys application. Many factors can influence on the fatigue properties, but with certain composition of material, phases and its appearances are the key factors. That means, uniform and fine grain size with dispersed, small and uniformed precipitates or the second phases are the ideal structure, especially the size of precipitate or the second phase must be very small, for example, 20nm or less. In this topic, we had tried to apply controllable electromagnetic energy in casting process and aging process respectively, and to reduce or avoid the fine agent adding in the casting process, then, in the aging process, making the precipitate particles uniform and small. The results show that, using CEME technology in casting process, the adding amount of the refining agent could reduce about 30% to 100%, and the size of the grain almost same with original samples. In the aging process, the test finds that, using CEME technology in aging process, the aging time could reduce more than 30%, and the particle size could be about 20nm and disperse uniformly. from the above experiments, a number of phenomena are benificial for fatigue properties, such as, reducing or avoiding adding refining agent in casting process could reduce the inclusion or large second-phase risks in the working parts, small precipitate and its uniform disperse could make the shape of the particles almost like a ball. Meanwhile, the CEME technique could be easily operated and can generate the small precipitate particles in a flexible condition.

15:30-15:55 Invited

Fabrication of Al Matrix Composites Reinforced with TiC and GNPs by Spark Plasma Sintering at Different Temperatures

Fei Lin[1]; Mengyuan Ren[1]; Ming Yang[2]; Zhixin Chen[1]; Zhengyi Jiang[1]; [1]University of Wollongong, Australia; [2]Tokyo Metropolitan University, Japan

Al matrix composites reinforced with TiC nanoparticles and graphene nanoplatelets (GNPs) were fabricated by powder metallurgy (ball milling followed by spark plasma sintering at different temperatures ranging from 475 to 550 °C). The effects of sintering temperature on the microstructures, Vickers hardness and wear resistance of the composites were analyzed. The results show that with the increase of sintering temperature, the densification of the composite is increased and the interfacial bonding between the reinforcements and the matrix is improved. In addition, Vickers hardness and wear resistance are improved significantly as the sintering temperature increases. The highest Vickers hardness and lowest specific wear rate are obtained in the composite sintered at 550 ℃ among all the samples, which are 145.2 HV and 0.0114 mm^3/Nm, respectively. This study provides a theoretical reference for the determination of the optimal SPS process for the fabrication TiC-GNPs reinforced AMCs with excellent mechanical and tribological properties.

15:55-16:15 Coffee break

16:15-16:45 Keynote

Study on Thermomechanical Treatment Process of 2050 Aluminum Alloy Extruded Bar

Qingfeng Zhu; Hao Wang; Yang Gao; Yihong Liu; Yubo Zuo; Northeastern University, China

The effect of pre-tensile ratio on the mechanical properties of 2050 aluminum alloy extruded bar of solid solution state and aging state were studied. The results show that after solution quenching, most of the phases in the alloy matrix are redissolved, and few small-sized recrystallized grains appear in the matrix. With the pre-tensile ratio increased from 0% to 5%, the yield strength of 2050 alloy increases from 321 MPa to 470 MPa, the tensile strength increases from 489MPa in solid solution state to 534 MPa, the elongation decreases from 27.1 ％ to

15.0 %, and the yield-tensile strength ratio increases from 65.6% to 88.0%. After aged at 155 ℃ for 72 hours, the tensile strength, yield strength, yield tensile strength ratio and elongation of 2050 alloy with pre-tensile ratio 2% are 587MPa, 555 MPa, 94.5% and 9.8% respectively.

16:45-17:10 Invited

Effect of Pre-tensile on the Fatigue Fracture of different heat treatment 7005 Aluminum Alloy Plates

Ni Tian; Xu Jiang; Yaozhong Zhang; Tianshi Wang; Zijie Zeng; Gang Zhao; Gaowu Qin; Northeastern University, China

In this work, the effect of pre-tensile deformation on the fatigue property, fatigue fracture initiation and fatigue crack propagation characteristics of a commercial 7005 aluminum alloy plate at under-aged condition and annealed condition were investigated by means of tensile and fatigue test combined with microstructure analysis. The results showed that there is no significant effect on the shape, size, number, distribution of second phase particles, and on the size and morphology of thin strips grain of under-aged and annealed 7005 aluminum alloy plate, as the pre-tensile deformation increased to 20%. The 7005 aluminum alloy plates in two heat treatment conditions all exhibit significant work-hardening effects. The yield strength, tensile strength and microhardness of the alloy plates monotonically increase and the elongation monotonically decreases as the pretension deformation increases. Under the 175 MPa pulsating tensile load condition (stress ratio R = 0), the overall fatigue life of the under-aged 7005 aluminum alloy plate firstly reduced, then prolonged and then shortened with the increase of pre-tensile deformation. The fatigue lifetime of the under-aged 7005 aluminum alloy plate without pre-tensile deformation is about 6.06×10^5 (cycles), and the fatigue life of the under-aged 7005 aluminum alloy plate is prolonged by about 75% and reaches about 1.06×10^6 (cycles) after 5% pre-tensile deformation. However, the fatigue life of the under-aged 7005 aluminum alloy plate is decreased greatly to 4.21×10^5 (cycles) and 2.89×10^5 (cycles) after 3% and 20% pre-tensile deformation, respectively. The evenly distributed high density dislocations or dislocationcells resulted by 5% ~ 16% pre-tensile deformation in the under-aged 7005 aluminum alloy plate can prolong the fatigue life of alloy plate by over 23%. Moreover, the fatigue performance of the annealed 7005 aluminum alloy plate Under the 155 MPa pulsating tensile load condition (stress ratio R = 0) was significantly improved by the pre-tensile deformation, and the alloy plate subjected to 20% pre-tensile deformation exhibited an optimal fatigue life of ~1.06×10^6 cycles, which was 5.7 times and 5.3 times that of the undeformed and 3% pre-stretched alloy plates, respectively. Two fatigue life plateaus were observed in the pre-tensile deformation ranges of 3–5% and 8–12%, which corresponded to heterogeneous dislocation distribution among various grains and within each grain, respectively. Moreover, two large leaps in the plot of the

fatigue-life–pre-tensile-deformation curve were observed, corresponding to the pre-tensile deformation ranges of 5–8% and 16–20%, respectively.

17:10-17:35 Invited

The Research and Application of Sophisticated Heat Treatment Process for Al-Cu Alloys

Yong Li; Northeastern University, China

High-precision heat treatment are necessary for high-quality aluminum alloys and copper alloys. Air cushion continuous furnace is often used to perform solution-quenching heat treatment for aluminum alloys such as automobile plates and aircraft skin plates. High-temperature air cushion continuous furnace with protective atmosphere is usually applied to conduct solution-quenching heat treatment for high-quality copper alloys connector strips. Roller hearth furnace is always employed on the high-precision quenching heat treatment of aluminum alloy thick plates for aircraft wings. Air cushion nozzle is the core component of the air cushion furnace. The flow field of the air cushion furnace was studied and the aerodynamic model of the air cushion nozzle was improved. A three-dimensional digital model of the full length of the quenching section of the roller quenching machine for aluminum alloy medium and thick plates was established. The three-dimensional dynamic continuous cooling simulation was carried out, and the change law of the temperature field of aluminum alloy medium and thick plates during the continuous quenching process was obtained. The laws acquired were applied on air cushion furnace and roller hearth furnace, and were well verified, and the control accuracy has been improved significantly in practices.

17:35-17:55 Contributed

Study on Microstructure and Properties of Al-Cu-Li/TiC Alloy

Haiyao Wang; Yong Li; Bing Lu; Wei Yu; Yin Wang; Northeastern University, China

Aiming at the problem of nano-TiC particles improving the properties of Al-Li alloy, this paper takes 2055 Al-Li alloy as an example to study the effect of adding different contents of TiC particles on the microstructure and properties of 2055 alloy. The microstructures of 2055, 0.5TiC and 1.0TiC alloys in the as-cast state were observed by field emission electron probe. The mechanical properties of three alloys in the state of T6 (500℃/15min+155℃/24h) and T83 (3% pre-stretching deformation+500℃/15min+155℃/24h) were tested using differential scanning The difference in the number of T1 phase precipitations in the three alloys was studied by calorimeter, and the difference in recrystallization resistance of the three alloys was discussed by electron backscatter diffraction. The experimental results show that the 2055 alloy added with TiC particles has obvious microstructure refinement effect, and the comprehensive performance is greatly improved. It shows that it is feasible to add particles to strengthen the aluminum-lithium alloy to improve the comprehensive performance, and it provides some ideas and references for the development of the third-generation aluminum-lithium alloy.

Aluminum Alloys, Zirconium Alloys and Other Alloys (Chairs: Ni Tian, Northeastern University; Qingfeng Zhu, Northeastern University)

19:00-19:20 Contributed

Effect of the Pulsed Magnetic Field Melt Treatment on Microstructure and Property of Casting Al-Si-Mg-Cu-Ni Alloy

Xinyu Bao; Yonglin Ma; Chunlei Yan; Qiao Cheng; Yihui Su; Inner Mongolia University of Science and Technology, China

Piston Al-Si-Mg-Cu-Ni alloys are used to produce high-performance automobile piston. Because of a very complex composition, it is necessary to control the formation of primary Si, α-Al and other compounds in casting ingots. In this study, we used pulsed magnet fields in piston alloy ingot casting processing to affect the occurrence and size distribution of primary Si and the morphology of α-Al dendrites and other high-temperature eutectic phases in piston alloy ingot. The ingot microstructure and phase composition, hardness of the piston alloy ingot were analyzed through the metallographic microscopes, XRD, SEM, microhardness apparatus, respectively, and the reason of the change on the piston alloy ingot microstructure and property was analyzed through the classical nucleation theory. After pulsed magnet fields treating, the large size primary Si in microstructure disappearance, the size of α-Al dendrites has significantly reduced by 13.8%; the amount of high-temperature eutectic phases in alloy significantly increased and uniformly distributed, the hardness of the alloy has improved by 37%. Through the classical nucleation theory, we found the energy of the pulsed magnet fields have an effect on the nucleation process, which will increase the nucleation rate on the melt, modifying and fining the solidification structure, promote the high-temperature eutectic phases form. The refinement of the primary Si and α-Al dendrites, with the increase of the high-temperature eutectic phases, has a potential benefit for the automobile piston high-temperature mechanical properties.

19:20-19:40 Contributed

Effect of Intermediate Thermal-mechanical Treatment (ITMT) on Microstructure and Properties of 7185 Aluminum Alloy

Yin Wang; Yong Li; Bing Lu; Wei Yu; Haiyao Wang; Guangming Xu; Zhaodong Wang; Northeastern University, China

The effects of different intermediate thermal mechanical treatment (ITMT) on the microstructure and properties of

7185 aluminum alloy were studied. The microstructure of the alloy was characterized by scanning electron microscopy (SEM) and transmission electron microscopy (TEM). The mechanical property was studied with tensile test and the corrosion resistance was studied with intergranular/exfoliation corrosion testing. The results showed that ITMT can significantly refine grain size by effectively inhibiting the degree of recrystallization, and the grain size of over-aged group (S-T) was the smallest. The homogenization group (J-T) sacrificed many mechanical properties, while the S-T did not sacrifice mechanical properties. Fine grain can increase the area fraction of grain boundary which is conducive to the formation of passivation film on the surface of the sample and the reduction of galvanic strength between grain boundary and inside grain. In addition, fine grain can also increase the distribution distance of grain boundary precipitates (GBPs) which increases the corrosion resistance of the alloy.

