INTERNATIONAL CONFERENCE ON ADVANCES IN METALLURGY OF LONG AND FORGED PRODUCTS

12–15 JULY 2020
Vail Marriott Mountain Resort • Vail, Colo., USA
Plant Tour: Climax Molybdenum Plants
ABOUT THE PROGRAM
Long and forged products are used in many critical applications, including transportation, energy and heavy equipment. This symposium intends to bring together international and domestic researchers from industry and academia to present on topics related to advances in the physical, mechanical, and product metallurgy of bars, tubes and forgings. Presentations will address new developments in areas such as alloy design, thermal or thermomechanical processing, microstructure control during steel manufacturing or heat treatment, application of alloys to the automotive and energy industries, and various other aspects of physical and mechanical metallurgy affecting manufacture of the raw materials and manufacture and service performance of the final products.

WHO SHOULD ATTEND
The conference should be attended by researchers and engineers interested in steel metallurgy focused on bars, tubes, and forged products who are responsible for the production and implementation of the products in steel mills, automotive facilities, energy products, and other industries, along with government and academic professionals and students.

REGISTRATION
Registration fee includes receptions Sunday–Tuesday, breakfasts and lunches Monday–Wednesday, dinner Tuesday and Conference Proceedings.

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HOTEL ACCOMMODATIONS
A block of rooms has been reserved at Vail Marriott Mountain Resort. Please call the hotel at +1.800.648.0720 or +1.970.476.4444 by 22 June 2020 to secure the AIST discount rate of US$189 per night for single/double occupancy.

PROFESSIONAL DEVELOPMENT HOURS
This course may qualify for up to 19.75 Professional Development Hour (PDH) credits. Each attendee will receive a certificate listing the quantity of PDH credits earned for the course. This course is not approved for PDH credits in New York, Florida, North Carolina and Oklahoma.

ORGANIZED BY
AIST’s Metallurgy – Processing, Products & Applications Technology Committee
Kip Findley and John Speer, Colorado School of Mines
Craig Darragh
Patrick Anderson, TimkenSteel Corp.

SCIENTIFIC ADVISORY COMMITTEE
Kester Clarke, Colorado School of Mines; Doug Wallace, Fiat Chrysler; Chris Easter, Gerdau Special Steel North America; Thomas Sourmail, ASCOMETAL SCHMOLZ + BICKENBACH Group; Matt Kiser, Caterpillar Inc.; Dennis Beuchesne, ECM; Matt Green, Liberty Specialty Steels; Doug Brown, Inductoheat Mass Heating Division; Kirk Baker, Chevron Corp.; Matt Poulter, John Deere; Pedro Rivera, Lancaster University; Goro Miyamoto, Tohoku University; Steve Jansto; Research and Development Resources; Bob Cryderman, Colorado School of Mines; Jose Rodriguez-Ibabe, CEIT; and Robert Glodowski, AMG-Vanadium.
Sunday, 12 July 2020

4–6 p.m.  
Registration

6–7 p.m.  
Reception

Monday, 13 July 2020

7 a.m.  
Registration and Breakfast

8 a.m.  
Introductions and Opening Remarks

8:10 a.m.  
Tailored Steel Microstructures for Fatigue Applications  
Matthias Kuntz, Robert Bosch GmbH

Hybridization and E-mobility requires products that provide reliable solutions for localized fatigue behavior due to the downsizing of components. Therefore, fatigue strength is one of the most important parameters for the successful development of these technologies. Understanding fatigue properties requires knowledge of the damage mechanisms under cyclic loading. Therefore, not only the static strength of a material has to be considered, but also the microstructure, its stability under cyclic loading, and the homogeneity in terms of ductility. In recent years, new steel microstructures such as ultrafine-grained and nanostructured bainitic microstructures have been developed and their fatigue properties have been investigated. These novel steel microstructures show a combination of tensile strength and ductility, which make them promising candidates for good fatigue behavior. Recent work on the tempering behavior of nanostructured bainite has demonstrated the particularly interesting tempering resistance of this microstructure. The present work combines the well-known performances of nanostructured bainitic steels with a secondary precipitation mechanism. These results will be linked to microstructural evolution due to the applied tempering secondary tempering treatment.

