THE 2ND INTERNATIONAL SYMPOSIUM ON THE RECENT DEVELOPMENTS IN PLATE STEELS

3–6 JUNE 2018 | ORLANDO, FLA., USA

DOUBLETREE BY HILTON HOTEL AT THE ENTRANCE TO UNIVERSAL ORLANDO

ABOUT THE PROGRAM

This symposium will highlight steelmaking and casting, hot rolling, accelerated cooling and direct quenching, flatness control, line pipe, hydrogen-induced-cracking (HIC) resistant steels, microstructure characterization, product strategies, as-rolled steels, heat treated steels, welding, and hardfacing. As-rolled steel applications include wind tower, offshore structures, shipbuilding and abrasion-resistant steels used in construction and machinery. Heat-treated steel applications include tank cars, pressure vessels, and quenching and partitioning to enhance steel product toughness and wear resistance. Due to the overwhelming response to the call for papers compared to the first symposium held in 2011, no keynote speakers are planned this time.

WHO SHOULD ATTEND

Steel production and applications engineers, researchers, users of steel plate and coil products, students, academics, and consultants.

ORGANIZED BY

AIST's Metallurgy — Processing, Products & Applications Technology Committee.
AIST's Plate Rolling Technology Committee.
Colorado School of Mines' Advanced Steel Processing and Products Center.

REGISTRATION FEES

Member US$1,225 | Non-member US$1,440
Advance registration by 23 April 2018

Member US$1,325 | Non-member US$1,540
Registration after 23 April 2018

Registration includes receptions Sunday–Tuesday, breakfast and lunch Monday–Wednesday, dinner Tuesday evening, and conference proceedings.

HOTEL ACCOMMODATIONS

A block of rooms has been reserved at The DoubleTree by Hilton Hotel at the Entrance to Universal Orlando. Please call the hotel at +1.800.222.8733 by 14 May 2018 to secure the AIST discount rate of US$139 per night for single/double occupancy.

PROFESSIONAL DEVELOPMENT HOURS

This course may qualify for up to 22.5 Professional Development Hour (PDH) credits. Each attendee will receive a certificate listing the quantity of PDH credits earned for this course. This course is not approved for PDH credit in New York, Florida, North Carolina and Oklahoma.

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SCHEDULE OF EVENTS

SUNDAY, 3 JUNE 2018

4–6 p.m.
Registration

6 p.m.
Reception

MONDAY, 4 JUNE 2018

Poster sessions available 8 a.m.–5 p.m.

7 a.m.
Breakfast and Registration

8 a.m.
Introductions and Opening Remarks

8:15 a.m.
Cleanliness of Plate Steels: Review and New Developments

8:40 a.m.
Analysis of Thermal Homogenization in Steel Refining Ladle Using Bottom Gas Injection

9:05 a.m.
Heat Transfer and Solidification Modeling of Continuous Steel Slab Casting

9:30 a.m.
The Use of Infrared Thermography to Detect Thermal Instability During Solidification of Peritectic Steels

9:50 a.m.
HD Mold Fiber Optic Technology for Mold Thermal Mapping and HD Scan-Ultrasonic Technology for Analysis of Internal Quality

10:10 a.m.
Break

10:25 a.m.
Investigation of Combustion, Heat Transfer and Slab Quality in Industrial Reheating Furnaces

10:50 a.m.
Modeling and Simulation of Mass Flow of Steel Plate/Slab During Hot Rolling

11:15 a.m.
Optimization of High-Strength Plate Steel Pass Schedules Using Physical Simulation and Numerical Modeling

11:40 a.m.
Through Thickness Microstructural Optimization in Plate Rolling of Nb-Microalloyed Steels

12:05 p.m.
Rolling Pressures During the Hot Roll of Three Different Steel Plates: Experimental, Theoretical and Finite Element Analysis

12:25 p.m.
Lunch

1:40 p.m.
Accelerated Cooling Studies of Steel Plates on a Pilot-Scale Runout Table

2:05 p.m.
Experimental and Numerical Combined Approach for Development of a Cooling Unit for Steel Plates

2:30 p.m.
Accelerated Cooling Capabilities at ArcelorMittal Burns Harbor 160-Inch Plate Mill

2:55 p.m.
Effect of Direct Quenching and Accelerated Cooling on Metallurgical and Mechanical Behavior of Low-Carbon Microalloyed Steels

3:20 p.m.
Development of High-Performance Steel Plates at NLMK Clabecq

3:45 p.m.
Break

4 p.m.
Optical Flatness and Thickness Measurement for Heavy Plates

4:20 p.m.
Overview of Heat Treat Leveler for ArcelorMittal Burns Harbor

4:45 p.m.
Effects of Cold Leveling and Shotblasting on Flatness and Residual Stress of High-Strength and Wear-Resistant Steel Plates

TUESDAY, 5 JUNE 2018

Poster sessions available 8 a.m.–5 p.m.

7–8 a.m.
Breakfast

8 a.m.
Evolution of Niobium-Microalloyed Line Pipe Steels and Associated Welding Technology

8:25 a.m.
Advance in Microstructure Control for High-Strength Steel Plates With Recent Thermomechanical-Controlled Processing and Applications for Large-Diameter Pipelines

8:50 a.m.
Mechanical and Microstructural Characterization for Spiral Submerged-Arc Welded X-80 Line Pipes

9:15 a.m.
Strengthening and Kinetic Effects of Vanadium Microalloying in Low-Carbon Bainitic Line Pipe Steel Plates

9:40 a.m.
Effect of Vanadium on the Hardening of Low-Carbon Microalloyed Steels During an Experimental Time-Temperature Study

10:05 a.m.
Break

10:20 a.m.
Effect of M/A Constituent on the Mechanical Properties of Low-Carbon Microalloyed Steels

10:45 a.m.
Alloy Design and Processing Considerations for the Successful Production of API X70 Grade Line Pipe Steel Through CSP Flex Mill

11:10 a.m.
Modified Impact Testing to Assess Toughness and Susceptibility to Splitting in X70 Pipeline Steels

11:35 a.m.
Recent Pipeline Service Experience and Its Implications on Line Pipe Steels

Noon
Lunch

1:15 p.m.
Strategy for Production of Plate Steels Requiring Resistance to Hydrogen-Induced Cracking

1:40 p.m.
The Effect of Coarse NbC Particles and Final Microstructure on the Hydrogen-Induced Cracking Behavior of X65/X70 Steel Plates for Sour Gas Applications

2:05 p.m.
Effect of Microstructure on Hydrogen-Induced Cracking in Sour Service Pipeline Steel

2:25 p.m.
Quantitative Characterization of Plate Steel Microstructural Inhomogeneity

2:50 p.m.
Methods to Characterize Large (>1 Micron) Carbide and Nitride Particles in Microalloyed Steels

3:15 p.m.
Break

3:30 p.m.
Assessment and Interpretation of Non-Metallic Inclusions in Plate Steel to Improve Steelmaking Technology

3:55 p.m.
Challenges in the Application of High-Strength Plate for Weight Reduction

4:20 p.m.
Research and Development Strategy on Heavy Plate Steels and Recent Results at Dillinger

4:45 p.m.
Operational, Metallurgical and Technological Developments in Microalloyed Structural Plate Steels

6 p.m.
Dinner

WEDNESDAY, 6 JUNE 2018

Poster sessions available 8 a.m.–5 p.m.

7–8 a.m.
Breakfast

8 a.m.
Nb- and V-Microalloyed Plate Steels for Wind Turbine Towers: Base Material Toughness and Fatigue Properties

8:25 a.m.
Nb- and V-Microalloyed Plate Steels for Wind Turbine Towers: Weldability Characterization

8:50 a.m.
High-Strength TMCP Steel Plate for Offshore Structure With Excellent HAZ Toughness at Welded Joints

9:15 a.m.
World-First Application of SMYS 552 Steel Plates for an Offshore TLP Project

9:40 a.m.
Development of EH40 Grade Steel Plate for Tandem EGW for Mega Container Ships

10:05 a.m.
Microalloyed Steel Plates With Excellent Abrasion Resistant Property

10:30 a.m.
Break

10:45 a.m.
Mo- and Nb-Based Alloy Design for Production of Weldable High-Strength Plate Steel

11:10 a.m.
Ultrafine Hardening Overlay Material With Improved Impact and Wear Resistance

11:35 a.m.
Lunch

12:50 p.m.
Development of a Very-High-Toughness Steel for Pressure Tank Car Application

1:15 p.m.
Puncture Analysis of Tank Cars Using Ductile Damage Model

1:40 p.m.
Development of Ultralow-Carbon Steel Plates for Pressure Vessels and Offshore Applications