19:40-20:00 Contributed

Microstructure and Mechanical Properties of a Medium Manganese Steel with Different Aluminum Addition after a Short Intercritical Annealing Time

Yan Li; Nan Zhang; Wei Ding; Inner Mongolia University of Science and Technology, China

In recent years, third generation AHSS under development have been designed to achieve a balance between acceptable cost and remarkable mechanical properties. Among the various types of the third generation AHSS, medium-manganese steels are considered to be a strong candidate for third generation AHSS. It is reported that addition aluminum to medium-manganese steels can get excellent mechanical propeties when the intercritical annealing (IA) time is short. But, the addition of aluminum will introduce some trouble such as alumina inclusion and a decreased the rate of continuous casting. Therefore, the content of Al should be limited to that within a suitable range. It is worth to research the influence of aluminum on the IA process, microstructure and mechanical properties of a medium manganese steel. The present research on the microstructure and mechanical properties of a medium manganese steel with different aluminum addition after a short IA time under different IA temperatures by thermodynamic simulation, scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray diffractometry (XRD) and uniaxial tensile tests. The results show that addition Al expands the IA temperature range and the range shifts to higher temperatures, which contributes to improving the mechanical properties with a brief IA time, i.e. 1min. IA temperature has a strong impact on the microstructure and tensile properties of the studied steels. The final microstructure after IA in 730 °C for the steel addition of 1.0Al (mass %) and 790 °C for the steel addition of 2.5Al (mass %) contain the highest amount of retained austenite and thus result in better tensile properties than the other IA temperatures. Those retained austenite have two different morphology, equiaxed retained austenite and lath retained austenite, and most of retained austenite transformed to martensite during deformation. There are two different types of those martensite, one is α'-martensite and the other is epsilon martensite(e-martensite). The best mechanical properties of investigated steel were obtained at 790 °C with containing 2.5Al (mass %), the tensile strength was 982.5 MPa, the elongation was 42.96% and the strength × ductility was above 42.00 GPa%.

Room F, Zoom Link:

Digitalization and Intelligent Manufacturing (Chief Organizers: Dianhua Zhang, Northeastern University; Jie Sun, Northeastern University)

Intelligent Manufacturing II (Chair: Shaowen Huang, Research Institute of Shangang Group)

14:00-14:30 Keynote

Studies on the Hot Rolling Plant: Lean and Intelligent Manufacturing

Jiaojian Ai; Shougang Jingtang Iron and Steel United Co., Ltd., China

This presentation briefly describes the steel company intelligent manufacturing history and trends. The studies focus on the hot rolling plant key problems, such as, data separated , too much Apps and platforms and no data connections and co-analyses. The system collected the whole data of the hot rolling plant, including the mills, media supply plants, roll shops and coil yards. Based on the big date platform, the system developed seven Apps: quality management, equipment operation and maintenance, power and cost management, security and environment monitoring, coil yard management, intelligent robot and vision application, data statics.

14:30-15:00 Keynote

The Basic Supporting of Advanced Data Communication System to Intelligent Steel

Lixun Li; Shuguang Kang; Xiaojiang Yang; Xin Wang; HBIS Laoting Steel Co., Ltd., China

Comprehensive intelligent manufacturing depends on comprehensive digitalization. There are a large number of high-frequency sensor data in the industrial production line to support the operation of the production line. How to realize high-speed precise sensing and duplex real-time measurement and control is not only the starting point of intelligent manufacturing, but also a key point. The industrial network distributed data communication system is a high-speed duplex network communication between the multi bus equipment and the measurement and control system in the bottom digital factory of intelligent manufacturing; the real-time duplex measurement and control communication between the process control system and the basic automation system (PLC, PAC, L1 system, single-chip microcomputer and intelligent sensor); the pre-stage of precise perception of data in the MES and ERP systems; the precision of big data center The key infrastructure of the data source. The data interface of network cooperative manufacturing system is reserved while the digitization, modulation and informatization of each process and workshop of manufacturing process are well done. Through industrial network and distributed industrial ICT system, the basic units are networked, perceived and coordinated, the whole metallurgical process driven by high-quality data, advanced metallurgical process model, deep network self-perception and wide area process network-cooperation system.

15:00-15:30 Keynote

Steel of the Future: A New Look at Digital-driven Manufacturing

Wenqi Gu; HBIS Digital Technology, Co., Ltd., China

Smart manufacturing, the conceptual core of Made in China 2025 to develop its advanced industry base and advance the steel dominance, provides a range of digital enablers for steel manufacturers to improve operational efficiency and profit margin. However, the current state of steel sector is rather complicated. Plants and assets often operate in silos, rather than being integrated to meet a larger strategic objective. Supply chain executives have little access to real-time information, leaving them unable to anticipate changes in the market. Steel producers are lack of the ability to anticipate and mitigate risk or jump on short-term opportunities. From an industry practitioner perspective, this section discusses possible solutions to better integrate data analytics and other new digital tools with metallurgical expertise to help digital transformation unfold in a way that was previously unattainable. Based on existent literature, it briefly reviewed the theories of CPS, five-tier architecture as well as information systems. It then proposes a creative structure for smart steel manufacturing, which comprehensively incorporates segments covering basic automation, process control, production planning, management and service. The proposed structure is applied in context-specific production scenarios and has yielded considerable performance improvements, a case in point of how digitalization is deeply changing metals production and taking today's steel industry into a smarter and cleaner future.

15:30-16:00 Keynote

Exploration and Practice of Digital Factory

Fucun Li; Jiangsu Jinheng Information Technology Co., Ltd., China

At present, the momentum of digital economy development is accelerating, and the digital transformation of enterprises continues to advance. The digital factory is an important starting point for a new round of scientific and technological revolution and industrial transformation characterized by intelligent manufacturing. The digital factory is a digital transformation and upgrade compared with the traditional factory, and is an innovation of the integration and application of a new generation of information technology and business scenarios. Jinheng Technology continues to explore and practice, integrates its own in-depth understanding of business, and builds an overall solution for the digital factory. On the basis of the industrial Internet platform, with data-driven decision-making as the center, data into value, simulation, evaluation and optimization of the production process, the establishment of a digital virtual factory integrating production, equipment, process quality, energy and other professional control, to achieve the whole process of manufacturing interconnection, transparency and visibility, trend prediction. Achieve lean management by digital means, optimize the production process, and ultimately achieve predictive manufacturing, so as to promote smarter production, more intensive control, and more efficient management.

16:00-16:15 Coffee break

Modelling and Simulation of Metallic Materials (Chief Organizer: Shuai Tang, Northeastern University)

High Temperature Process and Texture (Chair: Minghui Cai, Northeastern University)

16:15-16:45 Keynote

Obtaining the Solubility Products of TiN & TiC in Austenite by Measuring the Grain Growth at Elevated Temperature

Wei Wang[1]; Mingxing Zhou[2]; Haijiang Hu[2]; Guang Xu[2]; [1]Baosteel Research Institute, China; [2]Wuhan University of Science and Technology, China

Microalloying is one of the most important technologies in metallurgy and the solubility products of carbides and nitrides for different microalloying elements are fundamental variables in the technology application. A modeling analysis was conducted on the austenite grain growth with considering the pinning effect, and the size and volume evolution of TiN or TiC particles based on dissolution of the compounds and Ostwald ripening during heat up process in Ti microalloyed steels. Experiments were carefully designed by using a Ti containing steel. The austenite grain size evolution with time and temperature was measured. Analysis was conducted and it was found that the carbide totally dissolved itself to the lattice at a temperature around 1165℃ after a soaking duration of 30 minutes. Although above 1200℃, TiN would be the only left precipitate and the dissolution of the particles seemed quite slow. The measured austenite grain size was therefore used to fit the model and a reseanable solubility products in comparison with those in literature of the carbide and nitride were thereafter obtained.

16:45-17:15 Keynote

On the Magnitude of Solid-liquid Interfacial Energy

Lianwen Wang; Lanzhou University, China

Experimentally, the solid-liquid interface energy, ysl, was determined mainly by using two methods: (I) application of the Gibbs-Thomson equation to crystal nucleation (CN) from the melt or to melting point depression (MPD) and (II) observation of dihedral angles formed at the intersection of solid-liquid interfaces with other interfaces; e.g. grain boundaries. Method (II) did not seem well applicable for metal elements and, by involving additional factors e.g. the grain boundary energy, it increases in complexity and hence may decrease in reliability. In comparison, Method (I) is relatively easier in handling for metal elements, but the reliability shall depend on how well liquid crystallization or crystal melting is understood. At present, available solid-liquid interface energy ysl data for metal elements were mainly derived by using the CN method on which, however, it is difficult to have full confidence. The MPD method has for a long time been suggested to be a method for determining ysl, however, systemic analyses on available melting point depression data and on the application of this method are absent. It seems that the most recent experiment work on this method is by Jackson and McKenna in 1990 on organic materials. They suggested that this method may be at least as reliable as and easier to use than the homogeneous nucleation method. In is work, comparative analyses of the CN method and the MPD method for measuring ysl are carried out. The MPD method is found more reliable and has several advantages from experiment through data analysis to theoretical generalization. The MPD data in use, all reported before the 1970s, is updated with the derived ysl re-compiled. Finally, by invoking a melting model that we developed recently, an equation for calculating ysl is proposed on basis of the melting point depression method.

17:15-17:45 Keynote

The Role of Texture on the Grain Boundary Network in IF Steels

Hossein Beladi; Deakin University, Australia

The current study revealed that the development of γ-fibre texture in IF-steel through static recrystallisation alters the distribution of grain boundary misorientations and plane orientations. In the initial transformed condition, the grain boundary plane distribution has a maximum at the (110) orientation. However, as the intensity of the γ-fibre texture increased, the maximum shifted to (111) and intensified. Furthermore, the presence of γ-fibre texture gradually increased the low angle boundary population at the expense of high angle boundaries, leading to a nearly uniform misorientation angle distribution. A calculation of the disorientation distribution assuming random orientations along the γ-fibre showed a flat distribution in the domain from 0 to 60°, consistent with the observations. The presence of γ-fibre texture changed the intensity, but not the shape of the grain boundary distribution at ∑3=60°/[111], which displayed maxima at low energy {112} symmetric tilt boundaries.

17:45-18:15 Keynote

Modeling the Microstructure and Texture Evolution During Annealing Process of Ferritic Stainless Steel using Cellular Automaton Method

Chi Zhang[1,2]; Liwen Zhang[1]; Xiaole Tang[1]; Xiaoguang Zhou[2]; [1]Dalian University of Technology, China; [2]Northeastern University, China;

The formability of ferritic stainless steel sheet depends mainly on its grain size distribution and texture condition. Although many attentions have been paid on the texture evolution during deformation and recrystallization for ferritic stainless steel and some other alloys, the texture evolution during recrystallization process is still hard to be tracked due to the limited usage of in-situ or quasi-in-situ equipment. Moreover, the proposed mechanism of texture evolution based on the experimental results need to be testified further since the quite complex local interactions between adjacent grains. In this work, a cellular automation (CA) model, which contains a state variable of crystallographic orientation for every cell, was developed to model the topological microstructure and texture evolution during recrystallization process for ferritic stainless steel. The micro-texture of cold rolled ferritic stainless steel sheet was detected by electron backscattered diffraction and then input to the model as initial crystallographic orientation distributions. And the initial inhomogeneous distribution of strain at meso-scale was estimated by the Kikuchi pattern quality. Then the recystalllizaiton nucleation criteria based on critical dislocation density and the grain boundary migration relating to the disorientation of grain boundary were coupled to the model. The orientation of the recrystallization nucleus was assigned using a texture discretize method. Then the nucleation and growth of recrystallized grains can be simulated based on each cell's orientation and dislocation density. The developed CA model shows a good agreement of both topological microstructure and texture evolution with the experimental results. This CA model can be applied for predicting the recrystallization texture evolution and testifying the proposed texture evolution mechanisms.