8:45 a.m.  
Inclusion Engineering Based on Advanced Quantification Techniques Can Increase the Fatigue Life of a Component  
Patrik Olund, Ovako AB

The advances of ladle metallurgy have led to significant improvements in the internal cleanness of steel products. This development, which started with the design of the first functioning ladle furnaces with effective stirring facilities, has now reached a level where “standard” produced steels could compete with complex and costly remelting processes. Steelmaking advances necessitate corresponding developments in testing procedures, particularly the control of the non-metallic inclusion content in steel. The developments in steel processing will be reviewed and recent progress in the rating of non-metallic inclusions detailed, particularly regarding test methods encompassing ultrasonic techniques, but also automatic scanning electron microscopy and accelerated fatigue testing. Furthermore, recent advances in structural fatigue initiation will be discussed and related to content and morphology of microinclusions. By inclusion engineering, steel can be tailored to meet the increasing demands in critical application.

9:10 a.m.  
Effects of Nickel and Microstructure on Rolling-Sliding Contact Fatigue in Carburized Steels  
Nicholas Novack, Colorado School of Mines

Pits and spalls form under rolling-sliding contact fatigue (RSCF) by initiating as cracks on surface irregularities or subsurface inclusions and propagating below the surface, resulting in mass material removal. Tests were conducted to evaluate the effects of Ni contents in the range of 0.13 to 4.15 wt.% on the RSCF life of atmosphere carburized and hardened 25-mm diameter steel specimens. Surface roughness, microstructures and residual stresses were characterized prior to testing. Each specimen was tested under 3.2 GPa Hertzian contact stress and a -20% slide ratio with an oil lubricant at 100°C to determine the fatigue life. Interrupted tests were conducted to characterize the progression of fatigue damage. Ni content, surface roughness, retained austenite and inclusion content all correlated with the measured RSCF life.

9:35 a.m.  
Development of an Advanced Stainless Carburizing Steel  
Robert Buck, Carpenter Technology Corp.
The need exists for a strong, tough, carburizable stainless steel for high-performance gear and bearing applications exposed to humid or marine environments. Surface-hardened stainless steels not only involve a cumbersome carburization/heat treatment process, but have poor corrosion resistance after carburizing due to the formation of undesirable chromium-rich carbides in the case. Through-hardening stainless steels suffer from low impact and fracture toughness and similarly poor corrosion resistance after heat treatment. The net result is that a hard surface layer in carburized stainless steels is achievable, but corrosion resistance is usually no better than that of carburized alloy steels. A-21 (UNS S41429) is a new martensitic stainless carburizing steel that is designed to create a deep, hard and stainless case while maintaining a strong, tough and ductile core. Salt fog testing shows that A-21 could replace common carburizing alloy steels that are currently coated with ZnNi or Cd for corrosion resistance, thereby eliminating the need to coat, and replace carburizing and through-hardening “stainless” steels with a true stainless steel, thereby improving in-situ corrosion resistance in normal atmospheric, humid and harsh environments.

10 a.m.
Break

10:20 a.m.
The Impact of Steel Cleanness on Gear Fatigue Performance
Peter Glaws, TimkenSteel Corp.
The subject of steel cleanness has been has been a topic of interest for many years for both the steel manufacturer and the steel user. Despite the years of study and numerous publications on the subject, questions remain and interest in steel cleanness has not waned, as indicated by the number of recent papers and conferences dedicated to this theme. Steel manufacturers continue to focus their efforts on further improvement of steel cleanness to meet the increasing quality expectations of their customers, while steel users exploit the opportunities provided by the use of clean steel, incorporating power density concepts into their component design. This presentation considers an industrial example relating steel cleanness to gear performance for highly loaded marine applications.