2:05 p.m.
The Effect of Microstructure on the Mechanical Properties of Wear-Resistant Steels

2:30 p.m.
Quenching and Partitioning of Plate Steel — Design Methodology for Non-Isothermal Partitioning During Furnace Reheating

2:55 p.m.
Break

3:10 p.m.
Effect of Induction Treatment on Precipitation Strengthening in a Low-C TiMo Microalloyed Hot-Rolled Steel

3:35 p.m.
Heat Treating Response of 0.6% C Low-Alloy Steels

4 p.m.
Thermomechanical Modeling of Plate Annealing Process

4:25 p.m.
Recent Developments in Cast Alumina-Forming Austenitic Stainless Steel Furnace Rolls

4:50 p.m.
Closing Remarks

5 p.m.
Adjourn Conference

RECENT DEVELOPMENTS IN PLATE STEELS

SUNDAY, 3 JUNE 2018

4–6 p.m.
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8:15 a.m.
Cleanliness of Plate Steels: Review and New Developments

P. Chris Pistorius and Bryan Webler, Carnegie Mellon University

Steel cleanliness is an essential part of producing high-quality plate steels. The principles of clean steel production will be reviewed, including control of dissolved impurities, inclusion formation, removal and modification, and avoiding reoxidation. New developments include rapid quantitative prediction of the changes in inclusion concentration and composition during ladle treatment, advances in the speed and accuracy of automated inclusion analysis, and solidification effects. These techniques are a set of tools for quality assurance (designing appropriate clean steel practices) and quality control (measuring the resulting cleanliness).

8:40 a.m.
Analysis of Thermal Homogenization in Steel Refining Ladle Using Bottom Gas Injection

Chenn Zhou, Justina Lee, Dan Yan and Armin K. Silaen, Purdue University Northwest

In a steel refining ladle, heat loss from liquid metal to the refractory lining of the ladle is inevitable, and control of metal temperature is important to ensure good quality. In this paper, 3D computational fluid dynamics technique is used to simulate transient multi-phase flow and heat transfer in the ladle. For multi-phase flow, a VOF-Lagrangian approach is used whereas in the heat transfer model, non-uniform heat loss from sidewall to ambient air is considered. The temperature distribution in molten steel and the effect of different flowrate on melt thermal homogenization is examined and analyzed.

9:05 a.m.
Heat Transfer and Solidification Modeling of Continuous Steel Slab Casting

Richard A. Hardin and Christoph Beckermann, University of Iowa

A three-dimensional heat transfer model is described for continuous steel casters of rectangular section using realistic simulation operating conditions. Model realism considers mold heat transfer, each roll and spray from nozzles. Model conditions include: mold heat flux, roll positions and sizes, spray cooling tables, mapping spray cooling zone positions, spray nozzle layout, nozzle spray pattern, nozzle offset from slab surface, slab dimensions, and steel grades. Pre- and post-processing software interfaces are developed to enable setup, management, running and visualizing the model output in a graphical user interface environment. Results can be exported to the graphical visualization software Tecplot and to input files for stress analysis using the commercial finite element analysis software ABAQUS. Calibration and validation of the model is provided using temperature measurements for a 150-mm-thick slab caster.

9:30 a.m.
The Use of Infrared Thermography to Detect Thermal Instability During Solidification of Peritectic Steels

Kateryna Hechu and Begona Santillana, Tata Steel Research and Development; Carl Slater, The University of Warwick; Sridhar Seetharaman, Colorado School of Mines

Infrared thermography has been carried out on a range of commercial grades (including peritectic grades) during solidification inside a high-temperature confocal scanning laser microscope (HT-CSLM). It has been shown that this technique can distinguish the difference between solidification paths of a range of metals. This mimics techniques such as calorimetry; however, this technique offers the ability to observe the sample while also obtaining cooling rates outside the range of standard calorimeters. The thermal data was analyzed from the crucible and multiple points on the sample's surface, giving information on both the global and local emittance during solidification. When looking at the results, several differences were seen between peritectic and non-peritectic samples. This includes the differing level of heat transfer as well as spatial fluctuations/variations in thermal stability.

9:50 a.m.
HD Mold Fiber Optic Technology for Mold Thermal Mapping and HD Scan-Ultrasonic Technology for Analysis of Internal Quality

Joseph Laughlin, SMS group

HD mold uses a high density of fiber optical temperature measurement points along the height and width of the copper mold, as compared to conventional thermocouple systems. The location of the fiber optical sensors is very flexible, including the possibility of double sensors to provide heat transfer data through the copper. In combination with thermal modeling, HD mold provides optimization of casting parameters to address molten casting powder infiltration depth, narrowface shape, gutter formation, breakout prevention and detection of longitudinal face cracks. HD scan utilizes two ultrasound sensors and advanced software to provide fast and detailed feedback of the internal quality of as-cast samples, which can be used to optimize the casting process and maintenance requirements. Three-dimensional volume analysis of as-cast samples is available, as well as single-plane analysis, known from conventional sulfur printing or macroetching methods. Compared to conventional methods, HD scan requires less effort in sample preparation and eliminates the use of dangerous acids. It provides automatic segregation classification, detects internal cracks, visualizes equiaxed and columnar macrostructure, and automatically analyzes sample geometry.

10:10 a.m.
Break

10:25 a.m.
Investigation of Combustion, Heat Transfer and Slab Quality in Industrial Reheating Furnaces

Chenn Zhou, Ziang Liu, Guangqu Tang and Armin K. Silaen, Purdue University Northwest

Comprehensive numerical modeling and validation on industrial reheating furnaces were conducted. Both pusher-type reheating furnace and walking beam reheating furnaces are studied. A three-dimensional computational fluid dynamics (CFD) model was developed to simulate the flow characteristics, combustion process and multi-scale heat transfer inside reheating furnaces. The operation process was modeled with specific slab moving speed and fuel variations. A numerical method has been developed to model the growth of scale under varying conditions including temperature, gas atmosphere and steel grades. This model has been validated against published experimental work. The effects of growth of scale on the heat transfer from furnace gases to the steel slabs are also investigated. The model was validated with instrumented slab trials and operation level 2 models. The temperature field in the furnace and the temperature evolution of the slab predicted by the CFD model are in good agreement with those obtained from operation.

10:50 a.m.
Modeling and Simulation of Mass Flow of Steel Plate/Slab During Hot Rolling

K. Chandrashekhara, X. Wang, S. Ganguly, M.F. Buchely, S.N. Lekakh, D.C. Van Aken and R.J. O'Malley, Missouri University of Science and Technology; D. Bai, Y. Wang, SSAB Americas; T. Natarajan, U. S. Steel Research and Technology Center

The ability to predict mass flow behavior during hot rolling is essential to product quality. In this study, viscoplastic models of steel grades from SSAB Americas and U. S. Steel Research and Technology Center were developed based on experimental stress-strain curves. A three-dimensional non-linear finite element model was built to simulate a reversing plate hot rolling and a continuous slab hot rolling. Five- and seven-pass plate hot rolling schedules were simulated. The plate hot rolling simulation results show that the surface has larger plastic strain than the center of the plate. Through-thickness material flow and plastic strain distributions for the five-pass and seven-pass schedules are compared. The slab hot rolling simulation results showed that material flowed from the sides to the top and bottom surfaces during edging, and then was deformed to flat surface during rolling. Details of the material flow and strain distributions during scalebreaking, edging and rougher rolling are presented.

11:15 a.m.
Optimization of High-Strength Plate Steel Pass Schedules Using Physical Simulation and Numerical Modeling

Juha Pyykkönen and David Martin, Swerea KIMAB AB; Visa Lang and Saara Mehtonen, SSAB

The control of mechanical properties of thermomechanically rolled, direct quenched and tempered high-strength structural steels requires advanced alloy design concepts and sophisticated rolling pass schedules together with appropriate tempering conditions. Concerning the plate rolling stage, reliable prediction of the plate temperature, roll force, torque and austenite conditioning is essential for the proper setup of thermomechanical treatment schedules of the plate mill. The main objective of the work described in this paper is to optimize thermomechanical behavior and microstructure evolution of a structural steel with a minimum yield strength of 650–700 MPa. It is shown that the combination of physical simulation and numerical modeling can be beneficial in order to achieve desired austenite grain structure prior to quenching. Furthermore, the concept of hierarchical austenite grain structure evolution model is presented and discussed.