Advanced High Strength Steels (Chair: Chi Zhang, Dalian University of Technology)

19:00-19:30 Keynote

Alloy Design and Nano-engineering of Medium-Mn Steels

Wenwen Song; RWTH Aachen University, Germany

The diversities in crystalline structure and the hierarchical features of the structures in metals lead to their distinguished deformation behaviour, elastic properties, magnetic properties, electric properties, mechanical properties, etc. In the research of metallic materials, the linkage of structure-processing-property is considered as the very important principle to understand the alloys. Following this basic principle, one can further design, select and assess suitable materials for a specific application. Over the last decades, based on multi-scale understanding of the metallic materials - from metre (components) to micrometre (grains and phases) and further down to nanometre (second phases and stacking faults), a number of extraordinary metallic materials have been successfully developed and commonly applied, e.g. ultra-strong steels for automotive and aerospace applications, orthopedic medical materials, etc. This research work will present the alloy design and nano-engineering approaches that offer new opportunities to design and engineer the novel metallic materials into hierarchical structures with tailored properties, in particular with the example of medium-Mn steels. The addition of Cu and process alternatives will be introduced. New approach that aid controlling the process of phase transformation during deformation and/or thermal treatment in the steels will be discussed.

19:30-19:50 Contributed

Accelerating Behaviour of High Magnetic Field on Low Temperature Bainitic Transformation

Baoqi Dong; Tingping Hou; Kaiming Wu; Peter Hodgson; Deakin University, Australia

Low temperature bainitic steel has ultra-high strength (2.3 GPa) with excellent high ductility. However, one limitation is that its preparation takes a long isothermal time (even reached 60 days) due to slow transformation rate at low temperature. We studied the role of high magnetic field on the low temperature bainitic transformation and found that the bainitic transformation is significantly accelerated by a high magnetic field. The application of 12 Tesla magnetic field increased the bainite volume percentage by 193% and 106% after isothermal treatment at 300 ℃ for 1 and 5 h, respectively. Meanwhile, we also found that the carbon partitioning from bainitic ferrite to retained austenite was also promoted by magnetic field during transformation. The T0 -T0′ curve appears to shift to the right in the presence of high magnetic field.

19:00-20:20 Keynote

Mechanical Properties Prediction and Reverse Mechanism Deepening Based on Multi-mode Data Analysis

Wei Xu; Da Ren; Chenchong Wang; Northeastern University, China

The establishment of the ‘composition-microstructure-property’ relationship has been the focus of intensive research on designing and optimizing metallic materials. Many methods have been proposed to predict the tensile properties, such as mixture rule, mean-field homogenization approach and finite element method approach, but all suffer from the problem of parameter sensitivity. Although artificial intelligence has advantages in solving the problem of parameter sensitivity, statistical methods based on the "data-data" mode are inaccurate in abstracting microstructure information, and deep learning based on the "image-data" mode can only establish the relationship between the single-mode microstructure image and property, which ignores the effect of composition and limits the generality of the model. Therefore, in order to solve the above problems, based on the deep learning framework and the concept of multi-mode data coupling, the study proposes a multi-mode data coupling tensile property prediction framework without parameter sensitivity, which covers various compositions, various heat treatment processing routes (obtaining various phase morphologies) and multi-source microstructure images (KAM, BC, Phase). In the framework, multi-modal data coupling is firstly realized, that is, the composition value is normalized and multiplied by each pixel data value in the pixel matrix of each image to obtain a "coupling matrix"; Then, the integration of multi-source microstructure images is realized, that is, after obtaining the "coupling matrix" of the BC map, KAM map and Phase map respectively based on the above coupling method, all the "coupling matrices" are stacked; Finally, the deep learning convolutional neural network model takes the coupling matrices obtained after stacking as input to predict the tensile property. The framework shows high prediction accuracy for the multi-mode data set established in this study. Under the guidance of multi-mode information and multi-source microstructure images, the proposed model can predict the tensile properties accurately based on 23 samples and the R^2 above 90%. Further, a deep learning inverse visualization technique, Grad-CAM, is used to generate the heatmap, which can reflect key microstructure information that have great impact on property. The visualization technique improves the interpretability of the deep learning model and deepen the physical mechanism. The model proposed in this study can solve the problem of parameter sensitivity and establish a general and universal prediction framework in the large stress (600-1300 MPa) and large strain (2-20%) range. It provides an example for the establishment of the "composition-microstructure-property" relationship in steel materials, which has the potential to be transplanted into other material systems.

20:20-20:35 Coffee break

Phase Transformation (Chair: Wenwen Song, RWTH Aachen University)

20:35-21:05 Keynote

Application of High-energy Synchrotron X-rays to Study Microstructural Evolution in Steels During Heat Treatment

Peter Hedström; Sen Lin; KTH Royal Institute of Technology, Sweden

The control of final microstructure and properties of steel require a fundamental understanding of microstructure evolution during heat treatment. One useful approach to develop this understanding is in-situ high-energy synchrotron x-ray diffraction (HEXRD), which enables real time investigations in the bulk of the steel during the heat treatment. In this talk we will present the application of HEXRD to study microstructure evolution in various steels during heat treatment. We will delineate the experimental methodology and provide research examples from studies on e.g. the bainitic and martensitic phase transformations.

21:05-21:25 Contributed

Heterogeneous Segregation Behavior of Nb at the Stepped Migrating Interface During Phase Transformation

Haokai Dong[1]; Yongjie Zhang[2]; Goro Miyamoto[2]; Hao Chen[3]; Tadashi Furuhara[2]; [1]South China University of Technology, China; [2]Tohoku University, Japan; [3]Tsinghua University, China;

Not as generally-assumed 'smooth', the actual interface should consist of ledge structure with riser and terrace due to crystallographic constraint. However, the combined information of structure and chemistry for such stepped interface has not yet been available to date. Here the segregation behaviors of Nb at the migrating ferrite/austenite interface with ledge structure but totally different character are investigated. For the incoherent interface, a typical heterogeneous feature that the Nb atoms segregate at the less mobile terrace rather than the mobile riser is captured for the first time, while the segregation is absent at the semicoherent one. By optimizing the diffusion parameters, the theoretical calculation based on solute drag theory can well reproduce the experimental values for both types of interfaces. The present results may shed new light on the nanoscaled elemental segregation behavior and stimulate more accurate modelling on the transformation kinetics with consideration of interface structure.

21:25-21:45 Contributed

Rapid Analysis of Precipitates in Metal by Automated Transmission Electron Microscope

Roger Maddalena; Harold Phelippeau; Hiromi Sekiguchi; Thermofisher, United States

Nanoparticles are often analyzed by transmission electron microscope (TEM) due to the ultra-high resolution required to study nanometer-sized features. Microalloyed steel, for example, can have thousands of tiny Niobium Carbo-Nitride precipitates in just one square micron area. Until now, TEM analysis has been performed manually which is time consuming for the operator, and it is difficult to obtain statistically relevant sample sizes. Here we streamline the process with energy dispersive spectroscopy (EDS) mapping of very large sample areas. The high resolution images are then used to characterize the type, shape and count of 1nm to 100 nm precipitates. Sample preparation methods include the Plasma Focused Ion Beam (PFIB) which reveals location and orientation specific details, and the carbon replica method (etched metal) which is common for steel. This automated process is approximately 1,000 X faster than manual analysis of nanoparticles. Thus, process and product developers can now quantify whole populations of precipitates for each step in their thermomechanical process.

21:45-22:10 Invited

Thermodynamic Prediction of Martensitic Transformation Temperature in Fe-C-X (X=Ni, Mn, Si, Cr) Systems

Qun Luo[1]; Hongcan Chen[1]; Chenchong Wang[2]; Wei Xu[2]; Qian Li[1,3]; [1]Shanghai University, China; [2]Northeastern University, China; [3]Chongqing University, China

The martensite start temperature (Ms) is a significant parameter to describe the stability of retained austenite in steels. This paper provides a prediction model of Ms for lath martensite considering chemical and non-chemical driving forces. The magnetic parameters are carefully optimized because it affects the magnetic Gibbs free energy of austenite and ferrite, and have big impact on the chemical driving force. The non-chemical driving force includes shearing energy of austenite, dilatation strain energy of martensite and dislocation stored energy, where dilatation strain energy provides the major contribution. The integrated-models for dilatational coefficient are constructed in a wide composition and temperature range based on the experimental dilatational data. It expands the scope of application of thermodynamic model and improved prediction accuracy of martensitic transformation temperature (Ms). The prediction error reaches 5.6% for Fe-C-X (X=Ni, Mn, Si, Cr) and 6.5% for Fe-C-Mn-Si-X (X=Cr, Ni) steels.

Poster Session

Poster 1

Experimental Study on the Hot-Core Heavy Reduction Rolling Process on the Structure of Casting Billet

Ruihao Li[1]; Haijun Li[1]; Lin Wang[1]; Jinbo Li[1,2]; Yonglu Wang[2]; Guodong Wang[1]; [1]Northeastern University, China; [2]HBIS Group Co., Ltd., China

Hot-core heavy reduction rolling (HHR2) technology has been extensively studied in recent years as an energy-efficient technique to modify the solidification properties of cast billets. In the current study, the casting billets with a cross-section of 150×150 mm2 were investigated and prepared into Casting billet, low-temperature soft HHR2 (LS-HHR2) billet, low-temperature heavy HHR2 (LH-HHR2) billet and high-temperature heavy HHR2 (HH-HHR2) billet and high-temperature heavy HHR2 (HH-HHR2) billet, as well as the temperature conditions of the casting process and the deformation during rolling were calculated with the numerical simulation analysis software. Subsequently, observation samples were prepared from different experimental billet thickness directions and acid-etched, and the experimental findings were analyzed from three perspectives: macroscopic, mesoscopic, and microscopic, respectively. The results indicate that deformed billets can be macroscopically classified into unbroken columnar crystal zone, HHR2 broken zone, and central equiaxed crystal zones, while all the processes deformed by HHR2 can reduce the percentage of columnar crystal zone, and the best effect is obtained in the low-temperature large deformation process.