10:45 a.m.
TBD

11:00 a.m.
Precipitates Control of Anti-Grain Coarsening Low-Alloy Steel for Carburizing
Wen-Fang Chiu, China Steel Corp.
Carburization is widely used for low-alloy steel in order to achieve adequate surface hardness as well as good core toughness. However, with the high temperature and long duration time of the carburizing process, abnormal grain coarsening of steel is harmful for mechanical properties and lifetime of parts. In this study, anti-grain coarsening low-alloy steel was developed under the carburizing demand. Thermal mechanical processes were performed in order to achieve the suitable manufacturing process. Appropriate precipitates control such as AlN, Nb(C, N) was investigated through the effect of volume fraction, size and distribution of precipitates on grain coarsening. Abnormal grain growth can be effectively inhibited in the developed steel during carburizing, which could increase carburization efficiency without sacrificing mechanical properties.

11:30 a.m.
Alloy Design and Processing Strategies for Grain Coarsening-Resistant Carburizing Steels
Hardy Mohrbacher, NiobelCon bvba
Grain size is one of the most important parameters with regard to the properties of steel. For obtaining best performance, grain size should be small, and its distribution should be as homogeneous as possible. Smaller grain size provides higher strength, increased toughness and better fatigue endurance. The presence of individual large grains has negative effects and can lead to significant residual stress in quenched steels. The final grain size distribution in steels subjected to a carburizing treatment is the result of all prior heat treatment and forming operations. Traditionally, AlN precipitates are used for restricting austenite grain coarsening during carburizing treatments. However, at high carburizing temperature, AlN particles start dissolving and the pinning effect is lost. Microalloy carbo-nitride precipitates of Nb and Ti have better temperature stability than AlN and thus allow high-temperature carburization. However, it is important to establish a suitable particle population before and during the carburizing treatment. This requires a cradle-to-grave analysis of the microalloy precipitation. Recommendations will be given on alloy design and processing strategies for coarsening-resistant carburizing steels.
Formation Mechanism of Coarse Austenite During Cooling After Hot Forging for Case-Hardening Steels
Takeshi Miyazaki, Sanyo Special Steel Co. Ltd.

Case-hardening steels are used for gears and shafts for automotive and industrial components, and hot forging is mainly employed to fabricate these parts. In general, normalizing is applied after hot forging to obtain uniform, fine ferrite and pearlite microstructure, but omission of normalizing is required for cost saving. Formation of coarse austenite grain during cooling from the forging temperature often causes abnormally coarse pearlite and bainite microstructure. This abnormal microstructure results in coarse and inhomogeneous distribution of austenite grain size in the following carburizing process. Thus, it is necessary to avoid the formation of coarse austenite grain during forging and subsequent cooling for omission of normalizing. In the present study, austenite microstructure formed during forging and cooling process was investigated under various forging conditions by a thermomechanical simulator for JIS Scr420 (0.2C-0.3Si-0.8Mn-1.0Cr, in mass%), SCM420 (Scr+0.2Mo) and SCM420-Nb (Scr+0.2Mo+0.04Nb).

An Application of Nb-Ti Microalloying for Carburizing Steels
Rafael Stella Galdino, Gerdau Special Steel Brazil

The aim of this paper is to evaluate the microstructure evolution throughout the manufacturing chain of hot-forged carburized gears. A standard aluminum-refined steel (DIN 16MnCrS5) was compared to a Nb-Ti microalloyed steel with the same base composition. A significant austenitic grain refinement (36%) was achieved for the Nb-Ti microalloyed steel after carburizing at 930°C for 7 hours, reaching 11 µm. Grain size distributions showed that standard steel presented a higher amount of large grains compared to microalloyed steel. Both steels were tested at high-temperature carburizing (up to 1,050°C for 2 hours), and aluminum-refined steel presented abnormal grain growth. Nb-Ti microalloyed steel maintained good grain size stability for standard and high-temperature carburizing.

The Development of Non-Normalizing Hot-Forged Steels for CV Joints
Herng-Shuoh Jang, China Steel Corp.

Normalizing is a heat treatment used to produce smaller and more uniform grain size in some steel grades. Especially for the workpieces before quenching and tempering treatment or induction case-hardening, normalizing must be carried out after hot forging to improve uniformity and match the high precision requirements. However, the application of normalizing heat treatment significantly increases the production cost and period. The non-normalizing hot-forged steels were accordingly developed and attracted considerable attentions. Through introducing a few precipitates distributed in the austenite matrix, the grain growth is effectively inhibited and the following normalizing process can be removed. In this research, a medium-carbon steel with niobium precipitates was developed and successfully applied in hot-forged workpieces, which can be treated by induction case hardening with a prior grain size of G#5-8.

