LMPC 2017

Liquid Metal Processing & Casting Conference 2017

September 10-13, 2017
Hyatt at The Bellevue
Philadelphia, Pennsylvania, USA

CONFERENCE PROGRAM

SPONSORED BY:

TMS
The Minerals, Metals & Materials Society

TMS Materials Processing & Manufacturing Division (MPMD) and the Process Technology & Modeling Committee

www.tms.org/LMPC2017

THANK YOU TO OUR CORPORATE SPONSORS AND EXHIBITORS!

PLATINUM SPONSORS

AMG
ALD

AMERICAN FLUX & METAL

CONSARC
An Inductotherm Group Company

SILVER SPONSOR

ECM USA inc
VACUUM FURNACES

BRONZE SPONSORS

Innovative Research, LLC
Engineering Productivity via Computational Flow Modeling

WACKER

EXHIBITORS

AmpSci

STROHECKER Incorporated

Thermo-Calc Software

TABLE OF CONTENTS

WELCOME TO LMPC 2017

Dear Attendees,

Thank you for joining us here in Philadelphia for the Liquid Metal Processing & Casting Conference (LMPC 2017)! As some of you may know, this international forum takes place every two years. It was last held in Leoben, Austria, in 2015, and in Austin, Texas, USA, in 2013.

This unique symposium will showcase the latest technological and scientific advances related to processing and casting industrially relevant metals. As attendees, you will benefit from hearing both academic and industrial perspectives on topics including advances in controls, process simulation, ingot defect formation, and characterization studies.

We hope you make the most of your time at LMPC 2017. Over the next three days, take the opportunity to learn from technical presentations, network at social events, and connect with companies working in your field at the exhibit. This program will act as your guide to all of the meeting's activities, so keep it on hand for reference.

Thank you again for joining us at LMPC 2017, and enjoy your stay in Philadelphia!

Sincerely,

LMPC 2017 Organizing Committee

ORGANIZING COMMITTEE

LOCAL ORGANIZERS

Chair
- Stuart Rudoler, American Flux & Metal, USA

Co-Chairs
- Andrew J. Elliott, Consarc Corporation, USA
- Ashish Patel, Timet, USA

TECHNICAL ORGANIZERS

Co-Chairs
- R. Mark Ward, University of Birmingham, United Kingdom
- Matthew J.M. Krane, Purdue University, USA

SCIENTIFIC COMMITTEE

- A. Stewart Ballantyne, MeltMet Technologies LLC, USA
- Joseph J. Beaman, University of Texas at Austin, USA
- Jean-Pierre Bello, Institut Jean Lamour Nancy, France
- Harald Holzgruber, INTECO GmbH, Austria
- Alain Jardy, Institute Jean Lamopur, CNRS/ Universite de Lorraine, France
- Zhouhua Jiang, Northeastern University, China
- Koji Kajikawa, Japan Steel Works, Japan
- Abdelleh Kharicha, Montanuniversität Leoben, Austria
- Matthew J.M. Krane, Purdue University, USA
- Henry Lippart, ATI Allvac, USA
- Alec Mitchell, University of British Columbia, Canada
- Ashish Patel, TIMET, USA
- R. Mark Ward, University of Birmingham, United Kingdom
- Rodney L. Williamson, University of Texas at Austin, USA

ABOUT THE CONFERENCE

REGISTRATION

Your full-conference registration badge provides admission to each of the following events:

- Technical and poster sessions
- Sunday evening welcome reception
- Monday poster reception
- Monday evening conference banquet*
- Morning and afternoon refreshment breaks during session intermissions

**Please note that while one ticket for the conference banquet is included, registration was required for this event through the conference registration form. Check at the registration desk (Grand Ballroom Foyer, first floor) for more information.*

The registration desk will be located in the Grand Ballroom Foyer on the first floor and will be open during the following hours:

Sunday, September 10: 5:00 p.m. to 8:30 p.m.
Monday, September 11: 7:00 a.m. to 5:15 p.m.
Tuesday, September 12: 7:30 a.m. to 5:15 p.m.
Wednesday, September 13: 7:30 a.m. to Noon

INTERNET ACCESS

Guests staying at the Hyatt at The Bellevue enjoy free Wi-Fi for an unlimited number of devices in guest rooms and social spaces. All Hyatt Gold Passport® Diamond and Platinum members will receive a complimentary upgrade to premium Wi-Fi service when visiting Hyatt at The Bellevue.