Poster 2

Analysis of Cold Bending Cracking of 600MPa Hot Rolled Dual-phase Steel Plate

Dawei Zhang[1,2]; Dawei Zhang[1]; Xiaolin Li[1]; Qian Du[1]; Haoyuan Li[1]; [1]Shougang Group Co., Ltd., China; [2]Northeastern University, China

In this paper, the cause of cold bending cracking of 600MPa ferrite martensite Dual-phase steel with thickness of 11mm was studied. The fracture scanning analysis of the cold-bending cracked sample shows that the surface of the fracture is characterized by ductile fracture, and the grain on the surface of the steel plate at the bending deformation position is obviously elongated, showing good plasticity. The thickness center of the fracture is characterized by obvious dissociation, brittle fracture and stratification. Therefore, it is concluded that the starting point of cold bending cracking is at the center of fracture thickness. Through the metallographic observation of the section of the steel plate, the cracking and the qualified cold-bending samples were compared and analyzed. The microstructure of the cracked samples was abnormal, and the banded structure reached grade 2.5. A large number of chain-like martensite appeared in the center of the steel plate. The crack propagated along the martensite chain,

and obvious MnS inclusions were found in the crack. The proportion of chain-shaped martensite in the core of the uncracked sample steel plate is low, the banded structure grade is 1.5, and there is no MnS inclusion. Electron probe analysis of the section of the cracked cold-bending sample showed that the segregation of alloying elements C, Mn and P was serious, while that of alloying elements S and Cr was slight. According to the analysis, the reason of cold bending cracking is that alloy element segregation of steel plate leads to the formation of thick central chain martensite, and the combined effect of MnS inclusion defect and high crack sensitivity of martensite leads to cold bending cracking.

Poster 3

Development and Application of High Efficiency Air-jet Quenching Technology for Ultra-thin High-strength Steel Plates

Yanqi Ye; Tianliang Fu; Guanghao Liu; Zhaodong Wang; Northeastern University, China

The quenching of ultra-thin steel plates with high flatness is the core technology and industry problem in the field of plate and strip steel heat treatment. This paper introduces the gas quenching equipment and new technology using gas as the cooling medium, and clarifies the advantages of the gas cooling medium in the control of the quenched steel plate shape. For ultra-thin high-strength steel plates with a thickness of 2 mm and below, a new quenching process using high-pressure normal-temperature air as the cooling medium is developed. After industrial testing, a 2mm NM400 steel plate with tensile strength of 1204 MPa, elongation of 10.0 %, Brinell hardness of more than 372 HBW, and quenching unevenness of no large than 3 mm/m was obtained. This research lays the foundation for the development of new high flatness quenching equipment and technology for ultra-thin steel plates.

Poster 4

The Next Generation of Steel Coil Conveying System

Fuqiang Wei[1,2]; Jiangtao Zheng[2]; Fuqiang Wei; [1]Beijing Shougang Yunxiang Industrial Technology Co. Ltd., China; [2]Beijing Shougang International Engineering & Technnology Co., Ltd., China

This paper summarized the developments of the steel coil conveying technology of metallurgical enterprises in this century, introduced the super-capacitor and its applications in the public transportation area, described the first intelligent new energy coil pallet-car and its innovations in detail, compared two technical proposals of a real project that using the new pallet-car system and the traditional pallet system. It also described the first & second practical applications in hot strip mill plant, and pointed out the advantages and the possible applications of this technology in other fields and industries. The technology meets the requirements of Industry 4.0, and provides a reliable solution for intelligent heavy load logistics.

Poster 5

Analysis of Impingement Heat Transfer Characteristics of Hot Rolled Seamless Steel Tube in Motion

Yansheng Zhang; Northeastern University, China

As one of the most effective ways to improve mechanical properties, controlled cooling has been widely used in the hot rolled strip and sheet industry. However, in hot-rolled seamless tube manufacturing, uniform cooling is much more difficult than strip steel due to the circular hollow nature. Therefore, the realization of on-line controlled cooling of hot-rolled seamless pipes is a problem worth noting. Based on the finite element model of jet impingement cooling of hot-rolled seamless steel pipes, the effects of axial velocity (V), rotational speed (R) and nozzle distance (D) on the cooling characteristics of steel pipes were studied through orthogonal experiments. The results show that the surface temperature of the steel pipe is distributed in a spiral shape. Axial speed has the greatest impact on cooling effect, followed by nozzle distance, and rotational speed has the least impact. Based on the above research results, a mathematical model of the surface axial velocity, rotational speed, and temperature difference between nozzles was established, and the prediction accuracy was high. The research results have certain guiding significance for the arrangement of the jet impingement cooling process of the hot-rolled seamless steel pipe.

Poster 6

In Situ Observation of Ultrafast Cooling Phase Transformation of 28CrMoVNiRE Seamless Steel Pipe

Xiaodong Wang; Xirong Bao; Lin Chen; Baofeng Wang; Inner Mongolia University of Science & Technology, China

The microstructure evolution of 28CrMoVNiRE seamless steel pipe samples was dynamically observed in ultrafast cooling and the phase transformation process was analyzed using laser scanning confocal microscopy (LSCM). The microstructures after ultrafast cooling were observed by scanning electron microscope (SEM) and transmission electron microscope (TEM). The microstructure characteristics and strengthening and toughening mechanism of the experimental steel pipes in ultrafast cooling were explored. It is found that the faster the cooling rate is, the lower the martensitic start temperature (Ms) is, the faster the transformation speed is, the smaller the temperature range of transformation duration is, and the finer the martensite block is. When the ultrafast cooling rate reaches 70 °C/s, the explosive transformation of martensite can be induced and the ultrafine lath martensite with the feature of sub-grain refinement, nano coherent carbides and high-density dislocations can be obtained, which will significantly improve the strength and toughness of the experimental steel pipes.

Poster 7

Study on Microstructure and Mechanical Properties of X80 Pipeline Steel Pipe

Yuefeng Chen[1,2]; Yaobin Yang[1,2]; Xiaodong He[1,2]; Jian Han[2]; Lihua Qi[1,2]; [1]CNPC Tubular Goods Research Institute, China; [2]International Welding Technology Center, China

The mechanical properties of three kinds of X80 steel with 32.1mm wall thickness were tested in this study, and the microstructure of three kinds of X80 pipeline steels was investigated by optical microscopy (OM) and electron backscattered electron diffraction (EBSD). The results of EBSD and OM indicated that the tensile properties are mainly affected by the average effective grain size and the geometrically necessary dislocations density. The effect of grain refinement strengthening can be enhanced by the decrease of average effective grain size, and the increase of geometrically necessary dislocation density can increase the effect of working hardening, thereby improving the tensile strength of X80 pipeline steel. The impact performance is mainly affected by the ratio of high angle grain boundaries, Schmid factors and recrystallization volume fraction. The increase in the proportion of high-angle grain boundaries can effectively hinder the propagation of cracks, thereby improving the impact toughness of X80 pipeline steel.

Poster 8

Failure Prediction and Predictive maintenance of Key Equipment in Seamless Steel Tubes & Pipes Production Line

Fan Gao[1]; Yaohui Dai[2]; Shunbin Cao[2]; [1]ChongQing ChuanYi Automation Co., Ltd., China; [2]Hengyang Valin Steel Tube Co., Ltd., China

As a typical intermittent production process, seamless steel tube process has the characteristics of multi-period, nonlinear and multi-variable, and the key equipment mostly operates in the complex working conditions of strong impact and non-stationary load, which makes it difficult to accurately identify and predict the equipment failure. Aiming at the weak links and improvement direction in the equipment management of steel pipe production line, this paper implements status monitoring and failure prediction to key equipment based on information fusion of multi-parameters and multi-points, through comprehensive analysis of fault characteristic information under various operating conditions to determine the health / unhealthy status, fault type and fault severity, validity and accuracy of diagnostic conclusions such as rolling mill bearing run-off, cage fracture and shaft rotational loosening were verified by the equipment open and maintenance. Through the implementation of this project, it aim to promote equipment management from planned maintenance to forecast maintenance, realize Hengyang Valin Steel digital equipment intelligent operation and maintenance.

Poster 9

DWTT Properties of High Strength and Toughness X80M Pipeline Steel and Its Influencing Factors

Xiaodong He[1,2]; Lei Wang[1]; [1]CNPC Tubular Goods Research Institute//State Key Laboratory for Performance and Structure Safety of Petroleum Tubular Goods and Equipment Materials; [2]International Welding Technology Center, China

In the past half century, drop weight tear test (DWTT) is an important laboratory testing method to evaluate the fracture toughness of pipeline steel. The DWTT fracture process, absorbed energy and fracture morphology of X80M thick wall pipeline steel were studied by different hammer striking methods (pendulum and drop hammer) and high-speed camera. And the fracture appearance of DWTT was compared with that of steel pipe burst test. The results show that for X80M high strength and toughness thick-walled pipeline steel, the probability of an abnormal fracture is equal regardless of whether a pendulum or a drop hammer is used to hit the specimen. The formation of abnormal fractures for thick wall and high-strength pipeline steel is due to the obvious compressive plastic deformation and work hardening caused by the hammer impact. Thus, the abnormal fracture cannot truly characterize the fracture behavior of material, and evaluating the brittle fracture resistance of high-strength-ductile thick-wall pipeline steel by DWTT has certain limitations.

Poster 10

Influence of Off-line Heat Treatment Process on Mechanical Properties of Oil Casing for Ultra-deep Wells

Yunkai Wang; Jian Kang; Chao Wang; Zihan Wu; Guo Yuan; Guodong Wang; Northeastern University, China

With the development of oil exploration towards ultra-deep wells, the performance requirements of oil casing as a disposable material are getting more and more demanding. At present, domestic and international research has stagnated at V150 level. This paper aims to improve it to V170 level and design a novel alloy composition. To achieve this goal, the quenching and tempering temperatures in the off-line heat treatment process have been changed to detect experimental steel's original austenite grain size and final mechanical properties,like strength and toughness, etc. Meanwhile, this paper intends to explore how quenching temperature change impacts the original austenite size and final structure, and how tempering temperature change affects mechanical properties. The results show that the decrease in quenching temperature will reduce experimental steel's original austenitic grain size but increase its toughness, while its strength remains unchanged. In addition, reducing the tempering temperature will improve steel's strength but weaken its toughness.

Poster 11

The Effect of Ausforming and Austempering on Microstructure and Mechanical Properties of an

Ultrahigh-strength Bainitic Steel

Tianyu Zhang; Northeastern University, China

Ausforming, as a thermomechanical treatment, can effectively refine the bainitic sheaves. However, the effects of ausforming on bainitic transformation above and below Ms, the resulting microstructure, and mechanical properties are still debated. In this work, ausforming with 25% strain at 650 °C is applied to an ultrahigh-strength bainitic steel, which is subjected to austempering above and below Ms. The kinetics of phase transformation and microstructure characterization was carried out by dilatometry, SEM, EBSD, XRD and TEM. Combining tensile properties and work hardening analysis, the relationship among phase transition, microstructure evolution and mechanical properties were revealed. For austempering above Ms with ausforming, ausforming inhibits bainitic transformation and retains more retained austenite by strengthening undercooled austenite. The refined bainitic sheaves and the sustained TRIP effect can be obtained by ausforming, leading to the enhanced strain hardening ability, an improved the tensile strength and uniform elongation compared to the sample which is austempered above Ms. For austempering below Ms, ausforming hinders martensitic transformation and decreases Ms temperature via strengthening undercooled austenite, thus promoting bainite transformation. Compared to the samples which are austempered below Ms, the refined bainitic sheaves and the increased dislocation density in ausforming samples could improve the yield strength and tensile strength while maintaining the excellent plasticity.