Characteristics of Mo-Nb Carbide Precipitates During High-Temperature Vacuum Carburizing
Eunjung Seo, Colorado School of Mines

High-temperature vacuum carburizing dramatically reduces carburizing time and production cost, but abnormal austenite grain growth at high carburizing temperature can result in degradation of the fatigue properties. It was previously shown that the addition of Mo in combination with Nb more effectively suppressed the abnormal grain growth at high carburizing temperature conditions (>1,050°C) when compared with additions of Al and N or Nb alone. In this study, electron microscopy techniques were utilized to characterize the structure and properties of the microalloy precipitates, especially Mo-Nb carbides and Al nitrides, in order to elucidate their effects on the microstructure evolution during the thermal treatments.

Direct Quench Steel for Forged Parts, Bruno Cofino
Bruno Cofino, ArcelorMittal Global R&D Bars and Wires

Some conventional forged parts are made usually of quenched and tempered (Q+T) steels such as 42CrMo4 in order to obtain a good agreement in term of mechanical properties between ultimate tensile strength (UTS) and toughness. The need to reduce the different process steps to reach the final product
in order to reduce the cost and environmental impact led to the research of metallurgical solutions to reach a high level of toughness and UTS without the Q+T process. Thanks to its auto-tempering behavior, leading to a mixture of low-carbon fresh martensite and auto-tempered martensite, a low-carbon alloyed grade can reach in as-quenched state an impact toughness three to four times higher than conventional Q&T steels with high UTS (1,400–1,500 MPa). In addition, process robustness is excellent with repeatable microstructure and mechanical properties regardless of the cooling rate used, as long as a fully martensitic microstructure is guaranteed over a critical cooling rate. As a result, an improved toughness at high-UTS grade was obtained via a simple and robust process.

3:25 p.m.
**Relationship Between Strength, Fracture Toughness and Microstructure of a Multi-Stage Heat Treatment of Low-Carbon, Copper Precipitation-Strengthened, HSLA Steel**
Ricardo Gomes, Colorado School of Mines
For design and research and development of Cu containing low-carbon, high-strength, low-alloy (HSLA) steels, strength and impact toughness have been of primary importance. The effect of various heat treatments on the interrelated strength and toughness performance has been explored in several studies. However, subsea forgings used as thread connectors for oil and gas exploration also require fracture toughness as a design metric. Thus, this research is focused on developing heat treatment approaches to optimize strength and fracture toughness, measured with crack tip opening displacement, in a low-carbon, Cu-containing, 90-ksi HSLA steel. The heat treatment schedules are designed to vary the effective grain size, intercritical annealing and aging parameters.

3:50 p.m.
**Development of a High-Strength, Ultratough Alloy Steel for Powertrain, Energy and Aerospace Applications**
Robert Buck, Carpenter Technology Corp.
The performance of alloy steels used in aerospace, transportation and energy applications are generally limited because of strength, toughness, fatigue, ductility and/or operating temperature. In directional drilling applications, for example, the rate of penetration is primarily limited by the strength, fatigue limit and toughness of critical mud motor components. Some transportation applications would benefit from increased strength and toughness, but also necessitate the ability to be carburized for increased localized wear resistance. And some carburized aerospace alloy steel components could benefit by a higher operating temperature to permit high temperature coating techniques. The various aforementioned limitations affect component design that may conflict with design criteria such as space availability, weight limitations, endurance limits and cost restrictions. Clearly there is a need for a stronger, tougher, cost-effective alloy steel that can be carburized and tempered at a relatively high tempering temperature. UNS K52260 has been developed to provide an alternative to conventional quenched and tempered alloy steels and carburizing alloy steels. Results from both gas carburizing and vacuum carburizing trials indicate that UNS K52260 can be successfully carburized to case hardnesses of 61 Rc or higher while exhibiting high strength, good ductility, high core hardness and excellent CVN impact toughness after being tempered at 525°F. Additional carburization and mechanical property data will be presented.