TECHNICAL SESSIONS

All oral presentations will be held in the Grand Ballroom on the first floor of the Hyatt at The Bellevue. See the technical program on pages 17-27 for room locations.

KEYNOTE ADDRESS

The keynote address on Monday, September 11, will feature the following presentation:

Mary Lee Gambone
Head of Materials Engineering—Indianapolis, Rolls-Royce North America
"An Aeroengine Manufacturer View of Opportunities and Challenges in the Metals Industry"

Mary Lee Gambone is currently head of the Rolls-Royce Materials Engineering organization in Indianapolis and has worked in aerospace materials for more than 30 years. Since joining Rolls-Royce in 1998, she has held several roles, including Chief of Research and Technology Strategy and Manager of Critical Part Lifing. Her early career as a materials engineer was with the Allison Gas Turbine Division of General Motors, and she enjoyed several years with the U.S. Air Force as team lead for metal matrix composites research in the Air Force Research Laboratory, Materials Directorate. Gambone earned a B.S. in metallurgical engineering from Purdue University, a M.S in materials engineering from the Massachusetts Institute of Technology, and a Ph.D. from the University of Virginia in materials science.

PROCEEDINGS

Full-conference registrants will receive one printed copy of the proceedings, which also includes an electronic version of the proceedings on a USB drive.

NETWORKING & SOCIAL EVENTS

The **Welcome Reception** will be held on Sunday, September 10, from 7:00 p.m. to 8:30 p.m. in the Conservatory on the 12th floor of the Hyatt at The Bellevue.

A **Poster Reception** is planned for Monday, September 11, from 5:15 p.m. to 6:30 p.m. in the Grand Ballroom on the first floor of the Hyatt at The Bellevue.

The **Conference Banquet** will follow the Poster Reception on Monday, September 11, from 7:00 p.m. to 9:30 p.m. in the Rose Garden on the 19th floor of the Hyatt at The Bellevue. Please note that while one ticket for the conference banquet is included, advance registration was required for this event through the conference registration form. Check with TMS staff at the registration desk (Grand Ballroom Foyer, first floor) for more information.

SOCIAL FUNCTION

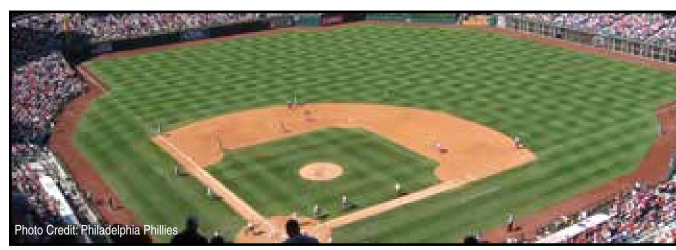


Photo Credit: Philadelphia Phillies

Philadelphia Phillies Baseball Game
Game Date: Tuesday, September 12
Game Start Time: 7:05 p.m.
Game Location: Citizens Bank Park

Tickets are required for this event and should have been purchased in advance through the LMPC 2017 registration form. Please also note that the conference has not arranged for transportation to and from Citizens Bank Park. If you are planning on attending the baseball game, plan on using public transportation or coordinate with other attendees.

A highlight of LMPC 2017 are two half-day facility tours on the afternoon of Wednesday, September 13. Tickets were required for both tours through the conference registration form. For information on availability of tour tickets, check at the registration desk (Grand Ballroom Foyer, first floor) for more information.