Poster 12

Effect of Thermal Processing on Grain Boundary Characteristic Distribution, Microstructure and Deformation Behavior of Metastable High-entropy Dual-phase Alloys

Zeyu You; Zhengyou Tang; Fuben Chu; Guofu Guan; Hua Ding; Northeastern University, China

In this study, to explore the effect of thermo-mechanical processes (TMPs) on the grain boundary characteristics distribution (GBCD), microstructure and normal temperature tensile properties of metastable high-entropy dual-phase alloys. The grain boundary characteristics distribution and microstructure distribution of the alloy in different stages of GBE were revealed by EBSD. The effect of GBCD optimization on the mechanical properties of TRIP-DP-HEA was tested by uniaxial tensile test at normal temperature. The tensile strength of GBE samples was observed by TEM. The microstructure characteristics before and after elongation fracture were analyzed, and the plastic deformation mechanism was analyzed. The results show that GBCD can play the role of grain refinement strengthening, promote the increase of special grain boundaries, interrupt the distribution connectivity of random high-angle grain boundaries, enhance the tensile properties of the alloy at normal temperature from

810Mpa to 910Mpa, and elongation increased by five percent, dislocation, stacking fault, deformation twinning and TRIP effect are the main deformation mechanisms of the test sample. Stacking fault and annealing twinning have a favorable effect on the increase of ΣCSL grain boundaries, and the increase of special grain boundaries improves the strength and toughness, hinder the propagation of fracture cracks.

Poster 13

Recrystallization in Ni85Ga15 Single Phase Alloys During Non-equilibrium Solidification

Yanhui Wang; Danrui Guo; Jianrong Gao; Northeastern University, China

Single-phase Ni85Ga15 alloys were undercooled using glass fluxing treatment leading to rapid solidification followed by slow solidification. Rapid solidification was observed in situ using a high-speed camera to determine dendrite growth velocity. Microstructure of samples was characterized using the electron back-scattering diffraction (EBSD) technique. Measured data of dendrite growth velocity show a change of growth kinetics from power law to a linear law at a critical undercooling of 120 K, suggesting segregationless solidification above a growth velocity of 10 m/s. EBSD characterization revealed the formation of equiaxed grains with a fiber-like texture in the sample with an undercooling of 151 K. However, grain size varies from one side to the other side of the sample. Low-angle boundaries and twin boundaries take a proportion of 25% and 18% out of the total grain boundaries, respectively. These features of microstructure provide evidence for grain refinement via dynamic recrystallization. It was determined that the grains recrystallized take a fraction of 80.5%. The origin of lattice strains driving dynamic recrystallization is discussed in terms of in situ observations of rapid solidification.

Poster 14

Effect of Ti-Zr Deoxidation Treatment on as-cast Microstructure of Low Carbon Steel

Zihan Wu; Chao Wang; Xin Wang; Jian Kang; Guo Yuan; Northeastern University, China

Acicular ferrite (AF) can effectively improve the mechanical properties of steel due to the interlocking microstructural morphology . The secondary phase oxide and sulfide particles with high melting point in steel have an important influence on the formation of AF. In this paper, the effects of different deoxidation processes on the secondary phase particles and as-cast microstructure of low carbon steel were studied through microstructure characterization and particle quantity statistics. Experimental steels with 0.005-0.035% Ti and 0.01-0.02% Zr were studied. The results showed that a large number of particles with diameter less than 1 μm can be produced at low Ti content, which significantly promoted the transformation of AF structure. The high Ti content promoted the transformation of polygonal ferrite. Compared with Ti deoxidation, Ti-Zr composite deoxidation treatment resulted in smaller Ti-Zr oxide particles in steel and the particle number density was larger. The ability of inclusion to induce AF transformation was enhanced, and the as-cast microstructure was further refined.

Poster 15

The Effects of Cold Rolling Reduction on Microstructure Evolution and Mechanical Properties in a New Resource-saving Fe-19Cr-0.6Al-12Mn Duplex Stainless Steel

Mingming Pan[1]; Xiaoming Zhang[2]; Jun Zhang[1]; [1]Shenyang University, China; [2]Northeastern University, China

Basically, the severe edge-cracking would be induced for the conventional duplex stainless steels during hot rolling due to uneven deformation between ferrite and austenitic structures which exhibited different strength during deformation, restricting the industrialization process for these products. To solve this problem, in this paper, a new resource-saving Fe-19Cr-0.6Al-12Mn dual-phase stainless steel was designed by partially replacing Ni, Cr with Mn and Al, respectively. Thus much more ferrite structure could be maintained in the hot rolled specimens, while the morphologies and quantity of austenite grains was mainly regulated in the annealing process after cold rolling. The microstructure evolution was characterized in detail, and mechanical properties of the final sheets were tested and investigated methodically. The relationship of cold rolling reduction, microstructure evolution and mechanical properties was clarified. The effect of cold rolling reduction on the grain structures of Fe-19Cr-0.6Al-12Mn dual-phase stainless steel was investigated through electron backscatter diffraction (EBSD). The results show that the phase transformation of austenite would occur during the annealing process for the cold-rolled specimens, Austenite nucleates at the grain boundary of ferrite. The equiaxed ferrite grains were broken under the large cold rolling reduction, and then, not only the grain boundary density and low angle grain boundaries increased, but also a large number of dislocations and sub-crystals could be observed inside the deformed ferrite grains. That was both beneficial to the nucleation for the austenite cores. Moreover, the distortion in the ferrite grains could greatly promote the transformation of ferrite to austenite, and the uniform distribution of these two phases would be improved as well. Therefore, the cold rolled-annealed specimens with larger rolling reduction presented the more enhanced comprehensive mechanical properties. This researched Fe-19Cr-0.6Al-12Mn duplex stainless steel presents a good combination of thermos-plasticity, strength and plasticity, and is expected to become a new type of resource-efficient dual-phase stainless steel.

Poster 16

Mn Heterogeneity and Ductility Improvement Realized by Slow Heating Mn-partitioned Pearlite

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Mn heterogeneity in the medium manganese steels has been realized deliberately using fast heating. However, fast heating is not feasible for industrial production. Conversely, slow heating is ignored for Mn heterogeneity due to the involved long-range Mn partitioning during austenite formation. Here, we explore the effect of slow heating on chemical heterogeneity, microstructure evolution and mechanical properties of a medium Mn steel. We counter-intuitively demonstrate that slow heating also can retain the Mn-heterogeneous distribution from alternative Mn-enriched cementite and Mn-depleted ferrite in the initial pearlite. A Fe-0.39C-3.69Mn (wt. %) steel was austenitized from manganese-partitioned lamellar pearlite, using a salt bath furnace having a fast heating rate of 80 °C/s (FH) and using a box resistance furnace having a slow heating rate of 5 °C/s (SH). Finally, the samples were both tempered at 200 °C for 30 min. After SH and FH, the microstructures are both comprised of 30 % martensite and/or austenite (M/A) islands and 70 % ghost pearlite. The ghost pearlite has a pearlite morphology-resembling structure consisting of film retained austenite (RA) and lath martensite. Compared to fast heating, a wider distribution (UMn = 4 ~ 16 %) and a lower average content of Mn (8.3±2.5 % vs. 11.2±1.6 %) in film retained austenite are achieved due to a transition of austenite formation from partition to negligible partition local equilibrium. In addition, during slow heating, the austenite formed at different temperatures would have different Mn content due to the slow austenite transformation kinetics. The Mn concentration and size of spherical RA (140 vs. 120 nm) in SH sample are both larger than FH sample due to the almost complete dissolution of cementite, resulting in a higher volume fraction of RA in SH sample than the FH sample (13.2 % vs. 8.3 %). As a result, the RA stability, morphology and fraction are modified by using the slow heating, resulting in a stronger austenite-to-martensite transformation during straining and, in turn, a larger strain hardening ability and an improved ductility. Meanwhile, the high strength keeps unchanged.

Poster 17

Effect of Ti-Ca-Zr Oxide on Isothermal Microstructure Transformation Behavior of a Low Carbon Steel

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Oxide induced acicular ferrite (AF) transformation is an effective way to refine the microstructure of steel, and the transformation temperature has a significant impact on the nucleation ability of AF. The effect of different isothermal temperatures on the microstructure transformation behavior of low carbon steel containing Ti-Ca-Zr oxide particles was studied by thermal simulation experiment. The results showed that Ti-Ca-Zr oxide particles could induce a large number of nucleation of AF achieving the effect of grain refinement, at 550~600 ℃. When the isothermal temperature decreased from 650 ℃ to 550 ℃, the hardness of the material increased from 156 HV to 218 HV . During the cooling process, with the decrease of temperature, the autocatalytic nucleation of secondary acicular ferrite occurred around the primary acicular ferrite which nucleated on the basis of Ti-Ca-Zr oxide particles. The secondary acicular ferrite could significantly refine the microstructure and improve the mechanical properties of steel.

Poster 18

Effect of Similar / Dissimilar Resistance Spot Welding on the Weldment Characteristic and Mechanical Properties of Q&P980 Steel

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In this paper, different resistance spot welding strategies have been carried out for Q&P980 steel with thickness of 1.8 mm, including similar welding (Q&P+Q&P, Q/Q) and dissimilar welding (Q&P/DP, Q/D). The study found that the nugget of dissimilar welding can be divided into four regions, fusion zone, partial melting zone, heat-affected zone and base metal. At the same time, An obvious partial melting zone accompanied by liquation crack characteristics can be observed on the Q&P steel, but not on the DP steel. This may be attributed to the influence of the inherent chemical composition of the base metal. However, the liquation crack in the Q/D specimen are basically the same as those of conventional welding, and the effect of dissimilar welding strategy to optimize liquation crack defect in QP steel has not been significantly reflected. There is local softening in the heat-affected zone on the DP steel side of the D/Q specimen, and the hardness of the nugget zone is also slightly lower than that of the Q/Q specimen. When the welding parameters are the same, the nugget sizes obtained under the two welding strategies are approximately the same, the shear-tensile properties of the D/Q specimens are significantly better than those of the Q/Q specimens, and the cross-tension properties of welds have the same trend.

Poster 19

Microstructure and Mechanical Properties of Medium Mn Steel Manufactured by Warm Rolling Process

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Medium Mn steel, with Mn content in the range of 4-12%wt, has attracted much attention because of their excellent combination properties of strength and ductility, for the needs of fuel economy and passenger safety. This is because the metastable austenite would transform to the martensite or form the mechanical twins during plastic deformation, namely transformation induced plasticity (TRIP) effect or twinning induced plasticity (TWIP) effect, which is significance to tailor the mechanical properties of steels. The TRIP or TWIP effect in steels is closely associated with the stacking fault energy (SFE) of materials. It is Generally accepted that mechanical twinning may be activated when the value of SFE in the range from 12 to 35 J/m^2. In addition, warm rolling is an effective method to achieve a partial recrystallization of deformed matrix and the mixture of austenite grains with different morphologies and sizes, which can lead to enhanced TRIP effect. Because the austenite grains have different stabilities in a range so that they can transform to martensite gradually and achieve better tensile properties. In this paper, we demonstrate the designed composition of 0.3C-12Mn-3Al to tailor the SFE and the manufacture of warm rolling without annealing to achieve super-high strength and good ductility in medium Mn steel. The hot rolled steel is subjected to warm rolling at 600/700/800℃, achieving partial recrystallized austenite matrix with ferrite or tempered martensite depending on the rolling temperature. The microstructure was characterized by scanning electron microscope (SEM) and electron backscatter diffraction (EBSD). Volume fraction of austenite was measured by D/max2400 X-ray diffractometer (XRD). The volume fraction of austenite in the sample rolled at 800℃(WR800) is 84%, which decreases with the increase of strain, to 17% in fracture. The EBSD result shows the nucleation of martensite at the thin plate-like defects in WR800 sample at 5% strain, and the deformed twin boundaries are also observed. Excellent mechanical properties with yield strength of 1149MPa, tensile strength of 1373MPa, total elongation of 20% is obtained for the Medium Mn steel, which can be ascribed to the operation of both TRIP effect and TWIP effect.