4:15 p.m.
**Design of High-Strength and High-Toughness Quench and Low-Temperature Tempered Steels Using Integrated Computational Materials Engineering**
E. Buddy Damm, TimkenSteel Corp.
Steels with 0.25–0.35 wt.% carbon can achieve strengths in excess of 175 ksi when tempered below 500°F. Low-temperature tempering (LTT) also provides a greater degree of work-hardening capacity, and therefore better damage tolerance compared to high-temperature tempered steels of similar strengths. The strengths achieved with LTT greatly surpass steels typically tempered at 900°F or above; however, reasonably high-impact energies (>25 ft-lbs) are needed to take advantage of these steels. Through the integration of computational models, laboratory experiments and mill trials, these new steels are being developed. High-throughput computational models in conjunction with extensive historical production processing records facilitate the rapid exploration of alloy composition space and identification of promising candidate alloys. Yield strengths in excess of 175 ksi, in combination with impact energy >25 ft-lbs are being targeted in alloy design efforts.

5-6 p.m.
**Reception**
Tuesday, 14 July 2020

7 a.m.
Registration and Breakfast

8 a.m.
Innovative Concepts for Developing Tough Ductile Ultrahigh-Strength Martensitic/Bainitic Steels Containing Finely Divided Retained Austenite
Mahesh Somani, University of Oulu
The University of Oulu in collaboration with its industrial partners has embarked on a program to establish novel processing routes with the specific aim of developing tough ductile ultrahigh-strength steels (YS >1,100 MPa). Two different strategies have been adopted. The first strategy is based on the principles of quenching and partitioning process, whereby a novel processing route comprising thermomechanical rolling followed by direct quenching and partitioning has been developed, aided by physical and laboratory rolling simulations of suitably designed 0.2–0.4C steels based on high silicon and/or aluminum content. Desired martensite-austenite microstructures were achieved, thus providing the targeted mechanical properties. The second strategy is to achieve bainitic transformation in high-Si/Al medium-carbon steels at temperatures close to Ms temperature in order to get highly refined bainite-austenite microstructures at nanometer level. However, this calls for a large number of nucleation sites, achievable only through ausforming at very low temperatures.

8:35 a.m.
TBD

9 a.m.
Hydrogen Embrittlement of 4340 With Martensitic and Bainitic Microstructures for Fastener Applications
Dane Hyer-Peterson, CAMPOS EPC
The hydrogen embrittlement (HE) resistance of martensitic and bainitic microstructures was evaluated in a range of hardness levels relevant to large fastener applications. Alloy 4340 was processed via quench and tempering, austempering, and austempering and tempering to achieve martensitic, bainitic and tempered bainitic microstructures. Bulk hardness, smooth-sided and notched round bar tensile testing were used to evaluate mechanical properties, while dilatometry, electron microscopy and x-ray diffraction were utilized to characterize the various microstructures. Hydrogen embrittlement was assessed via incremental step-load testing of notched tensile specimens in 3.5% NaCl with concurrent cathodic polarization at an applied current density of 0.1 mA cm⁻². Hydrogen embrittlement susceptibility increases with increasing strength or hardness, with some microstructural effects. The austempered bainitic conditions are more susceptible to hydrogen than the martensitic conditions for a given yield strength. The highly tempered bainitic condition offers improvement in Kth over a comparable hardness/strength martensitic condition. The more HE-resistant materials fail at high stress intensities, via transgranular cracking, while the greatest strength conditions exhibit intergranular cracking along prior austenite grain boundaries at a similarly low Kth. Intergranular fracture along austenite grain boundaries presents a lower bound limit for Kth.