11:40 a.m.
Through Thickness Microstructural Optimization in Plate Rolling of Nb-Microalloyed Steels

José M. Rodríguez-Ibabe, Xabier Azpeitia, N. Isasti, and P. Uranga, CEIT; D. Stalheim, DGS Metallurgical Solutions; M. Rebellato, Eurosport

Through-thickness homogeneity in hot-rolled thick plates is a critical issue to achieve the mechanical properties. The development of advanced modeling tools is an interesting possibility to integrate the chemical composition/processing parameters/mechanical property analyses. MicroSim-PM® software is a plate mill model developed using worldwide practical industrial and academic experience. Its combination with finite element analysis is particularly useful for final homogeneity evaluation and to detect the limits of robust processing windows. There are metallurgically key thicknesses where an optimized per pass reduction should be taken to result in a homogenization of the through-thickness austenite grain conditioning in Nb-microalloyed steels. The microstructural evolution modeling through thickness will enlighten the minimization of microstructural gradients from the surface to the centerline by a suitable combination of rolling schedule and alloy designs.

12:05 p.m.
Rolling Pressures During the Hot Roll of Three Different Steel Plates: Experimental, Theoretical and Finite Element Analysis

Mario Buchely, David Van Aken, Ronald O'Malley, Xin Wang, K. Chandrashekhara and S. Lekakh, Missouri University of Science and Technology

Calculation of rolling pressure is an important subject in hot rolling of plate and this information is useful for rolling mill operation and design. Many theories related to the calculation of rolling pressure are available in the literature; however, experimental rolling data is not often found. In this paper, rolling pressures for three different steels were studied: AISI/SAE 1018, 15V38 and ASTM A992.

12:25 p.m.
Lunch

1:40 p.m.
Accelerated Cooling Studies of Steel Plates on a Pilot-Scale Runout Table

Matthias Militzer and Vladan Prodanovic, The University of British Columbia; Hans-Jürgen Kirsch, Roland Schorr and Volker Schwinn, Dillinger

Accelerated cooling is a key technology in producing thermomechanically controlled processed (TMCP) steels with increased strength. The cooling efficiency is affected by nozzle design and arrangement, water flowrate and temperature as well as surface roughness of the steel plate. In particular, the role of surface roughness requires further studies. A series of systematic top and bottom cooling studies were conducted on a pilot-scale runout table test rig using stainless steel plates with surface roughness values ranging from 1 to 40 µm. The test plates were instrumented with embedded thermocouples. Based on the measured temperatures, the surface heat flux was quantified using an inverse heat conduction analysis to construct boiling curves that were used to identify the processing conditions under which surface roughness significantly affects cooling efficiency. Based on these observations, accelerated cooling practices can be optimized for the production of TMCP steel plates.

2:05 p.m.

Experimental and Numerical Combined Approach for Development of a Cooling Unit for Steel Plates

Makhlouf Hamide, ArcelorMittal Maizières Research; Charles Romberger, ArcelorMittal USA Research & Development; Mickael Kapustin, ArcelorMittal Burns Harbor; Fall Adbou, ArcelorMittal SA

To meet increasing market requirements and reduce production costs of high-strength steels, advanced accelerated cooling was developed and tested on an industrial line. The objective of this paper is to describe the systematic experimental and simulation analysis that was done to develop and optimize this cooling technology. Computational fluid dynamic modeling by finite element solid analysis was developed to analyze the cooling efficiency, water discharge and flatness behavior for different processing conditions. This numerical approach was supported by extensive laboratory testing. Different cooling process parameters were studied. Temperature data were processed using an inverse heat conduction model to calculate the corresponding surface heat fluxes. The heat transfer coefficient was compared for each case and used to tune and validate the simulations. The developed approach combines experimental and rigorous models; simulations of flows, heat transfer and flatness distortion have been developed and evaluated for several test cases and have been successfully used for the scale-up and development of an industrial unit. A full-scale prototype was developed and tested in an industrial line. The application of the new cooling technology showed better plate flatness performance than previous existing accelerated cooling unit.

2:30 p.m.

Accelerated Cooling Capabilities at ArcelorMittal Burns Harbor 160-Inch Plate Mill

C. Romberger, M. Kapustin, T. Ros-Yanez, V. Ames, B. Felton, M. Hamide, F. Huet and M. Regnier, ArcelorMittal USA

A first-of-its-kind accelerated cooling system for steel plate products, known as ACCTec, was commissioned at the ArcelorMittal Burns Harbor 160-inch plate mill. The ACCTec concept features a unique design of water application to the plate surface resulting in high cooling rates and more uniform through-thickness temperatures than conventional cooling systems. The ACCTec configuration consists of two high-cooling modules and four soft-cooling modules capable of producing plate products with uniform mechanical properties and improved flatness. The new cooling rate module was installed with minimal disruption to the plant operation, using the existing infrastructure from the former ADCO accelerated cooling system for water delivery. A level 2 model was implemented and thermal characterization was successfully performed. Accelerated cooling practices for the production of TMCP and direct-quench plates were optimized by a series of cooling conditions. ACCTec is being used to expand ArcelorMittal plate products, offering higher strengths and thicker gauges for structural, shipbuilding, pressure vessel, offshore and line pipe applications.

2:55 p.m.

Effect of Direct Quenching and Accelerated Cooling on Metallurgical and Mechanical Behavior of Low-Carbon Microalloyed Steels

Qiulin Yu, Jacob Lewis, Jon Walton and Blane Vines, Nucor Steel Tuscaloosa Inc.

A direct quenching and accelerated cooling (DQ-AcC) device has been installed and commissioned at Nucor Steel Tuscaloosa Inc. since October 2016. In this paper, the effect of direct quenching and accelerated cooling on metallurgical and mechanical behavior of low-carbon microalloyed steels is investigated. By employing the dilatation method in the Gleeble 1500D, continuous cooling transformation (CCT) diagrams of low-carbon microalloyed steels were measured via a considerable number of specimens with a diameter of 10 mm under various cooling rates. The effects of variations in microalloy contents on phase transferring temperatures are obtained by comparing the CCT diagrams. Based on the diagrams, serial ultrafast cooling rates were applied to low-carbon microalloyed steels. Ultimately, desired acicular ferrite and upper bainite are achieved. With combining ultrafast cooling with thermomechanical control rolling process, mechanical properties including strength and toughness are also improved significantly.

3:20 p.m.

Development of High-Performance Steel Plates at NLMK Clabecq

Philippe Hernaut, NLMK Clabecq, and Bruno C. De Cooman, NLMK Group

While it is, in principle, not difficult to produce high-strength (UTS <1 GPa) and ultrahigh-strength (UTS ≥ 1 GPa) steel grades, their strength is inversely related to their toughness, i.e., their toughness decreases with increasing strength. Although most high-strength ferritic steel grades usually fracture in a ductile manner when tested at room temperature, fracture becomes a very important issue when these steels are used in applications that require both high strength and a tough, i.e., damage-tolerant, behavior. Typical applications include natural gas line pipes, offshore structures, pressure vessels and shipbuilding.

A combination of factors, such as the presence of non-metallic inclusions and carbides, the temperature dependence of the mechanical properties, and the presence of embrittling solutes at grain boundaries, makes the design of tough plate steel grades challenging. The presentation will focus on the approach used by NLMK Clabecq in Belgium to produce high-performance, high-strength, damage-tolerant plate steel, based on a clean steelmaking practice (low inclusion levels, improved slab internal quality), alloy design and the precise control of the microstructure evolution (thermomechanical-controlled processing, leveling and cooling technologies) during processing.

3:45 p.m.
Break

4 p.m.
Optical Flatness and Thickness Measurement for Heavy Plates
Par Kierkegaard, Shapeline AB; Achim Sonntag, Micro-Epsilon Messtechnik
Laser line triangulation has been used for accurate and reliable flatness measurement for a long time. Recently, laser lines have also shown advantages over point sensors for optical thickness measurement. The paper describes the state of the art for flatness and thickness measurement based on laser lines. The first part of the paper describes flatness measurement based on the double laser line principle and specifically how the technology can be applied to hot environments and how issues like heat shimmering, calibration and maintenance can be solved. The second part explains technology and advantages using discrete laser line triangulation in thickness gauges. Furthermore, the performance of these gauges in hot applications up to 2,192°F material temperature is discussed. The paper is concluded with a description of how optical flatness and thickness measurement can be combined into a measurement cell where the two technologies are integrated to deliver flatness, width, length and thickness data.

4:20 p.m.
Overview of Heat Treat Leveler for ArcelorMittal Burns Harbor
Hiroyuki Uematsu, Keizo Abe and Toru Aoyama, JP Steel Plantech Co.
The new heat treat leveler for ArcelorMittal Burns Harbor (AMBH) was installed as one of the key components of the modernization of the plate quenching/tempering facility and has been in operation since April 2012. This leveler is the so-called fourth-generation plate roller leveler (SuPerLeveler™), which has the infinite rigidity control system. Special features include adopting newly developed special self-aligning roller bearing for backup rolls to meet increasing leveling force, employing special design of changeable 5 and 9 leveler rolls to realize different roll pitch, and adopting individual driving system to prevent universal joints from damage by excessive torque. The leveler covers all required products of high tensile strength and heavy gauge to be produced by the new heat treatment facility in AMBH. Here, JP Steel Plantech Co. introduces the plate leveler from a position of machine builder.