TOUR OPTIONS

AMERICAN FLUX & METAL

Tour Time: Noon to 4:00 p.m.
(times are approximate)
Transportation Details:
Bus departs from hotel lobby

Your tour ticket will include transportation to and from the facilities in Hammonton, New Jersey, and an overview of the following technologies:

- ESR Flux—production of prefused flux, including blending, melting, crushing, sizing and packaging.
- Molybdenum—refining of molybdenum trioxide to 99.95% pure molybdenum powders and pellets using hydrogen reduction and sintering furnaces.

CONSARC
An Inductotherm Group Company

Tour Time: Noon to 6:00 p.m.
(times are approximate)
Transportation Details:
Bus departs from hotel lobby

Your tour ticket will include transportation to and from the facilities in Rancocas, New Jersey, and will show you firsthand how products at the Inductotherm Group—made up of 40 full-service companies including Consarc Corp. and Inductotherm Corp.—come together. Learn more about each facility:

- Consarc Corporation specializes in vacuum and controlled atmosphere melting and makes furnaces and related systems for vacuum induction melting (VIM), vacuum arc remelting (VAR), electroslag remelting (ESR), vacuum precision investment casting (VPIC), induction skull melting (ISM), as well as specialty furnaces for proprietary processes.
- Inductotherm Corporation is the worldwide leader in induction technology with a focus on induction melting, heating, holding, pouring and coating systems.

The exhibition will be located in the Grand Ballroom on the first floor of the Hyatt at The Bellevue.

Monday, September 11

Set-Up: 7:00 a.m. to 8:00 a.m.
Exhibit Hours: 8:15 a.m. to 6:15 p.m.
Poster Session and Reception:
5:15 p.m. to 6:30 p.m.

Break from 10:00 a.m. to 10:40 a.m. and 2:50 p.m. to 3:30 p.m.

Tuesday, September 12

Exhibit Hours and Poster Session:
8:15 a.m. to 5:10 p.m.

Break from 10:00 a.m. to 10:40 a.m. and 2:50 p.m. to 3:30 p.m.

Wednesday, September 13

Exhibit Hours and Poster Session:
8:15 a.m. to noon
Exhibit Removal: noon to 1:00 p.m.

Break from 10:00 a.m. to 10:40 a.m.

Thank you to the following Corporate Sponsors and Exhibitors for their generous support of the conference:

PLATINUM SPONSORS

ALD Vacuum Technologies
ALD is the world's leading provider of VIM, ESR, VAR, EB, and plasma cold hearth remelting furnaces used to cast large ingots of superalloy, titanium, and engineered alloys for forging and further processing. ALD has provided over 2,000 furnaces worldwide and is the only technology/equipment supplier that supplies all applicable technologies serving the aerospace industry's vacuum metallurgy needs. ALD also provides furnaces for net shape investment casting, gas atomization, master melts, hot isothermal forgings, EB/PVD thermal barrier coatings, and other special applications. ALD's presentations at LMPC 2017 will discuss advancements in plasma melting of titanium, ESR process control, and levitation melting. http://ald-vt.com/cms/en/

AMERICAN FLUX & METAL

American Flux & Metal
AF&M provides ESR Flux and Molybdenum to the aerospace, chemical and automotive industries. We are the world's largest producer of specialty ESR flux, a chemical refining agent used to produce high performance superalloys. Our Molybdenum products are also used in superalloys, as well as for the coatings on automotive parts and as catalysts in the production of chemicals.

CONSARC
An Inductotherm Group Company

Consarc Corp.
Consarc Corporation, an Inductotherm group company, is celebrating 55 years as a manufacturer of vacuum furnaces. Consarc designs and manufactures furnace systems for a variety of metallurgical processes, including: vacuum arc remelting, electroslag refining, vacuum induction melting, vacuum precision investment casting, induction skull melting, vacuum brazing, and vacuum heating (graphite hot zones, metallic hot zones, and induction heated to 3,000˚C). Consarc is ISO 9001-2015 certified, and with operations on five continents, is well equipped to tackle fully customized furnace projects globally.