Poster 20

Failure Prediction and Health Management of Ladle Turret Low-Speed and Heavy-Load Slewing Bearings

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Low speed and heavy load equipment is the key equipment in industrial production and manufacturing systems. This article focuses on the failure prediction and health management of ladle turret low-speed and heavy-load slewing bearings. Firstly, research status of slewing bearing condition monitoring, fault diagnosis and residual life prediction were introduced, and whole life cycle common failure types of slewing bearing were analyzed, then Stresswave analysis technology was applied to the monitoring and diagnosis of slewing bearing. StressWave Analysis listens for shock and friction raising events. Once detected, it can also quantify the energy from shock and friction providing a read on the area/size of the damage in the machine. It takes into account both the amplitude and duration of the event, thus providing not only an indication of damage, but also a quantitative measurement of damage severity. Based on SWE and feature vectors, failure deterioration trend tracking of slewing bearing were carried out, and through the application cases of equipment failure prediction and health management, the validity and accuracy of diagnostic conclusions such as eccentric load, gear mesh and bearing failure were verified by the equipment maintenance. This case provides practical guidance to implement predictive maintenance and condition maintenance of ladle turret slewing bearings.

Poster 21

Effect of Different Process Parameters on Solidification End Position of Continuous Casting Round Billet

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In this paper, a three-dimensional unsteady continuous casting model is used to simulate the solidification process of continuous casting round billet, which can simulate the temperature distribution of different parts, solid liquid distribution and shell thickness of continuous casting billet in real time. Different from the method of slice analysis of the continuous casting process and selecting a certain length of continuous casting billet for research, the 3D unsteady continuous casting model takes into account the temperature transfer along the casting direction of the continuous casting billet and can accurately simulate the entire casting process. In this paper, the accuracy of the JMatpro software is first verified and the high temperature physical properties of the continuous casting round billet material are obtained through this software. After that, the boundary conditions of the heat transfer of the continuous casting round billet are inversely calculated and the solidification heat transfer model of the continuous casting round billet is established. After verifying the calculation results of the model, the effects of superheat, pulling speed and specific water volume on the position of the solidification end of the continuous casting round billet were studied through the solidification model. The results show that for a continuous casting round billet with a diameter of 500mm, when the drawing speed is 0.33m/min, the specific water volume is 0.25L/kg, and the superheat degree is 20℃, the thickness variation curve of the continuous casting billet can be roughly divided into three stage. In the first stage, due to the cooling effect of the cooling water in the mold and the secondary cooling zone, the thickness of the billet shell increases rapidly, and the length of this section is 3.4m. In the second stage, the continuous casting slab enters the air cooling zone after passing through the end of the secondary cooling zone. Due to the release of the latent heat of solidification during the solidification process, the increase rate of the thickness of the shell is reduced, and the length of this section is 13.7m. In the third stage, the continuous casting billet reaches the end of solidification. Although the cooling intensity does not change, the equivalent specific heat capacity decreases because the latent heat of solidification is released, and the billet shell of the continuous casting billet increases rapidly, and finally completes the solidification. The length of this section is 0.7m. When the superheat degree of Q235 continuous casting round billet with a diameter of Φ500mm increases by 10℃, the position of the solidification end moves backward by about 0.3m; When the specific water volume increases by 0.1L/kg, the solidification end moves forward by 0.78m on average; For every 0.1m/min increase in the continuous casting billet pulling speed, the position of the solidification end moves backward by an average of 4.69m. With the increase of superheat degree, the increase of the length of the liquid core is almost unchanged; With the increase of the specific water amount, the decrease of the length of the liquid core gradually decreases; With the increase of the pulling speed, the increase of the length of the liquid core gradually decreases.

The pulling speed has the most obvious effect on the position of the solidification end of the continuous casting slab.

Poster 22

Study on Austenite Static Recrystallization Inhibition of Element Ti

Ning Cai; Xianchun Dong; Jianping Cao; Ning Cai; Shougang Group Institute of Technology, China

In hot rolling process, deformed austenite will undergo dynamic and static recovery and static recrystallization at the interval of each roller pass. The recrystallization proportion will directly affect the grain size of the austenite, and then affect the subsequent transition microstructures after cooling. Therefore, the research on recrystallization at the interval time of hot deforming is an important basis for optimizing rolling process and controlling of the microstructures and properties. Ti and Nb are the most commonly used micro-alloying elements. There are more researches on the effect of Nb on austenite recrystallization, but less research on the effect of Ti. The effect of Ti on austenite recrystallization was studied by double compression simulation method. The interval time between the compressions is 10 seconds, 40 seconds and 100 seconds respectively. The content of Ti was 0.078%, 0.03% and lower than 0.002% respectively. The static recrystallization rate was measured by 2% compensation method. The results show that ≤0.03% Ti has little effect on the static recrystallization of austenite, and 0.078% Ti has significant effect on the static recrystallization of austenite.

Poster 23

Heterogeneous Quenching and Partitioning from Manganese-partitioned Pearlite: Retained Austenite Modification and Formability Improvement

Chao Zhang; Dezhen Yang; Zhiping Xiong; Beijing Insititute of Techonlogy, China

Increasing quenching temperature in the conventional quenching and partitioning (CQ&P) process usually increases the fraction of retained austenite (RA) being dominant by blocky morphology, which can only ensure a good global formability but deteriorate the local formability. Instead of austenite having homogeneous Mn distribution in the CQ&P, the present study proposes a Q&P process purposedly based on the austenite having heterogeneous Mn distribution deliberately inherited from partitioned pearlite. Outstandingly, this partitioned pearlite-based Q&P process (PPQ&P) unusually achieves a large RA fraction being dominant by film morphology. In addition, the microstructure is refined through hierarchical transformation of heterogeneous austenite during the quenching process. Therein, the Mn-enriched austenite areas originated from cementite lamellae can be nearly retained as film RA at room temperature due to its high stability, which makes the film morphology in RA dominant and additionally guarantee the total RA quantity. The large total RA fraction ensures a large total elongation and the dominant film morphology ensures a large post-uniform elongation, indicating both good global formability and local formability, respectively. Additionally, the yield strength is increased by 200 ~ 300 MPa predominantly because the refined width of lath martensite significantly contributes to an improved grain boundary strengthening. Introducing the austenite having heterogeneous Mn distribution into the Q&P process provides a feasible way to achieve a large total RA fraction being dominant by film morphology through controlling the RA characteristics by hierarchically affecting the transformation of heterogeneous austenite.

Poster 24

Dendritic Segregation and Nanoindentation of CrCoNi Medium Entropy Alloy

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Elemental segregation plays a significant role in the deformation behaviors of multiple principal element alloys. Here, we investigated the microstructures and nanoindentation behaviors of as-cast and homogenized equiatomic CrCoNi medium-entropy alloy (MEA) comparatively. Cellular dendritic structure formed in the as-cast alloy while it disappeared after homogenization at 1200 ℃ for 24 hours. Ni was randomly distributed over the as-cast specimen. Yet, Cr enriched with synchronous Co depletion in the cell wall. The strong bonding between Cr atoms and high lattice distortion caused by Cr enrichment generate the highest hardness in the wall. On the contrary, Cr depleted in the interior of the cell arising the lowest hardness. The hardness increased after the homogenization with higher elastic modulus and more homogeneous elemental distribution. Besides, higher stress would be needed to nucleate and propagate dislocations when the elements are uniformly distributed on basis of comparing the pop-in loads divided by the strain bursts in the aged and homogenized samples.

Poster 25

Effects of Cooling Rate on the Transformation Behavior in the CGHAZ and Mechanical Properties of Medium-Mn and V-microalloyed Dissimilar Steel Weld

Zhen Tao; Cairu Gao; Linxiu Du; Northeastern University, China

In recent years, the medium Mn steels are fashionable and widely used for industrial field because of their excellent combination of strength, ductility and low cost. However, it is rarely applicated for potential severe service environment, such as offshore platform and other infrastructure, owing to the constraints on the weldability and post-weld low temperature toughness. It is therefore impendency to optimize the medium Mn steels weld parameters to achieve extensive application, especially when welding with other microalloyed steels, such as V-microalloyed steel and Nb-microalloyed steel. In terms of dissimilar steel weld, the joints are high susceptibility to stress cracking caused by high residual stress, resulting from remarkable difference of thermal expansion coefficient of the two base materials. Hence, the local phase transformation and mechanical properties in the dissimilar weld joints should be further clarified. The paper aims to provide insight into different cooling rates on the impact of continuous cooling transformation in the coarse grain heat affected zone (CGHAZ) and the corresponding impact toughness and microhardness of medium Mn and V-microalloyed dissimilar steel welding joints. Samples were heated to a peak temperature of 1350 °C holding for 2 s at the rate of 120 °C/s, then followed by cooling at different rate (between 800°C and 500 °C) from 0.5 to 100 °C/s based on 2D Rykalin mathematical model, using a MM-300 thermo-mechanical simulator. In addition, the observation of microstructure and testing of microhardness and impact toughness at -40 °C were obtained through the simulated samples of weld CGHAZ thermal cycles. The connected transformation temperatures A_{c3}, A_{c1}, B_s, B_f, M_s and M_f were also measured by using the curve of dilatation and temperature. At slow cooling rates pro-eutectoid ferrite and pearlite were observed in V-microalloyed steel and a mixture of lath bainite, granular bainite and very few martensite was observed in medium Mn steel but no pro-eutectoid ferrite was observed. At moderate cooling rates, granular bainite gradually transformed into lath bainite in V-microalloyed steel and the proportion of martensite increased in medium Mn steel. At high cooling rates, lath bainite and lath martensite was observed in aforementioned steels, respectively. Based on the above mentioned results, the CCT diagrams of weld CGHAZ region of the two dissimilar steels were established. Furthermore, the prior austenite grain size was varied from 13 to 65 μm with the increasing cooling rate. When the prior austenite grain size was approximately 30 μm, that is v=40°C/s, the optimum impact toughness of 239.5 J and 77.4 J for V-microalloyed steel and medium Mn steel samples was achieved, simultaneously, which meeting the China Classification Society (CCS) performance indictors and even up to the performance of base metal. Therefore, control of the austenite grain size is essential for realizing a high toughness of the CGHAZ. The simulated results provide the relationship between medium Mn and V-microalloyed steel for actual welding parameters formulation to ensure the integrity and reliability of dissimilar welding joints.