4:45 p.m.
Effects of Cold Leveling and Shotblasting on Flatness and Residual Stress of High-Strength and Wear-Resistant Steel Plates
Anna Philipsson and Anders Carlestam, SSAB Special Steel
For high-strength and wear-resistant steel plates, excellent control of flatness and residual stresses are demanded by customers, but they can be very challenging to achieve. They require not only optimization of the quenching, tempering, cold leveling and shotblasting processes, but also the development of the appropriate methods to measure flatness and residual stress of a plate. At SSAB, a Shapeline gauge is the primary tool used to measure plate flatness. Over the years, key parameters and procedures have been developed to optimize plate flatness and for correcting flatness issues. SSAB has also developed internal procedures to evaluate residual stress in plate. It is well known that cold leveling affects the flatness and residual stresses of steel plates. However, the effect of shotblasting on plate flatness and residual stresses has not been well studied. In the present study, mill trials with cold leveling and shotblasting were performed, and the results are used to optimize the processes to produce flat plate with low and balanced residual stresses.

TUESDAY, 5 JUNE 2018
7–8 a.m.
Breakfast

8 a.m.
Evolution of Niobium-Microalloyed Line Pipe Steels and Associated Welding Technology
J. Malcolm Gray, Microalloyed Steel Institute; Phil Kirkwood, Micro-Met International
This paper covers the evolution of niobium-strengthened line pipe steels over five decades and the parallel changes in welding technology that have been required to support steelmaking and pipe manufacturing innovations. The path of development from the first use of niobium in a semi-killed X52 line pipe steel in 1959 to the advanced concept X80, and even stronger, steels of today is uncovered. The important metallurgical developments that have enabled increasing technical demands to be met are explained and recent trends toward the adoption of lower carbon levels that permit the more efficient utilization of higher levels of niobium, in what are colloquially termed HTP steels, are explored. A particularly promising extension of the HTP steel technology to produce a range of ultralow-manganese steels for severe sour gas service at the X65 strength level is also unveiled. As line pipe steel strength and toughness levels progressively increased, particularly over the last 40 years, it became essential for that progress to be matched by innovations in welding technology for both pipe mill submerged-arc welding and field girth welding. The paper reviews such developments and highlights their success. Countless miles of high-pressure X65-X80 pipelines have now been installed worldwide and are operating safely today.

8:25 a.m.
Advance in Microstructure Control for High-Strength Steel Plates with Recent Thermomechanical-Controlled Processing and Applications for Large-Diameter Pipelines
Nobuyuki Ishikawa, Junji Shimamura, Akihiko Tanizawa, Shinichi Kakihara and Joe Kondo, JFE Steel Corp.
Thermomechanical-controlled processing (TMCP) enables plate steels to have high strength and excellent toughness with lean chemistry, which improves weldability. Steel for large-diameter line pipes for oil and gas transmission is one of the applications of TMCP steels that requires a variety of material properties, such as heat-affected zone toughness, crack arrestability, deformability, compressive strength, heat-induced cracking resistance and so on, as well as high strength. In order to achieve multiple material properties,

microstructure control technologies have been developed by applying advanced TMCP with the on-line accelerated cooling process and the heat treatment on-line process. Variety of microstructure controls such as bainite-MA multi-phase microstructure and homogeneous bainitic microstructure were available for the high-strain application and the deepwater application, respectively. In this paper, microstructure control technologies for the recent line pipe steels using advanced TMCP are summarized and the future applications are discussed.

8:50 a.m.

Mechanical and Microstructural Characterization for Spiral Submerged-Arc Welded X-80 Line Pipes

Ashish Kumar Singh, PN Mahida and TS Kathayat, Welspun Pipes Inc.

Developments of high-strength grade line pipes (X-80 and above) are crucial for the efficient and safe transportation of oil and natural gases. Double submerged-arc welded line pipes of 1,066 mm diameter and 19 mm thickness were successfully manufactured. A detailed characterization including microstructural analysis, tensile, hardness, impact, drop weight tear test and steel chemistry are presented for base metal, weld and heat-affected zone. The presence of acicular ferrite and fine polygonal ferrite microstructure in both base and weld metals resulted in excellent mechanical properties of the X-80 line pipes. The effects of strain aging on mechanical properties of steel during coating of these pipes were also analyzed in detail.

9:15 a.m.

Strengthening and Kinetic Effects of Vanadium Microalloying in Low-Carbon Bainitic Line Pipe Steel Plates

Fateh Fazeli, Colin Scott and Babk Shalchi Amitkhiz, CanmetMATERIALS; Brian Langelier, McMaster University

The strengthening effect of vanadium addition to bainitic line pipe steels has been studied. The kinetics of the bainitic transformation during fast cooling and the tempering of fresh bainite during coiling simulations were substantially influenced by vanadium. Vanadium shifts the bainite transformation to lower temperatures, refining the lath structure and increasing the dislocation density of bainitic ferrite. Further, atom probe tomography confirmed the formation of V-C and V-N clusters after coiling at temperatures above 500°C, contributing markedly to the strength of bainite. It is proposed that vanadium interactions with carbon atoms compete with carbon segregation to dislocations, thus changing the initial plastic yielding behavior of tempered bainite. These effects were also investigated in the presence of Nb. This paper provides guidelines to exploit the synergistic effect of vanadium and niobium alloying for the development of advanced line pipe plates.

9:40 a.m.

Effect of Vanadium on the Hardening of Low-Carbon Microalloyed Steels During and Experimental Time-Temperature Study

Julian Benz and Steven Thompson, Colorado School of Mines

In modern microalloyed steels for line pipe and structural applications, vanadium has been increasingly utilized along with processing routes to produce complex bainitic microstructures. However, the precipitation of microalloy carbides in these bainitic microstructures are not well studied. In the present work, two experimental low-carbon steels, one without and one with vanadium addition, were selected. A time-temperature study was conducted, in which samples were transformed to bainite after reaustenitization and accelerated cooling and immediately held at temperatures between 400–600°C for various times. At hold temperatures of 500 and 550°C, the microhardness continuously increases with increasing hold time in the time range investigated. The evolution of microstructure with aging time was investigated using transmission electron microscopy.

10:05 a.m.

Break

10:20 a.m.

Effect of M/A Constituent on the Mechanical Properties of Low-Carbon Microalloyed Steels

Dengqi Bai, Eric Lynch, Chase Rawlinson and Rick Bodnar, SSAB Americas

In modern low-carbon microalloyed steels, martensite/retained austenite (M/A) is one of the important microstructural constituents of steel plates produced via thermomechanical-controlled processing. Depending on the size, morphology, volume fraction and crystal structure, the M/A constituent could have very different effects on the mechanical properties of steel. In general, coarse M/A islands with a twinned martensite structure could negatively affect the toughness of steel. On the other hand, fine and uniformly distributed M/A constituent could produce continuous yielding behavior and lower yield/tensile strength (Y/T) ratio for a steel. For applications such as line pipe steel, not only is a good combination of strength and toughness essential, but also a low Y/T ratio is desirable.
It is important to control the size, distribution and volume fraction of this microstructural constituent in order to achieve optimal mechanical properties. In the present study, the effects of the M/A constituent on the mechanical properties of several severely control-rolled line pipe steels are examined. The effect of steel chemistry on the formation of the M/A constituent is also analyzed.

10:45 a.m.

Alloy Design and Processing Considerations for the Successful Production of API X70 Grade Line Pipe Steel Through CSP Flex Mill

Chirag Mahimkar, Amar De, Tommie Kifer, Dennis Hennessy and Jay Martin, Big River Steel

Production of API grade high-strength line pipe steels is increasingly becoming challenging due to stringent internal quality and toughness considerations.
The daunting task of guaranteeing quality, mechanical properties and a heat-affected zone–friendly chemistry is still the subject of continuous

improvement for steelmakers of any rank and profile. The challenge faced by Compact Strip Production® mini-mills is compounded by the fact that they lack operational and processing flexibility. However, with the introduction of advanced technological interfaces and controls, processing of advanced steels such as high-toughness line pipe steels has become possible with suitable alloy and processing design. At Big River Steel, an alloy and processing recipe was adopted to take advantage of newer casting, hot rolling and cooling technologies for the production of high-toughness API X70 grade hot strips. The first mill trial has demonstrated that API X70 grade hot-rolled coils could be successfully produced with excellent low-temperature drop weight and impact toughness properties for 12.5-mm-thick pipes.