SILVER SPONSOR

ECM USA Inc
VACUUM FURNACES

ECM
ECM USA Inc. is the world leader in low pressure vacuum carburizing and high pressure gas quenching furnaces. ECM's implementation of these heat treat systems has added flexibility, safety, reliability, and cost savings to our customers. Our innovations have led to designs that offer solutions to captive in-line systems or compact systems with specific requirements. With experience and innovation, ECM USA Inc. can take your heat treating into the future.

BRONZE SPONSORS

Innovative Research LLC

Innovative Research LLC offers software products MeltFlow-VARTM and MeltFlow-ESRTM for comprehensive simulation of the vacuum arc remelting (VAR) and electroslag remelting (ESR) processes. These software tools utilize advanced process-specific computational fluid dynamics (CFD) models for detailed and efficient analysis of electromagnetic, flow and thermal phenomena to predict pool evolution, thermal history, macrosegregation and metallurgical structure in the ingots produced. Leading specialty metals companies are using these tools for cost-effective process improvements to produce superior quality ingots of superalloys, steels, and titanium alloys.

Wacker

Wacker (www.wacker.com) is a globally active chemical group headquartered in Munich, Germany. With a wide range of state-of-the-art specialty products, Wacker is a leader in numerous fields and industries. Its products are required in countless high-growth end-user sectors, such as photovoltaics, electronics, pharmaceuticals and household/personal-care products. In 2016, the Group generated sales of some €5.4 billion, operates 26 production sites and maintains subsidiaries and sales offices in 31 countries across the globe. Wacker can look back on a long tradition in the development and production of premelted electroflux products and fluxes. All product workflows, from development through raw materials procurement to production and shipping, are subject to quality assurance checks and are described in an Integrated Management System manual.

EXHIBITORS

AmpSci

Born from the DOE's National Energy Technology Laboratory, Ampere Scientific was formed by the inventors of VARmetricTM to deliver robust, industrial hardened systems for VAR and ESR operations and to provide real-time process dynamic measurements that lead to better product quality measures. Ampere Scientific manufactures the award winning VARmetricTM arc position sensing technology, which combines standard process signals with magnetic field flux measurements to provide unparalleled levels of process information during VAR and ESR melting. VARmetricTM allows operators to monitor arc location during melting in real-time, identifying deleterious operating conditions, providing a mechanism to avoid conditions that lead to unsafe operations, defect formation and sidewall integrity, thereby increasing the quality and yield in reactive, ferrous and nickel-based alloys.

Strohecker

Well-established specialist in the fabrication and repair of copper crucibles, hearths and related equipment used in VAR, ESR, EBM, PAM, as well as various similar processes. Serving producers of the reactive metals and alloys, nickel alloys, refractory metals, and steel alloys.

Thermo-Calc Software

A leading developer of software and databases for calculations involving computational thermodynamics and diffusion controlled simulations. Thermo-Calc: a powerful tool for thermodynamic calculations for multicomponent systems. DICTRA: a module for accurate prediction of diffusion in multicomponent alloys. TC-PRISMA: a module for simulations of precipitation kinetics. Thermodynamic and kinetic databases are developed using the CALPHAD approach and more than forty databases are available for steels, Ti, Al-, Mg-, HEAs, Ni-superalloys and other materials. From 2017 a new Property Model Development Framework has been introduced to allow users to develop their own property models written in Python and integrate them into Thermo-Calc.

CONFERENCE POLICIES

BADGES

All attendees must wear registration badges at all times during the conference for admission to events included in the paid fee such as technical sessions, exhibition, and receptions.

REFUNDS

The deadline for all refunds was August 18, 2017. No refunds will be issued at the conference. Fees and tickets are nonrefundable.