9:25 a.m.
Enhancing Properties of Bainitic Steel SOLAM® B1100 During Manufacturing of Forged Parts
Bruno Cofino, ArcelorMittal Global R&D Bars and Wires
Air-cooled cementite-free bainitic (CFB) steels are increasingly being considered as substitutes to quenched and tempered (Q&T) martensitic steels or precipitation hardened ferrite-pearlite steels for the production of automotive hot-forged parts. However, for some applications, bainitic steels struggle to compete with Q&T steels because of their relatively lower impact toughness and yield strength (YS)/ultimate tensile strength (UTS) ratio in the as-forged state. Based on a comprehensive study of the mechanisms controlling YS and impact toughness of hot-forged bainitic steels, a simple but efficient blown air cooling pattern has been developed to improve significantly both impact toughness and YS/UTS ratio in the as forged state. SOLAM® B1100, one of the ArcelorMittal's bainitic steels family developed for high-performance hot-forging applications, exhibits a large bainitic domain. High-performance steels allow lightweight design, which results often in more complex shapes linked to optimization of the performances of parts. Trials using a semi-industrial pilot to blow air on different parts with complex geometry have proved that obtained impact toughness and yield strength are significantly higher and even more homogeneous with an optimized cooling pattern than after still air cooling.
Advances in Equipment Design for Temperature-Controlled Rolling and Comparison of Operational With Simulated Results Through Thermomechanical Processing of Long Products
Michael Kruse, Friedrich Kocks GmbH & Co. KG

Thermomechanical processing offers a high potential for product improvements with resulting benefits for the downstream industry. Using the example of a recently installed rolling mill, this paper describes several thermomechanically processed materials on the basis of achieved technological results and microstructures. In order to illustrate the process and microstructure control of the entire process, these results are put in comparison with the results modeled through a simulation program prior to the rolling procedure. An account of the simulation program’s flexible application possibilities concludes this part. The second part illustrates advances in water box design. Especially in contrast to existing ones, this new design offers increased flexibility as well as high-precision cooling in combination with a new automation and control concept.

Thermomechanical Rolling of H Beams
Ronaldo Barbosa, RBM Engenharia

H structural steels are rolled from beam blanks or billets depending on the product size. In general, the hot rolling schedule for large size beams occurs in three stages: sizing, roughing and finishing. Medium sections, 100 to 600 mm are rolled in reversible, semi-continuous or continuous mills with intermediate and final cooling. Super heavy sections, 600 to 1,000 mm, are mostly rolled in reversible mills with finishing cooling. This paper analyzes the physical metallurgy regarding the thermomechanical processing of H-beams rolling. C-Mn and microalloyed steels were used to test possibilities in terms of the stages of hot rolling. Dissolution and precipitation of Nb(C, N), recrystallization, pancaking, phase transformation and mechanical properties are considered. A discussion is presented aiming at highlighting improvements in the hot rolling schedule and consequences to mechanical properties.

Different Functions of Nb in Medium-C Long Products During Hot Rolling
Jose Rodríguez-Ibabe, CEIT and University of Navarra

The application of Nb as a microalloying element in medium-carbon grades introduces new opportunities in the austenite conditioning during hot rolling of bars and rebars. In addition to its classical solute drag effect by modifying recrystallization kinetics, the lower solubility of Nb, as carbon content increases, opens the opportunity to "modulate" austenite grain growth during reheating prior to rolling but also after last rolling pass before transformation. This control of grain growth at the exit of hot rolling can occur in statically or metadynamically recrystallized microstructures, both of them depending on the rolling strategy characterized by very short interpass times. This work analyzes these aspects, including also the effect that hot charging could have in the ratio of dissolved/precipitated Nb before rolling.

Modeling of Austenite Evolution During Hot Rolling of Medium-High C Long Products
Beatriz Lopez, CEIT and University of Navarra

Modeling of austenite evolution of Nb microalloyed grades with medium-high C contents, combined with different rolling strategies associated with long products, is not a mere extrapolation of classical thermomechanical processing of low-carbon flat products. This paper analyzes how this approach has been done for the case of carbon contents ranging from 0.2 to 1%. The model incorporates the different effects of Nb on austenite evolution from pass to pass taking into account the singularities of these higher-carbon-content grades’ rolling schedules. The model allows for evaluating how this microalloying can help in the achievement of proper austenite microstructures before transformation.

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Global Process and Physical Metallurgy Technological Developments in Niobium-Containing Long Products and Forging

Steven Jansto, Research and Development Resources

The connection between process and physical metallurgy is evolving through the integration of research that is aimed at improving product quality in both long products and forgings. This increased demand for the production of higher toughness, improved fatigue resistance and higher-strength, value-added, quality Nb-containing long product and forging steel grades is linked to the changes in the process metallurgy of Nb-steelmaking, ladle metallurgy, continuous casting, reheat furnace practices and thermomechanically controlled process hot rolling. This advanced integrative process/physical metallurgical (IP/PM®) approach is applicable in commodity rebar, earthquake-resistant rebar, structural infrastructure and bridge beam sections, angles and channels, and power transmission special bar quality automotive products.