11:10 a.m.

Modified Impact Testing to Assess Toughness and Susceptibility to Splitting in X70 Pipeline Steels

Haytham M. Al-Jabr, SABIC; John G. Speer and David K. Matlock, Colorado School of Mines

Modern pipeline steels exhibit toughness levels that typically exceed the capacity of standard Charpy V-notch (CVN) impact test equipment. Unstable crack growth in high-toughness steels is often associated with splitting, i.e., delamination aligned on planes perpendicular to the primary crack growth plane and aligned along the direction of crack growth, and the toughness decreases with an increase in splitting. In this study, a modified Charpy V-notch (MCVN) impact test specimen with side grooves was designed to increase tensile stresses induced parallel to the notch root to enhance splitting. With the MCVN, samples of high-toughness commercially produced X70 pipeline steels were tested on a conventional Charpy V-notch machine. Ductile-to-brittle transition curves and observations of the extent of splitting were obtained and compared to conventional Charpy impact data. Impact tests based on the MCVN sample are interpreted to assess the effects of alloying, processing and microstructure on toughness.

11:35 a.m.

Recent Pipeline Service Experience and Its Implications on Line Pipe Steels

Steve Rapp, Enbridge; Young-Yi Wang, CRES

There have been a number of in-service girth weld failures of newly constructed pipelines and girth weld failures during construction hydrostatic testing. There were no discernable anomalies in those welds; the welds were fabricated, inspected and accepted per industry acceptance standards, such as API 1104. The pipes met the requirements of industry standards, such as API 5L. The loads on these welds tended to be higher than those on most welds in cross-country pipelines, but within expected range for normal pipeline construction and service conditions. In some cases, failures occurred at an applied strain of less than 0.5%. The toughness of the welds was good and the service temperature was on the upper shelf of the brittle-to-ductile transition curves. By historical experience, these failures were not expected. Metallurgical and structural mechanics analysis to date indicate the primary contributing factors are: (1) unintentional weld strength undermatching due to pipe strength being much higher than the specified minimum strength, (2) heat-affected zone (HAZ) softening, and (3) bevel geometry of manual welding processes that favor tensile failure through plastic straining along the softening HAZ. In examining the history of line pipe steel manufacturing, it is noted that recent vintage of control-rolled and microalloyed steels could have very low hardenability, which is a major contributor to the HAZ softening. In addition, these steels tend to have low strain hardening and low uniform elongation, which can reduce their tolerance to anomalies and deformation. Some of the drivers for the new steel chemistry and processing routes were to increase toughness and to reduce the susceptibility to hydrogen-assisted cracking in the HAZ, while increasing the overall strength of the steels (grade). It appears that these approaches have led to unintended negative consequences. This paper starts with a review of recent pipeline incidents. The contributing factors to these incidents are examined through metallurgical and structural mechanics analysis. Possible changes to steelmaking and other industry practice, such as welding, are suggested, including but not limited to: (1) increasing hardenability, (2) increasing strain hardening, (3) limiting allowable maximum of pipe tensile properties, (4) alternative requirements for welding procedure qualification, and (5) rigorous and practical test procedures to assist the implementation.

Noon

Lunch

1:15 p.m.

Strategy for Production of Plate Steels Requiring Resistance to Hydrogen-Induced Cracking

Douglas Stalheim, DSG Metallurgical Solutions Inc.

Various grades of pipeline and pressure vessel steels require capabilities to resist cracking when exposed to service requirements containing hydrogen. Termed "sour service" applications, not only do these steels need to meet the mechanical property requirements of strength and toughness, but they also need to meet hydrogen-induced cracking (HIC) specifications. Since hydrogen migrates to areas of high stress concentrations within the steel matrix, minimization of areas of high stress is critical to success. This means that the key component to HIC resistance is the phases and grain size/distribution of the microstructure. Key strategies in production of these steels involve alloy and processing designs that are focused on creating the proper microstructural phases and cross-sectional grain size/distribution for optimum balance of all properties. Strategies in alloy/process design and the resultant microstructure design that have been proven to provide an optimum balance of mechanical properties and HIC performance will be discussed.

1:40 p.m.

The Effect of Coarse NbC Particles and Final Microstructure on the Hydrogen-Induced Cracking Behavior of X65/X70 Steel Plates for Sour Gas Applications

C. Isaac Garcia, University of Pittsburgh; Alberto Perea-Garduño, Altos Hornos de Mexico (AHMSA)

It is well understood that hydrogen is always a harmful element in steel. Hydrogen can be dissolved in steel at different stages: (a) in the liquid phase due to its high solubility, (b) during steelmaking and casting, (c) during reheating, and (d) during austenite decomposition to low-temperature-transformation products. At low concentrations, hydrogen can also be segregated at different structural factors such as coarse particles, non-metallic inclusions, grain boundaries, dislocations and hard microstructural components, i.e., bainite and/or martensite. The preferred segregation site (trap) for hydrogen will depend on their binding energy. The present study documents the role of coarse NbC particles and the presence of bainite on the induced cracking behavior of X65/X70 steel plates for sour gas applications. This study examines the different

processing stages from solidification of the slab, reheating, hot rolling and transformation behavior. The results of this work will be presented and discussed.

2:05 p.m.

Effect of Microstructure on Hydrogen-Induced Cracking in Sour Service Pipeline Steel

Mary O'Brien, Kip Findley and John G. Speer, Colorado School of Mines

Hydrogen-induced cracking is of concern for steel pipelines used in sour service applications. In this investigation, several thermomechanically processed pipeline steels were charged with hydrogen to simulate H_2S cracking using NACE TM0284 solution or cathodic charging in a 0.1N sulfuric acid electrolyte, and subsequently characterized. The characterization included measuring the crack length ratios and evaluating crack interaction with the microstructure. All of the steels are low-carbon microalloyed steels, with microstructures ranging from mixed ferrite/pearlite microstructure, to non-equiaxed, highly substructured ferrite. All steels exhibited intergranular and transgranular cracking parallel to the rolling plane as a result of hydrogen charging. The effect of several microstructural features including M/A microconstituents and local crystallographic orientation was assessed. M/A microconstituents do not appear to crack more frequently than other microstructural features and $\Sigma 29a$ grain boundaries appear to crack less frequently than other special boundaries in the X70 steel.

2:25 p.m.

Quantitative Characterization of Plate Steel Microstructural Inhomogeneity

George F. Vander Voort, Struers Inc.; A. Kazakov, D. Kiselev and E. Kazakova, Peter the Great St. Petersburg Polytecnic University

Techniques were developed for quantitative characterization of all kinds of microstructural inhomogeneities observed in plate steels revealed by light optical microscopy. The panoramic imaging approach utilized by the Thixomet image analyzer allows metallurgists to conduct precise measurements at a high resolution using a sufficient area to obtain adequate assessment of microstructural inhomogeneity. The Thixomet motorized image analyzer provides an objective quantitative characterization of all kinds of microstructural inhomogeneities observed in plate steels, such as banding, general anisotropy, blocks of bainite with lath morphology and centerline segregation. These techniques were used for establishment of structure-properties relationships.

2:50 p.m.

Methods to Characterize Large (>1 Micron) Carbide and Nitride Particles in Microalloyed Steels

Rafael Mesquita, CBMM North America

The formation of carbide or nitride precipitates over one micron may be observed in some cases of microalloyed steel plates, especially when intense segregation during solidification occurs. Those particles are undesirable, since they may initiate cracks and lead to low fatigue or toughness-related properties, such as impact strength, drop weight tear test or total fatigue life. While the mechanism of carbides or nitrides follow the same basis of other high-alloyed steels, they are less commonly observed in microalloyed products and therefore the characterization may not be straightforward. This work shows several techniques that may be used to characterize the nature of such precipitates found in the central segregated region a Nb-Ti microalloyed steel, including optical microscopy, scanning electron microscopy with energy-dispersive x-ray spectroscopy analysis and transmission electron microscopy in samples obtained with focused ion beam. The precipitates were characterized as particles of NbC and TiN formed during solidification, thus present within the microsegregated bands and associated with the macrosegregated regions of plates. Thermodynamic calculations showed that the concentration of carbide and nitride in the central segregated regions precluded their dissolution during reheating because, due to segregation, the local concentration was above the solubility limit for normal rolling temperatures. Therefore, the elimination of those particles is only possible with the decrease in local concentration, which in turn means the reduction of segregation effects. A few alternatives with this respect are discussed in the end of the paper.

3:15 p.m.

Break

3:30 p.m.