Poster 26

The Generalized Additivity Rule for Anisothermal Austenite to Ferrite Transformation Kinetics

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The Scheil's additivity rule is widely applied to converting the isothermal reaction kinetics to the anisothermal one for the physical metallurgical reactions, including recrystallization, precipitation, and phase transformation. However, it has never been validated mathematically or theoretically and often causes serious discrepancies between the experimental and calculated results, especially when converting isothermal phase transformation kinetics to an anisothermal one. To obtain more accurate anisothermal kinetics from anisothermal experimental data and better describe the anisothermal phase transformation kinetics, we proposed a generalized additivity model based on the diffusion kinetics and Johnson-Mehl-Avrami-Kolmogorov (JMAK) equation, and it was mathematically established by analyzing the diffuse-controlled nucleation and growth behaviors of ferrite in austenite and the carbon atom migration behaviors between two phases. Based on the mechanisms of “nucleation and growth” (N&G) and “site-saturation” (S&S) for austenite to ferrite phase transformation proposed by Cahn, the parameters in nucleation kinetics and JMAK equation were determined with the general additivity model. and the ferrite volume fractions for one C-Mn steel and three Nb micro-alloyed experimental steels under different anisothermal conditions were accurately predicted by using the general additivity model proposed in this work. Based on the general additivity rule, the changes of additivity values with the temperature at different cooling rates for all experimental steel were analyzed, and the effects of steel composition and cooling rate on transformation kinetics were analyzed. The results showed that the additivity values for different steels were closely related to temperature, and in the general sense, they are always less than 1.0 when the phase transformation follows the mechanism of S&S, and sharply change when the phase transformations change. For the three Nb micro-alloyed steels, the increase of Nb mass fraction and cooling rate can promote the nucleation of ferrite, and the total nuclei number lgN keeps the linear relationships with Nb content and undercooling degree ΔT.

Poster 27

Effects of Coiling and Cooling Processes on the Formation of Oxide Films on Medium and High Carbon Steels

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The effects of different coiling temperatures, air cooling and slow cooling processes on the formation of 65Mn oxide film on medium and high carbon steel were studied by scanning electron microscopy (SEM), optical microscopy (OM), X-ray diffractometer (XRD) and electron probe probe (EPMA).The results show that the oxidation film of 65Mn hot rolled steel coil can form several typical microstructure under different coiling temperature and cooling process. There are many cracks in the oxide film on the surface of hot coiling process at 720℃ and slow cooling process. The oxide film shows flake peeling shape, and the thickness of the oxide film is 10-15μm. The structure of the oxide film is composed of the outer Fe granular layer, the middle Fe3O4 layer and the inner FeO layer. Moreover, serious intergranular oxidation occurs on the surface of the matrix, and the depth of intergranular oxidation is about 20μm.Decreasing coiling temperature and increasing post-coiling cooling speed can reduce the thickness of oxide film and the enrichment layer and the intergranular oxidation depth. When coiling temperature is lower than 600 ℃ , the outermost elemental Fe particle layer disappears, and the intergranular oxidation depth is controlled below 3μm.The morphology and intergranular oxidation depth of the oxide film are affected by alloying elements. With the addition of C, Si and Mn elements, the elemental Fe layer and intergranular oxidation degree of the oxide film are increased.

Poster 28

Effect of Cooling Rate in the Annealing Process on the Performance of Mg-Al Laminate

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In order to analyze the effect of annealing cooling rate on the performance of Mg-Al laminates, four groups of Mg-Al laminates were prepared by different annealing cooling processes. The performance of Mg-Al laminate was analyzed by means of metallographic test, tensile test, hardness measurement and so on. It was found that: 1) With the reduction of the cooling rate, the average diameter of the magnesium layer grains in the Mg-Al laminate increased from 20.03μm to 22.69μm in the rolling direction and from 20.23μm to 23.47μm in the width direction; 2) The Vickers hardness of the magnesium layer decreased from 132.57 to 116.65 in the rolling direction and from 127.42 to 105.53 in the width direction; 3) With the reduction of the cooling rate, the tensile strength of the Al-Mg laminate decreased from 191.07 MPa to 176.32 MPa in the rolling direction, from 188.55 MPa to 182.78 MPa in the width direction, and the yield strength decreased from 160.41 MPa to 147.73 MPa in the rolling direction and from 161.66 MPa to 142.21 MPa in the width direction, and the tensile strength along the rolling direction was more sensitive to changes in the cooling rate; This study helped to design and improve the cooling rate process for Mg-Al laminate annealing.

Poster 29

Influence of Stirring Head Shape and Welding Process on Friction Stir Welding of 6063 Aluminum Alloy Pipes

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6063 aluminum alloy pipes are widely used in the power industry due to the characteristics of low density, good corrosion resistance and excellent electrical conductivity. However, there are many problems such as poor joint quality and low production efficiency when it is formed by traditional fusion welding methods because of the low melting point of 6063 aluminum alloy. As a new type of solid-state joint technology, FSW makes use of the heat generated by friction to plasticize the material. It has the advantages of small deformation, high quality and no pollution, and is an effective method to solve the forming problem of 6063 aluminum alloy. The quality of FSW is affected by many factors, among which the appropriate shape of the stirring head and the reasonable welding process of FSW are the most important factors. There have been many reports on the research of FSW in the world, but there are few studies on the shape of shoulder and the rotation direction of the stirring head. In this paper, the influence of the stiring head with different shoulder features, two different rotation modes including clockwise rotation and counterclockwise rotation and different welding processes on the quality of the welding seam was studied. The results show that the welding seam is not prone to burr defects when the shoulder surface of the stirring head is concave and smooth, and the surface of the welding seam has high quality; the bottom of the welding seam is not prone to void defects when the rotation direction of the stirring head is consistent with the thread direction of the stirring pin, and the internal quality of the welding seam is good; the quality of the welding seam is better under the welding parameters of 600r/min-50mm/min, and the hardness of the welding seam section is distributed regularly in a "W" shape.

Poster 30

Vacuum Roll Cladding Technology of 7xxx Aluminum Alloy Thick Plates

Xin Zhang; Zongan Luo; Guangming Xie; Zhaosong Liu; Northeastern University, China

7xxx series high-strength aluminum alloy extra thick plates are widely used in applications in aircraft, high-speed rail, military, and other fields. The compression ratio of aluminum alloy thick plates produced by the traditional ingot hot rolling method is severely limited, and there were some problems such as segregation and porosity in the internal structure. Vacuum roll cladding (VRC) is a very convenient and efficient solid-state bonding technology that can improve the compression ratio of the plates with limited residual thermal stress. In this study, the vacuum stir friction welding equipment developed by ourselves has been used for vacuum (10-2 Pa) welding encapsulation of 7050 aluminum alloy plates with clean surfaces, followed by hot roll cladding at 450 ℃. Subsequently, two-stage solid solution and T74 two-stage aging treatment were carried out. The bond interface was examined by electron probe microanalysis (EPMA). The results showed that the elements at the bonding interface were evenly distributed without any impurities. The microstructure analysis of the interface based on electron backscatter diffraction (EBSD) showed that the bonding interface of hot-rolled clad plates underwent significant dynamic recrystallization and the bonding interface disappeared completely. After solution and aging treatment, the bonding interface still showed a good healing effect. The results of the mechanical properties tests showed that the shear strength at the bonding interface of the hot-rolled and aged clad plates were 151MPa and 245MPa respectively, which reach the level of the matrix. The shear fracture all showed sufficient dimples, which indicated that the fracture mode was the ductile fracture. Therefore, the principle of preparing aluminum alloy clad plates by VRC technology included the following points. 1. Surface oxidation of the aluminum alloy can be reduced by vacuum weld packaging to prevent the thickening of the surface oxide film during pre-roll heating to inhibit interfacial bonding. 2. The bonding interface achieved good metallurgical bonding by dynamic recrystallization during the hot rolling process. 3. To improve the comprehensive properties of aluminum alloy clad plates by solid solution and aging treatment.

Poster 31

Investigation on Ultrasonic Cavitation Erosion Behavior of 2024 Aluminum Alloy in Distilled Water

Liping Ning; Xindong Yang; Jingtao Zhao; Yinglong Li; Northeastern University, China;

Cavitation erosion is a common natural phenomenon. The surface damage, material erosion and noise impact caused by cavitation erosion have caused widespread concern. In this study, ultrasonic cavitation corrosion experiments were carried out on 2024 aluminum alloys using ultrasonic cavitation equipment. The ultrasonic cavitation corrosion behaviors of 2024 aluminum alloys in distilled water were evaluated by cumulative mass loss, scanning electron microscopy and three-dimensional topography. The results show that mass loss and surface damage of 2024 aluminum alloy significantly increased with the increasing cavitation erosion time. In the initial stage of ultrasonic cavitation erosion, the erosion and material mass loss are negligible. With the increase of cavitation time, cavitation bubbles repeatedly act on the material surface, resulting in the accumulation of deformation and eventually material denudation. After 300 minutes of cavitation time, the maximum cumulative mass loss of 2024 aluminum alloy is 19.7 mg, and the maximum cumulative weight loss rate is 0.085 mg/min.

Poster 32

Austenite Deformation Induced Carbide Precipitation in Low Carbon Ti/Ti-Mo Steel

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Ti-Mo microalloyed high-strength steels based on the ThermoMechanical Control Process (TMCP) have been of interest due to the significant precipitation strengthening effect of nanocarbons. The previous results indicate that deformation induced precipitation in austenite affects the isothermal precipitation as well as its precipitation strengthening effect since the volume fraction of nanocarbons in the steel is limited. In addition, deformation induced precipitation inhibits austenite recrystallisation which allows for grain refinement. In order to clarify the effect of Ti and Mo on deformation induced precipitation, the precipitation kinetics of low-carbon Ti and Ti-Mo steels were investigated by stress relaxation on a Gleeble-3800 thermal simulator, producing precipitation-time-temperature (PTT) curves. In addition, microscopic analyses such as optical microscopy

(OM)/transmission electron microscopy (TEM) were used to study the changes of austenite structure and carbide precipitation during stress relaxation at 900°C. The result of the stress relaxation experiments revealed that there was a distinct plateau phase in the stress relaxation of the low carbon Ti and Ti-Mo steels, indicating the occurrence of deformation induced precipitation. Both PTT curves showed a "C" shape with their nose point temperatures around 900°C. Compared to the low carbon Ti steels, the overall curve for the low carbon Ti-Mo steels showed a significant backward shift. OM observation of the austenite grains on the experimental steels after double-pass compression and holding for different times before water quenching revealed that austenite recrystallisation was significantly inhibited in Ti and Ti-Mo steels, while the effect was more significant in Ti-Mo steels. Through TEM observation of the precipitate particles, it was found that the precipitate particles of low carbon Ti steel and Ti-Mo steel were TiC and (Ti,Mo)C respectively; with the extension of isothermal time after compression, (Ti,Mo)C had a smaller growth trend than TiC.The results show that deformation induced carbide precipitation in Ti-Mo microalloyed high-strength steels significantly inhibits austenite recrystallisation, therefore unrecrystallised controlled rolling can be used to refine the grain in production, resulting in fine grain strengthening and improved toughness, for which the PTT curves provide the basis. However, deformation induced precipitation precedes isothermal precipitation, reducing the precipitation strengthening effect of the nanocarbons.The interrelationship between deformation induced precipitation and isothermal precipitation in Ti-Mo microalloyed high-strength steels and the effect on mechanical properties need to be investigated in depth.