Effect of Compressive Stress on Diffusional Transformation in 0.5%C Spring Steels With Different Austenite Grain Sizes

Rintaro Ueji, National Institute for Materials Science

The effect of stress on the isothermal pearlite transformations in a high-carbon spring steel, SAE9254 (0.53wt.%C-1.48%Si-0.76%C-0.70%Mn-bal.Fe), was studied in order to understand the relation between hardenability and stress. The spring steel samples were austenitized at different temperatures to change the austenite grain size, and then cooled down to 823 K, followed by isothermal holding to examine the dilatometry under various compressive stresses. The results shows that, if an applied stress is much larger, the incubation time becomes shorter with larger austenite grain size, indicating that the larger grain size provides more negative effect of stress on the hardenability. The methodology for the dilatometry under the applied stress will be exhibited and the possible mechanism for the interaction between stress and diffusional phase transformation will be discussed.

Residual Stresses and Hardness Development in Annealed, Cold-Rolled and Stress-Relieved Flat Steel Wire

Clarissa Gallardo, Colorado School of Mines

Flat steel wires used as armoring for oil and gas pipelines are susceptible to stress corrosion cracking and hydrogen embrittlement because of residual stresses developed during manufacturing. Annealed, cold-rolled and stress-relieved bars were studied. Residual stress profiles were determined with the hole-drilling method, and hardness maps were completed across the cross-section of each bar.

Effect of Al Content on Intermittent Turning Wear

Ryosuke Ohashi, Daido Steel Co. Ltd.

In order to reduce the manufacturing cost, it is important to improve the machinability of steel. Regarding the influence of chemical compositions on tool wear, there are few reports on intermittent cutting, only on Si. However, the increase in the Si content has the disadvantage that the tool wear deteriorates during continuous cutting because the material hardness increases. In this study, three samples of carbon steels based on JIS-40C with different amounts of Al were examined after forging and normalization. The increase in Al suppressed the flank wear depth of the tool. When Al was added, an Al oxide film was formed on the surface of the tool. In two-dimensional intermittent turning, the friction coefficient did not change with an increase of Al content. The suppression of flank wear depth by increasing Al might be due to improved resistance to adhesion wear and diffusion wear caused by the increased stability of the oxide film.

Investigation of Coarse Boron Nitride Formation Window in Creep-Resistant Martensitic Forged Products

Drew Huck, Carnegie Mellon University

Boron and nitrogen have become increasingly important in modern steels to impart greater creep resistance in forged products for elevated temperature applications. During solid-state processing, these two elements can combine under certain conditions and form coarse boron nitrides (BN), which can negatively impact properties and decrease the effect of these elements on creep resistance. This study uses thermodynamic calculations and laboratory-scale heat treatments to establish a temperature, time and composition window for BN stability.
during secondary processing of an aerospace alloy. The results will enable process optimization to minimize the risk of BN formation.

2:55 p.m.
**Root-Cause Analysis of Rotary Crop Shear Lower Drum Failure**
James Pellegrino, RJ Lee Group Inc.
The results of a laboratory investigation to determine the root cause of the rotary crop shear lower drum failure in a new US$2B+ rolling mill revealed that the failure was defect-governed and related to material quality. Specifically, the failure, which initiated at the section change radius of the blade slot, was as a single-event brittle fracture. The fracture initiated at a very small fatigue crack in the section change radius of the corroded blade slot in the lower drum, which exhibited poor fracture toughness because of improper heat treatment and contained a large volume of MA phase platelets. The presence and size of the MA platelets adversely impacted the mechanical properties (ductility and toughness) of the drum barrel. Because of the location, the manufacturer used for the QA tests did not realize that the forging did not meet the requirements of the governing specification.