Assessment and Interpretation of Non-Metallic Inclusions in Plate Steel to Improve Steelmaking Technology

A. Kazakov, A. Zhitenev, Peter the Great St. Petersburg Polytecnic University

It has been shown how the critical problems of non-metallic inclusions in plate steel could be solved by interdisciplinary knowledge based upon steelmaking theory and practice, quantitative metallography, and automated feature analysis based upon the scanning electron microscopy-energy-dispersive spectroscopy (SEM-EDS) analytical technique. The methods developed can be used for non-metallic inclusions assessment and interpretation to improve steelmaking technology and have successfully been tested on an industrial scale.

3:55 p.m.

Challenges in the Application of High-Strength Plate for Weight Reduction

Matthew Kiser, Caterpillar Inc.

While availability of thick (≥25 mm), high-strength (>345 MPa) plate is increasing, the application of this plate to enable lightweighting in construction and mining equipment is still facing challenges. This paper will describe the structural loading conditions that limit the benefit of high-strength plate and will summarize findings from a literature review on efforts to improve weld fatigue performance. The impact of post-weld thermal processing will also be explored. Ultimately, additional development is required to enable lightweight structures through the application of plate with yield strength greater than 345 MPa.

4:20 p.m.

Research and Development Strategy on Heavy Plate Steels and Recent Results at Dillinger

Volker Schwinn, AG der Dillinger Hüttenwerke

The microstructure-based design is one central element of the heavy plate research at Dillinger, since it provides, especially in combination with a complete modeling and simulation of the microstructure, the basis to meet the demand of shorter and more efficient development cycles. The approach of Dillinger will be described. More and more complex models are utilized for the material development and the optimization of processes. The big data created during steel- and platemaking and testing are systematically collected and evaluated by neural networks. These neural networks are meanwhile established to optimize the material concepts, to reduce the production costs and ensure the delivery reliability. A further central element for the continuous progress is strategic plant investments in advanced technologies. Recently, a new continuous caster came into operation, which allows the casting of slabs with a thickness of up to 600 mm. As a result of service failures, oil and gas companies raised concern with regard to hard spots. In response to this concern, a non-destructive testing method, based on an eddy current testing technique, was developed, which allows a 100% plate surface inspection as an integral part of the industrial plate production process and which reliably detects any and all areas with increased hardness. An in-line inspection system came recently into operation. Such central elements provide the basis for continuous developments, which are driven by demands from highly-sophisticated applications. These needs reflect in plates with higher thickness, larger width, higher toughness also at lower temperatures, higher strength and/or better resistance to sour environments. The progress will be explained and illustrated by recent developments.

4:45 p.m.

Operational, Metallurgical and Technological Developments in Microalloyed Structural Plate Steels

Steven Jansto, CBMM North America Inc.

Recent developments in the structural steel plate sector is focused upon improvements in quality; grain size homogeneity through the thickness; leaner, more cost-effective, low-carbon chemistries; water cooling technologies; and improved productivity. Also, the new generation of value-added low-carbon-low-manganese microalloyed structural steels for both low- and high-yield-strength and high-energy-absorption applications is under development. These materials engineering considerations are shifting designers to consider new lower-cost and more robust structural plate materials even for low-yield-strength applications. Applications involve wind towers, pressure vessels, bridges, offshore platforms, storage tank containers and ship plate. The civil engineering and end-user communities demand structural products with improved energy absorption and fatigue properties. With more severe climatic conditions, demands for improved fire and seismic resistance, low-temperature performance, yield-to-tensile ratio consistency, improved bendability and weldability are in the forefront. There is a global shift in motion to low C-Nb-bearing construction steels displacing traditional materials. For example, within the plate steel construction sector, further property improvements result with microalloy optimization at 0.015 to 0.025% Nb in low-carbon steel with appropriate hot rolling metallurgy for S355 and S420 grades.

6 p.m.

Dinner

WEDNESDAY, 6 JUNE 2018

7–8 a.m.

Breakfast

8 a.m.

Nb- and V-Microalloyed Plate Steels for Wind Turbine Towers: Base Material Toughness and Fatigue Properties

Keith Taylor and Rick Bodnar, SSAB Americas; Steve Jansto and Rafael Mesquita, CBMM North America Inc.

In North America, steel plate for wind turbine towers is commonly ordered to ASTM A572/A709 Grade 345 or EN 10025-2 Grade S355. For sites with low ambient temperatures, stringent low-temperature toughness requirements may be specified, e.g., 57 J at –40°C. If plates are ordered to ASTM A572/A709 Grade 345, low-carbon high-strength, low-alloy (HSLA) steel is typically employed. However, plates ordered to EN 10025-2 Grade S355 often require normalized rolling. To comply with the EN 10025-2 normalized rolled definition, higher-carbon steel is employed to ensure that mechanical properties would be satisfactory after a normalizing treatment. A paper at the first Conference on Recent Developments in Plate Steels compared properties of low-carbon-Nb control-rolled steels and higher-carbon-Nb, normalized-rolled steels. This presentation expands on the earlier work by including grades with V and by examining additional properties, including fatigue crack growth rate and low-temperature fracture toughness.

8:25 a.m.

Nb- and V-Microalloyed Plate Steels for Wind Turbine Towers: Weldability Characterization

Erik Soderstrom, Rick Bodnar and Lingyun Wei, SSAB Americas; John Procario and Nate McVicker, The Lincoln Electric Co.

The current study presents the findings, as they relate to weldability, of an ongoing investigation of the properties of low- and medium-carbon plate steels that are typically used during the fabrication of wind towers. Steel plate manufacturers can utilize different alloying and processing techniques to meet the ASTM A572/A709 Grade 50 or EN10025-2 Grade S355 standards that are commonly used in this application. It was previously shown that low-carbon, high-strength, low-alloy steels offer improved mechanical properties when compared to medium-carbon steels in the as-received condition. However, as-welded properties such as heat-affected zone toughness can vary significantly between these types of steels, even when the same welding procedure is used. Five different base metals were welded using single and tandem submerged-arc processes. Properties of these weldments are presented, including transverse tensile, microhardness and impact testing results.

8:50 a.m.

High-Strength TMCP Steel Plate for Offshore Structure With Excellent HAZ Toughness at Welded Joints

Kazuhiro Fukunaga, Tsuyoshi Yoneda, Yoshiyuki Watanabe, Ken-ichi Yoshi, Hirokazu Ususki and Yasuhiro Shinohara, Nippon Steel & Sumitomo Metal Corp.

The steel plate for offshore structures is required to have excellent low-temperature heat-affected zone (HAZ) toughness because of more severe environmental conditions such as deeper sea and frigid oceanic conditions. Therefore, the steel plate with excellent HAZ toughness for offshore structures has been developed. As an important point in the development of the steel

is the refinement of the effective grain size of the HAZ microstructure, strengthening of formation of intragranular ferrite (IGF) has been tried on Ti-O steel. Addition of Mn to Ti-O steel, an important element for Ti-O steel for IGF formation, was increased intentionally. Consequently, IGF has increased as compared with conventional Ti-O steel, ferrite side plate size has decreased and HAZ toughness has been improved. The developed steel has excellent crack tip opening displacement properties at –20°C, thus it can be applied to offshore structures in frigid sea.

9:15 a.m.

World-First Application of SMYS 552 Steel Plates for an Offshore TLP Project

Masahiro Oguri and Hideo Sakibori, Nippon Steel & Sumitomo Metal Corp. Kashima Works; Tsuyoshi Yoneda, Nippon Steel & Sumitomo Metal Corp.; Takahiro Kamo, Nippon Steel & Sumitomo Metal Corp. Kashima R&D Lab

Grade 80 steel plate (SMYS 552 MPa) for offshore structures has been developed. The combination of the copper precipitation and thermomechanically controlled processed (TMCP) technology realized high strength without deteriorating toughness and weldability. Heat treatment for Cu precipitation was carried out to optimize the balance of strength and toughness of the base metal. The developed steel also shows good heat-affected zone crack tip opening displacement property up to 76.2 mm thickness in several welding conditions including after post-weld heat treatment. The developed steel has been supplied for a major offshore tension leg platform project, and has contributed to realize an extremely large-sized structure. The quality of the steel in mass production was strictly controlled and stable properties are successfully attained. The developed steel is able to contribute to increase flexibility in designing large-sized structures.

9:40 a.m.

Development of EH40 Grade Steel Plate for Tandem EGW for Mega Container Ships

Seung-Jae Jo, Sung-Doo Hwang, Young-Joo Cho, Jae-Hong Ryu and Young-Chan Seo, Hyundai Steel Co.