Poster 33

Evolution of Recrystallization Microstructure during Rolling and Annealing in Ti-40Nb Alloys

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Ti-40Nb (wt. %) alloy of β-type has wide application prospects in the field of low Young's modulus biomaterials because of its higher strength modulus ratio, superior biocompatibility and excellent corrosion resistance, compared with traditional metal implant materials. The Young's modulus of Ti-40Nb alloy has a significant orientation dependence, and the γ (<111//normal direction, ND>) texture is unfavorable. The effects of static recrystallization (SRX) and strain-induced boundary migration (SIBM) on the microstructure evolution of Ti-40Nb alloy are analyzed in this work. The results show that the static recrystallization (SRX) occurs in the samples after 55% and 75% cold rolling and annealing at 950℃. Compared with the initial state, the recrystallized grain size of SRX is significantly refined and γ recrystallization texture increases from 55% to 75% with the increase of deformation. After cold rolling of 12% reductions and annealing at 900℃, the samples recrystallize driven by the strain-induced boundary migration, but the weak of γ recrystallization texture was not observed. Compared with SRX, SIBM effectively reduces the proportion of high angle grain boundaries, but cannot optimize the γ texture, which can be attributed to the complex stress distribution under the cold rolling, although the γ grains obtain the higher orientation-dependent strain energy during the rolling.

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Data-based Mill Vibration Prediction in Rolling Mill

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Mill chatter is a major restriction in high-speed rolling of the high-strength and thin strip, which affects the quality of the strip. The most common rolling mill vibration models were mill vibration mechanistic model and the mill vibration model based on data-driven method. In the past decades, mill chatter characteristics were usually analyzed by mill vibration mathematical mechanism models, and many remarkable achievements have been made by mill vibration mechanistic models. However, the cold rolling mill is a very complicated mechanical–hydraulic coupled manufacturing system. Many assumptions have been made for establishing chatter mechanistic models of rolling mills because of the highly integrated equipment, extremely severe rolling environment (high load, high speed and complicated lubricate conditions), and strongly nonlinear coupling characteristics. As a result, it was more and more difficult to improve the vibration mechanism model of rolling mill. Besides, rolling mill vibration mechanism model cannot meet the needs of real-time monitoring in the field and it was more and more difficult to improve the vibration mechanism model of rolling mill. In this paper, a comprehensive test about the rolling mill vibration was done occurring on 1450 mm strip rolling mill. Based on the testing data, a novel data-driven rolling mill vibration prediction method is proposed. Three neural network-based models, including artificial neural network (ANN), genetic algorithm artificial neural network (GA-ANN) and deep neural network (DNN) were proposed for mill chatter prediction by combining vibration sensor signals with rolling condition process data. Mean absolute error (MAE), mean absolute percentage error (MAPE), root mean square error (RMSE) are calculated to evaluate the prediction performance of the models. The mill vibration acceleration amplitude prediction performances of the selected neural network-based models were evaluated. The results show that the data-driven mill vibration DNN model was suitable for mill vibration prediction with the highest determination coefficient value and lowest mean absolute percentage error. Furthermore, effects of rolling process parameters on vibration were analyzed by PCA technique.

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Length Prediction Model for Heavy Plate after Cooling Bed Based on BP Neural Network

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Length variation of heavy plate after cooling bed is hard to calculate accurately because of large size, uneven temperature and material property. The thermal expansion coefficient is not consistent even the same steel grade, since different steel rolling process and different thickness of the specification. In order to solve this problem, BP neural network is used to build a model to predict the length. At the same time, ReLU function is used to replace Sigmoid function to solve the problem of gradient disappearance. In addition, BP neural network, CART and the results calculated by thermal expansion coefficient are compared with the actual values. The comparison shows that the correlation coefficient R2 of the BP neural network model is much higher than the calculated results of CART and thermal expansion coefficient, and the BP neural network model has a higher approximate value with the actual data, which has very strong practicability.

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Numerical Simulation of Electron Beam Welding for 3Cr2Mo

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3Cr2Mo steel is widely used to manufacture precision moulds due to its excellent comprehensive properties. Vacuum electron beam welding (VEBW) as an efficient and accurate welding technique is widely used in welding 3Cr2Mo steel. Compared with other welding methods, the VBEW has the characteristics of high power and small deformation, making 3Cr2Mo steel less prone to crack during VBEW. Thanks to advances in computer numerical simulation, modeling and simulation of VBEW process has proven to be highly accurate and efficient for research. In comparison with the VEBW experimental study, the welding process and their relationship with welding parameters can be illuminated by finite element analysis and reduce the costs of experiments. Therefore, carrying out temperature field, residual stress field by numerical simulation analysis helps to provide the theoretical basis for VEBW, which has very important significance.

In this research, a finite element numerical model for VEBW of 3Cr2Mo steel has been established based on ABAQUS finite element analysis software. The influences of different welding processes on the temperature field and stress field of 3Cr2Mo steel were analyzed, and the simulation results of the weld morphology were verified by metallographic microscopic observation. The high temperature mechanical properties of 3Cr2Mo weld were tested by thermal simulation machine. The results showed that weld width and weld depth of 3Cr2Mo steel were positively correlated with welding power and welding line energy, and negatively correlated with welding speed.

The welding residual stress was mainly concentrated in a 5mm area around weld line and characterized by tensile stress. The maximum Mises residual stress was found at the welding speed of 600mm/min with the same welding power, while the minimum Mises residual stress was found at the welding power of 4000W with the same welding speed. The results of high temperature tensile test showed that the weld of 3Cr2Mo steel has higher elongation at the welding speed of 300mm/min.

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Numerical Simulation of Jet Cooling of a Seamless Steel Tube with Different Jet Spacing

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In the production and manufacturing process of hot rolled seamless steel tubes, heat treatment process plays an extremely important role in exploring the performance potential of metal materials and improving the service life of steel tubes. However, in the production field of hot rolled seamless steel tubes, due to the complexity of production equipment and the shape characteristics of annular section, the cooling and heat transfer mechanism of hot rolled seamless steel tubes has not been clear, which seriously restricts the application of controlled cooling technology in the field of seamless steel tube production. The rapid and uniform cooling of hot rolled seamless steel pipe has become an urgent demand in production. In the cooling process of seamless steel tubes, an annular multi-jet cooling method is adopted. The jet spacing is an important process parameter of cooling equipment, which directly determines the distribution of the cooling medium on the surface of seamless steel tubes and affects the uniformity of the cooling of seamless steel tubes. In this study, the axial spacing and circumferential spacing of double jets were studied by numerical simulation. Other process parameters remain constant values. Through the wall heat transfer coefficient distribution curve, the cooling efficiency and cooling uniformity with different spacing were analyzed. The results suggest that with jet spacing increases, the wall heat transfer coefficient between the jets gradually decreases. Furthermore, the best jet spacing was obtained by comparing the standard deviation of heat transfer coefficient. When the water flow is 6 L/min, the best jet spacing in the axial direction is 10d and the best jet spacing in the circumferential direction is 15°.

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Analysis of Casting Roll Thermal Deformation in Twin-Roll Strip Casting Process

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Twin-roll strip casting technology has attracted the attention of many iron and steel enterprises and research units around the world as a green, environmental protection, sustainable development near net shape steel manufacturing short process technology in the iron and steel industry. The casting roll is essential in the industrial production process of twin-roll strip casting, in the process of cycling contact with molten steel, it is repeatedly heated and cooled, then the roll profile of the casting roll changes as the process parameters vary. The cooling action of the casting roll solidifies the molten steel on the surface of the casting roll, and the casting strip is formed through the roll gap by the extrusion of the casting roll. The actual roll gap shape has a great influence on the strip shape and the stability of the strip casting process. Because the thermal deformation of the casting roll is the direct factor affecting the shape of the roll gap, all factors affecting the thermal deformation of the casting roll will indirectly affect the size and shape of the roll gap, so it is necessary to study and analyze the related process parameters affecting the thermal deformation of the casting roll. Considering that the faster casting strip speed and cooling water flow rate lead to the smaller temperature difference in the axial direction of the casting roll, a two-dimensional finite element model of casting roll is established, based on ANSYS finite element analysis software platform, through secondary development. The effect of factors such as casting speed, the cooling capacity of casting roll, and thickness of roll sleeve on the thermal deformation of casting roll is studied. The effect law of each factor on the thermal deformation of casting roll is given, and a corresponding mathematical model is constructed, providing a theoretical foundation for the design of casting roll profile and casting roll use.

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Simulation and Experimental Verification of 3Cr2Mo Vacuum Rolling Composite Process

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Vacuum hot rolling is an effective method to produce high quality extra-thick composite plate. The quality and cost of the composite plate product is severely affected by the rolling process due to the complicated stress changes during the vacuum hot rolling process . In this paper, ABAQUS finite element software was used to study the numerical simulation of the rolling process of 3Cr2Mo composite plate, and the stress field of the weld zone under the eight passes rolling process were studied. The research shows the equivalent stress in the weld area increases gradually with the increase of rolling passes. The internal equivalent stress of the weld with different depth is different, and it affects whether the weld zone cracks in the rolling process. When the welding speed is 360mm/min and the welding power is 6400W, the weld depth of 12mm is more suitable for the preparation of composite plate. The actual rolling results of the weld obtained under different welding processes are consistent with the simulation results, which verifies the accuracy of rolling simulation and the feasibility of production guidance.

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Machine Learning Strain-induced Precipitation Behavior of Nb(C,N)

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Strain-induced precipitation (SIP) in Nb micro-alloyed steels plays an important role in determining the final microstructure and mechanical properties because it can effectively retard the progress of recrystallization and improve the strength by precipitation strengthening. It is necessary to accurately control the SIP behavior in hot rolling process. The relationship between precipitation onset time and compositions and processing parameters has been established by different researchers, but the prediction accuracy is limited. It has been clearly shown that the same deformation condition can generate significantly different dislocation densities in Nb micro-alloyed steels with different compositions, which may lead to different precipitation behaviors. Therefore, when we develop the kinetic model to describe the SIP process, both of elemental concentrations and deformation conditions need to be considered. However, because the present models for strain-induced precipitations of Nb (C, N) are mainly based on the Avrami equation combined with the Dutta & Sellars model, they are only adaptive to a small number of steel grades. In order to accurately predict the strain-induced precipitation behavior for wide range of compositions and processing conditions, new modeling methods need to be established. In this paper, based on the "precipitation-time-temperature" data of Nb (C, N), the main parameters in the models for precipitation start (t0.05) and finish (t0.95) times were optimized by the genetic algorithm (GA) under different compositions and processing conditions. The relationships between t0.05 / t0.95 and compositions and processing conditions were established by the generalized regression neural network (GRNN). The results show that the machine learning (ML) models showed much improved precisions with the measured values than the classic models such as Dutta & Sellars model. By using the ML models, the influences of Nb concentration in steel, strain and strain rate on t0.05 and t0.95 were further clarified, which may lay the foundation for accurately controlling strain-induced precipitation behavior during hot rolling.

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Study on Mechanical Properties of Laser Welding Seam and Simulation of Temperature Field

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The production of modern wide cold-rolled strips mostly adopts endless rolling technology. In the actual production process, when the welded joints of strip steel goes through the subsequent tension correction or rolling process, weld strip breakage often occurs due to the mechanical properties defect of welded joints, which not only affects the production rhythm but also reduces the benefit of the enterprise.Based on this background, this paper takes the welded joint in the high strength strip production of a cold rolling line as the research object, tested the

microstructure, grain size and Vickers hardness of the weld zone, and analyzed their distribution.Through microstructure analysis, understand the mechanical properties and defect causes of weld area. The welding finite element model was established to simulate the welding thermal process, and the thermal cycle characteristics of the welding process were studied. From the perspective of the temperature field, this paper analyzed the causes of the microstructure and mechanical properties of the weld area. It provides a theoretical basis for the microscopic study of the weld area.

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Supressing grain growth in a "common metal" HEA with Cu and Al addition

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