3:20 p.m.
**Latest Developments in Abrasive Cutting and Grinding of Long Rolled Products and Large-Scale Forgings**
Norbert Asamer, Braun Maschinenfabrik
At various stages during their manufacturing processes — from casting to finishing before delivery — semi-finished steel and special alloy products must be cut and surface-treated as well. The requirements for the individual conditioning steps, however, can be quite different. For example, the workpiece can be hot, warm or cold. At any rate, the product must always be perfectly prepared for the next manufacturing step — reliably, in the shortest possible time and at the lowest-possible cost. For cutting and grinding, BRAUN has developed innovative technologies and highly flexible, tailor-made solutions which meet these requirements in the most optimal way. In particular, BRAUN’s cutting and grinding technologies can also be used for large-scale products.

3:45 p.m.
**Effects of B Addition and Cooling Rate on Charpy Impact Properties in Medium-Carbon Steels**
Sukjin Lee, Colorado School of Mines
The addition of small amounts of boron along with enough titanium to prevent free nitrogen is used to achieve high hardenability in medium-carbon steels while minimizing the need to add expensive alloys. The effects of a boron addition and cooling rate on Charpy impact properties were investigated in medium-carbon steels. Steels of compositions similar to SAE 4130 with and without boron were austenitized at 870°C and cooled at rates of 870, 110 and 25°C·s^{-1} to simulate quenching of light, medium and heavy sections. Prior austenite grain size (PAGS) was measured, boron segregation was determined using nano-SIMS, and Charpy impact tests were conducted. The PAGS were the same within error ranges in the all steels regardless of the different cooling rates. Boron segregation and precipitation of boro-carbides increased with decreasing cooling rate. Impact test results are compared with the cooling rate and the presence of boron and boro-carbides in the prior austenite grain boundaries.

4:10 p.m.
**Nitriding and Ferritic Nitrocarburizing of Quench and Tempered Martensitic Steels**
Mei Yang, Worcester Polytechnic Institute
A physics-based software model is being developed to predict the nitriding and ferritic nitrocarburizing (FNC) performance of quenched and tempered martensitic steels. The microstructure of the nitrided and FNC steels is comprised of a white compound layer of nitrides and carbides below the surface with a hardened diffusion zone that is rich in nitrogen and carbon. The composition of the compound layer is predicted using computational thermodynamics to develop alloy-specific nitrogen potential KN and carburizing potential KC phase diagrams. The thickness of the compound layer is predicted using parabolic kinetics. The diffusion in the tempered martensite case is modeled using diffusion with a reaction and diffusion with trapping mathematics. Diffusion paths are also developed on these isopleths. These model predictions are compared with experimental results.
Post-Process Heat Treatment of Additively Manufactured Steels

Mei Yang, Worcester Polytechnic Institute

Steel alloys of 8620, 5160 and M2 have been formed from powder by selective laser melting. The microstructure and mechanical properties of these alloys are tested along with wrought versions of the same alloys to determine if the heat treating performance was similar. The as-additively manufactured (AM) microstructure for each steel was observed to be tempered martensite. The as-received wrought was mostly ferrite and pearlite. After normalizing, the microstructures were similar. Porosity was observed in the AM steels while inclusions were observed in the wrought alloys. A lower carbon concentration was measured in the AM steels due to decarburization during the laser melting. The carburization performance of the normalized AM and wrought alloys was similar with some variations in total carbon flux. In addition, the tensile and impact properties were measured. The results are discussed in terms of microstructural variations.

Wednesday, 15 July 2020

7 a.m.
Registration and Breakfast

8 a.m.
Transportation and Heavy Equipment Panel Discussion

9 a.m.
Break

9:15 a.m.
Energy Panel Discussion

11 a.m.
Lunch

Noon
Plant Tour of Climax Molybdenum Plants 🏭

4 p.m.
Return From Plant Tour and Adjourn Conference
UPCOMING EVENTS

27th Crane Symposium
7–9 June 2020
Omni William Penn Hotel
Pittsburgh, Pa., USA

Maintenance Solutions: Fundamentals and New Frontiers
15–17 September 2020
Embassy Suites San Antonio Riverwalk
San Antonio, Texas, USA

Secondary Steelmaking Refractories — A Practical Training Seminar
6–8 October 2020
Holiday Inn Nashville Vanderbilt
Nashville, Tenn., USA