The steel plate used in large container ships must have good heat-affected zone (HAZ) toughness with high strength and thick thickness under ultralarge heat input for work efficiency and safety. In order to improve the toughness of the HAZ, it is very important to control the microstructure, particularly to suppress the growth of prior austenite grains at a high temperature more than 1,350°C. This study is concerned with issues related to enhance HAZ toughness using high-titanium nitride technology in EH40 grade steel.

10:05 a.m.

Microalloyed Steel Plates With Excellent Abrasion Resistant Property

Naoki Takayama, Yoshiaki Murakami, Yasuhiro Murota and Ryuzo Nishimach, JFE Steel Corp.

Steel plates used for construction and industrial machinery need to have high strength and good abrasion resistance as basic material properties. Additional requirements have been placed on the abrasion-resistant plates, such as low-temperature toughness, weldability and formability in recent years. Increasing surface hardness of the steel plate is a basic measure for improving abrasion resistance. However, richer chemistry for increasing hardness inherently causes deterioration of toughness and weldability. To balance these material properties, microalloying and thermomechanical control processing technologies were applied. Fine-grained martensitic microstructure with optimum chemistries exhibit good weldability and formability, as well as superior abrasion resistance. Effect of microstructure on abrasion resistance property and formability are described in this paper. Wear behavior under various wear conditions is also discussed.

10:30 a.m.

Break

10:45 a.m.

Mo- and Nb-Based Alloy Design for Production of Weldable High-Strength Plate Steel

Hardy Mohrbacher, NiobelCon bvba

High-strength plate steel grades have become the backbone of many industrial applications. Grade 60 to 80 alloys are common for use in large-diameter pipelines. Strength in the order of 100 ksi is utilized for frame structures of heavy vehicles. Applications such as crane booms, penstock or machinery equipment nowadays even involve steel in the strength range up to 160 ksi. Thermomechanical processing during hot rolling combined with accelerated cooling and, for the upper strength range, direct quenching are appropriate means of producing such steel grades. Considering the alloying concepts, the use of niobium and molybdenum is very efficient to achieve high strength and good toughness. However, all targeted applications of such high-strength plate involve extensive welding. Therefore, weldability of such alloys is a key property. The present study demonstrates alloy concepts and particularly the effects of Mo and Nb in combination with such processes. Furthermore, weldability tests have been performed using high- and low-heat-input welding techniques. For more detailed understanding, heat-affected zone (HAZ) subzones were generated using Gleeble® simulations in combination with systematic variation of alloying elements to indicate their specific effects. The results indicate that Mo and Nb alloyed in the usual range provide a good HAZ toughness level and guarantee sufficiently low ductile-to-brittle transition temperature.

11:10 a.m.

Ultrafine Hardening Overlay Material With Improved Impact and Wear Resistance

Lingyun Wei, SSAB; Erik Soderstrom and Rick Bodnar, SSAB Americas R&D; Jesper Gordon, SSAB Services

It is well known that traditional hardfacing overlay is a useful and economical way to improve the performance of steel plate components under severe wear conditions. However, such overlay materials are often brittle and do not perform well under impact loading conditions. The main objective of the present study was to metallurgically characterize a newly developed ultrafine overlay material and also subject it to field testing. The ultrafine overlay was analyzed by scanning electron microscopy (SEM)/electron backscatter diffraction (EBSD)/energy-dispersive spectroscopy (EDS) and it was found to contain a unique high volume fraction of refined complex borocarbides with an average size of ~500 nm in a ductile matrix, with uniform through-thickness hardness. Abrasion wear and impact wear testing was conducted on the overlay. Compared to traditional chromium carbide overlay composed of hard carbides in the 150 to 200 μm range, the ultrafine borocarbide phases reduce the stress concentration, thereby preventing premature pull-out delamination and crack nucleation. The net result is a product with a combination of significantly improved wear and impact resistance.

11:35 a.m.
Lunch

12:50 p.m.
Development of a Very-High-Toughness Steel for Pressure Tank Car Application

Steve Jansto, CBMM North America Inc.; Sree Harsha Lalam, ArcelorMittal Global R&D; Frank Feher and John Battisti, ArcelorMittal Burns Harbor

A low-carbon pressure vessel steel with enhanced low-temperature impact as well as drop weight toughness was developed at ArcelorMittal Global R&D through limited microalloying and lean substitutional alloying approach. The steel processed in normalized and stress relieved conditions (simulating post-weld heat treatment conditions) revealed outstanding low-temperature impact as well as drop weight toughness compared to traditional steels at all test temperatures of practical interest and maintained the properties in actual formed tank car heads. Lower-carbon alloy design also improved weldability of the steels greatly and a heat-affected zone toughness close to the base metal toughness could be developed. Fracture analysis using notched tensile tests revealed higher ductility in the new steel compared to the traditional medium-carbon steels guaranteeing improved puncture resistance in case of an accidental intrusion. Current paper outlines the product physical metallurgy principles adopted in innovating the new steel.

1:15 p.m.
Puncture Analysis of Tank Cars Using Ductile Damage Model

Sandeep Abotula, Bharath Konda, William Walsh and Murali Manohar, ArcelorMittal Global R&D; Amar K. De, Formerly with ArcelorMittal Global R&D

A new puncture-resistant steel is developed to improve the safety of tank cars transporting flammable liquids. The puncture behavior of the tank cars is simulated using a ductile damage model available in the finite element program ABAQUS. The damage model assumes that, for a given stress-state (triaxiality), failure initiates at the maximum load-carrying capacity. The subsequent damage evolution is defined by its fracture energy. To investigate a range of triaxiality conditions, uniaxial tensile tests are performed on notched, round-bar specimens for both current and new steel grades. Numerical simulations of each test are performed and validated with the test data. The relation between equivalent-plastic-strain at failure initiation and stress triaxiality (damage initiation) is obtained from test data and simulations, as is the fracture energy (damage evolution). Impact simulations are performed on the tank car and the results show that the new steel absorbs more impact energy, thereby delaying puncture.

1:40 p.m.
TBD

2:05 p.m.
The Effect of Microstructure on the Mechanical Properties of Wear-Resistant Steels

Antti Kaijalainen, Henri Tervo, Ilona Hautamäki and Jukka Kömi, University of Oulu; Teppo Pikkarainen, Pasi Suikkanen and Vili Kesti SSAB

The effect of microstructure on the mechanical properties of three thermomechanically rolled and direct-quenched wear-resistant steel plates was investigated. The prior austenite morphology and transformed microstructure was studied and compared to tensile properties, impact toughness, hardness and bendability. Decreasing the finishing rolling temperature increased the level of austenite pancaking. Centerlines of samples consisted mainly of auto-tempered martensite. With lower finishing rolling temperatures and higher reductions in the non-recrystallization regime the formation of polygonal ferrite and bainite increased at the subsurface layers. High fraction of polygonal ferrite seemed to have a detrimental effect on strength and impact toughness. Impact toughness is also impaired by the presence of coarse inclusions. Homogeneous, mostly martensitic microstructure through-thickness seemed to ensure good bendability.

2:30 p.m.
Quenching and Partitioning of Plate Steel — Design Methodology for Non-Isothermal Partitioning During Furnace Reheating

Rachael Stewart, John G. Speer, Brian Thomas, Emmanuel De Moor and Amy Clarke, Colorado School of Mines

Quenching and partitioning (Q&P) is a new heat treatment concept to develop high-strength martensitic microstructures with retained austenite that has been implemented industrially to make sheet products. This process is also of interest for thicker plate products to employ transformation-induced plasticity of microstructures containing austenite to enhance toughness and/or wear resistance. Thermal gradients developed in thick plate Q&P steel are much greater than in thinner sheet products, and are expected to have a profound influence on microstructure development. The authors have recently applied Q&P microstructure development concepts to plate cooling. The present contribution considers the partitioning behaviors encountered during off-line plate heat treating involving the transfer of a quenched plate and reheating in a furnace. A "non-isothermal degree of partitioning" concept, originally developed by Thomas and co-workers, and based on the Hollomon-Jaffe Tempering Parameter, is applied to through-thickness thermal profiles developed in steel plates during furnace reheating. A 1D numerical model developed in Matlab was first used to simulate temperature evolution in a flat plate during a batch-type furnace reheat. The plate partitioning concept is evaluated experimentally through dilatometry experiments with a Si-containing steel, heat treated according to the numerically simulated thermal profiles. In this and in recent work, design methodologies have been developed for both the quenching and the partitioning steps of plate processing. This conceptual development is an important first step toward commercial Q&P plate processing.

2:55 p.m.
Break

3:10 p.m.
Effect of Induction Treatment on Precipitation Strengthening in a Low-C TiMo-Microalloyed Hot-Rolled Steel

Pello Uranga, Gorka Larzabal, Nerea Isasti and Jose M. Rodríguez-Ibabe, CEIT

Advanced design concepts are extending in the production of thick plates in order to meet the demanding market requirements. This can be achieved with a microalloying concept. Precipitation strengthening mechanism has been extensively employed in thin strip products, due to the possibility of attaining enhanced final properties through the optimization of coiling strategy. Nevertheless, the formation of effective precipitation during continuous cooling after hot rolling is more complex in thick plates. With the purpose of gaining further knowledge concerning this strengthening mechanism, plate hot rolling conditions were reproduced in a low-carbon TiMo-microalloyed steel by laboratory simulation tests, generating different final microstructures. Afterwards, a rapid heating process was applied in order to simulate induction heat treatment conditions. The results indicate that the matrix microstructure nature affects the achieved precipitation hardening.

3:35 p.m.
Heat Treating Response of 0.6% C Low-Alloy Steels

Ronald C. Youngblood and John G. Speer, Colorado School of Mines; Kaitlyn McNaughton and Mark Taylor, Blount International

Medium-carbon steels are used in a variety of applications requiring strength, fatigue and wear resistance, and adequate toughness. In the present work, two steels (grades 8667 and 9260) were subjected to a variety of heat treatments to explore microstructure and property development. The 9260 alloy contains about 2% Si (by weight), enabling the production of carbide-free bainite or "quench and partitioned" microstructures. Austempering, quenching and tempering, and quenching and partitioning (9260 only) processing routes are explored. The resulting microstructures are characterized using optical microscopy and scanning electron microscopy. X-ray diffraction is utilized for the 9260 alloy processing conditions to assess the volume fraction of retained austenite and the carbon content of the austenite phase. A variety of mechanical tests were performed to assess the properties resulting from each processing route and corresponding microstructure.

4 p.m.
Thermomechanical Modeling of Plate Annealing Process

Andreas Johnsson and Mats Karlberg, Swerea MEFOS

A user-friendly, non-linear, thermomechanically coupled, finite element–based simulation tool with a user-friendly interface suitable for optimizing process control in plate annealing was developed. The model enables process parameters such as coiler tension, strip thickness, crown, coil dimensions and time/temperature vectors for the annealing cycle to be included in the analysis. Besides, the grade-specific thermal conductivity, heat capacity, density and initial grain size are incorporated. This model performs fast calculations of the thermomechanical, stress relief and microstructural evolution, e.g., grain size and precipitation, for each position inside the coil, or coils, since any stacking sequence and combination of number and coil dimensions is handled. The short calculation times makes the model suitable in optimizing the plate annealing process, e.g., to be used by process engineers. The model was validated by two full-scale bell furnace annealing campaigns at Duroc with very good agreement.

4:25 p.m.
Recent Developments in Cast Alumina-Forming Austenitic Stainless Steel Furnace Rolls

G. Muralidharan, Y. Yamamoto and M.P. Brady, Oak Ridge National Laboratory; Tanya Ros-Yanez, ArcelorMittal USA; Stan Fauske, ArcelorMittal Coatesville; Roman Pankiw and Garrett Hadley, Duraloy Technologies; Jim Myers, MetalTek International

Cast chromia-forming austenitic stainless steels such as HP-type alloys are used in a wide range of industrial applications that demand high-temperature microstructural stability, corrosion resistance and creep strength. For example, microalloyed HP-type alloys are used for furnace rolls in steel heat treat furnace applications. Although alumina scales offer better corrosion protection at these temperatures, developing cast austenitic alloys that form a stable alumina scale and achieve creep strength comparable to existing cast chromia-forming alloys, has been challenging. This work outlines the recent development of cast Fe-Ni-Cr-Al austenitic stainless steels for use in high-temperature industrial and chemical environments. This talk will highlight results on the performance of samples made from developmental alloys and a furnace roll manufactured using one down-selected alloy being evaluated in a heat treat furnace at the ArcelorMittal facility in Coatesville, Pa., USA.

4:50 p.m.
Closing Remarks

John G. Speer, Colorado School of Mines

5 p.m.
Adjourn Conference

POSTER SESSIONS TO INCLUDE:

Microstructural and Texture Effects on Thick Plate X70 Pipeline Steel Toughness

Emily Mitchell and Kester Clarke, Colorado School of Mines; Sven Vogel, LANSCE Los Alamos Neutron Science Center

The effects of plate thickness and microstructure on impact fracture toughness and separation development of four X70 API pipeline steels are investigated. Characterization of bulk and through-thickness variations in texture from the as-received plates is necessary to understand how specific crystallographically favored microstructures develop as a function of prior processing (i.e., hot rolling). Using the HIPPO (HIgh Pressure Preferred Orientation) neutron beam at LANSCE, bulk and through-thickness texture measurements can be used to determine the texture anisotropy in each steel plate as a function of thickness. Correlations between texture and macroscopic fracture behavior during impact testing (velocities on the order of 1–10 m/second) can be developed. For the steels plates tested, the focus is to understand fundamental connections between microstructure and fracture behavior of next-generation high-strength steel plate materials required for continuously more challenging oil and gas pipeline applications.

Ferrite-Pearlite Microstructure of Plate Steel in Terms of Inheritance of Slab Structural Zones

A. Kazakov, E. Kazakova and O. Pakhomova, Peter the Great St. Petersburg Polytecnic University

Using the example of a commercial slab of ferrite-pearlite steel, the matching patterns between elements of the dendritic structure and the grain structure have been established. Further evolution of a slab's as-cast structure to the plate steel structure was studied using the Gleeble® 3800. As to the slab's as-cast structure, in the pure dendritic axes, "Widmanstätten" ferrite is observed, while in the interdendritic spaces formed at the early stages of solidification with a minor degree of segregation, polygonal ferrite is observed; and, at the end of solidification, allotriomorphic ferrite is observed surrounding MnS inclusions. All features of the slab's as-cast structure are inherited by the plate steel. Large ferritic grains without sulfides are inherited from the dendritic axes; network from fine ferritic grains with vanadium segregations at their boundaries are inherited from the interdendritic space between the second-order axes; while coarse ferritic regions with sulfides are inherited from the interdendritic space of the end of solidification.

Forecast of Centerline Segregation Class in the Plate Steel by the Assessment of the Central Heterogeneity in the Continuously Cast Slab

A. Kazakov, E. Kazakova and A. Kur, Peter the Great St. Petersburg Polytecnic University

The central heterogeneity zone in slabs from X70 grade steel and centerline segregation in plate made from these slabs were evaluated. The size of the wide central zone and the volume fraction of segregation freckles in wide and narrow slab central heterogeneity zones were measured. The class of plate centerline segregation was evaluated in accordance with the GB/T 13298 technique. Correlation between centerline segregation class in the plate steel and the character of the central heterogeneity zone in the slab was revealed. A wide segregation zone in a slab always leads to a high class of centerline segregation in the plate at any volume fraction of segregation freckles in the slab central zone. In the absence of a wide zone in a slab, the class of plate centerline segregation is non-linearly increased with an increase of the volume fraction of segregation freckles in the narrow central zone of a slab.

Automatic Storage and Retrieval System (ASRS) for Plates

Jagannathan Rajagopalan, Pesmel; Juha Suksi, Pesmel Oy

Handling of plates, especially thicker and wider plates, is a real challenge in steel plants and service centers. Similarly, when it comes to storage on the floor one above the other as multiple plates, tracking them is a tough task needing multiple duplicate jobs with the least throughput. Modern vertical storage in a totally automatic, automatic storage and retrieval system (ASRS) utilizing the volume/height is the best way to store plates in a very compact space. The main benefits of the vertical storage ASRS for plates are compact storage, automatic in-feed to storage from the mill, easy tracking and sorting, efficient operation with higher throughput, safe handling of plates with no bending, special storage system for wider plates during transportation, totally automatic with no or least manpower, minimum buildings and electric overhead traveling cranes, total safety, quality and assured cost saving per unit handling, and storage of plates. The details with case studies are explained in this paper.

ORGANIZING COMMITTEE

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UPCOMING EVENTS

AIST's 25th Crane Symposium
10–12 June 2018 | The Omni William Penn Hotel, Pittsburgh, Pa., USA

Cold Rolling Fundamentals – A Practical Training Seminar
9–13 September 2018 | Huntsville, Ala., USA

System Automation Fundamentals – A Practical Training Seminar
10–13 September 2018 | Huntsville, Ala., USA

Secondary Steelmaking Refractories – A Practical Training Seminar
22–25 October 2018 | Hyatt House Charleston/Historic District, Charleston, S.C., USA

Continuous Casting – A Practical Training Seminar
8–11 October 2018 | Detroit, Mich., USA

For a complete list, visit **AIST.org**