AMERICANS WITH DISABILITIES ACT

The federal Americans with Disabilities Act (ADA) prohibits discrimination against, and promotes public accessibility for, those with disabilities. In support of, and in compliance with the ADA, we ask those requiring specific equipment, or services to contact TMS Meeting Services in advance at mtgserv@tms.org.

CELL PHONE USE

In consideration of attendees and presenters, we kindly request that you minimize disturbances by setting all cell phones and other devices on "silent" while in meeting rooms.

ANTI-HARASSMENT

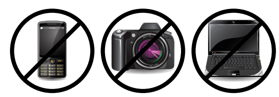
In all activities, TMS is committed to providing a professional environment free of harassment, disrespectful behavior, or other unprofessional conduct.

TMS policy prohibits conduct that is disrespectful, unprofessional, or harassing as related to any number of factors including, but not limited to, religion, ethnicity, gender, national origin or ancestry, physical or mental disability, physical appearance, medical condition, partner status, age, sexual orientation, military and veteran status, or any other characteristic protected by relevant federal, state, or local law or ordinance or regulation.

Failure to comply with this policy could lead to censure from the TMS Board of Directors, potential legal action, or other actions.

Anyone who witnesses prohibited conduct or who is the target of prohibited verbal or physical conduct should notify a TMS staff member as soon as possible following the incident. It is the duty of the individual reporting the prohibited conduct to make a timely and accurate complaint so that the issue can be resolved swiftly.

PHOTOGRAPHY AND RECORDING



TMS reserves the right to all audio and video reproduction of presentations at TMS-sponsored meetings. By registering for this meeting, all attendees acknowledge that they may be photographed by TMS personnel while at events and that those photos may be used for promotional purposes, in and on TMS publications and websites, and on social media sites.

Any recording of sessions (audio, video, still photography, etc.) intended for personal use, distribution, publication, or copyright without the express written consent of TMS and the individual authors is strictly prohibited. Attendees violating this policy may be asked to leave the session.

ANTITRUST COMPLIANCE

TMS complies with the antitrust laws of the United States. Attendees are encouraged to consult with their own corporate counsel for further guidance in complying with U.S. and foreign antitrust laws and regulations.

TMS DIVERSITY AND INCLUSION STATEMENT

The Minerals, Metals & Materials Society (TMS) is committed to advancing diversity in the minerals, metals, and materials professions, and to promoting an inclusive professional culture that welcomes and engages all who seek to contribute to the field. TMS recognizes that a diverse minerals, metals, and materials workforce is critical to ensuring that all viewpoints, perspectives, and talents are brought to bear in addressing complex science and engineering challenges. To build and nurture this diverse professional community, TMS welcomes and actively engages the participation of underrepresented groups in all of its initiatives and endeavors.

EMERGENCY PROCEDURES

The chances of an emergency situation occurring at LMPC 2017 are quite small. However, being prepared to react effectively in case of an incident is the most critical step in ensuring the health and safety of yourself and those around you. Please take a few moments to review the maps of the Hyatt at The Bellevue printed in this program (on page 31). When you enter the building, familiarize yourself with the exits and the stairs leading to those exits. When you arrive at your session or event location, look for the emergency exits that are in closest proximity to you.

For any emergency situation at the Hyatt at The Bellevue, call extension 55 for assistance. If an alarm has sounded indicating a fire:

1. Listen to the voice on the alarm. The message will indicate to stay put, proceed to the nearest fire exit, or to evacuate the building.
2. In case of an evacuation, there are two fire exits--one on the north side and one on the south side of the building. These exits will take guests to Chancellor Court or Walnut Street.
3. Hotel personnel will be available at both street exits to provide directions and assistance.
4. If both exits are impassable:
    a. Place something at the base of the door to help block the smoke.
    b. Dial extension 55, giving your name and location.
    c. Turn off the air conditioner to keep smoke from entering the room.
    d. Stay low and avoid inhaling smoke.

Additional emergency information and tips:

- Safety is the number one priority
- Designate a leader
- Keep calm under all circumstances; do not panic or run
- Do not take elevators

WELCOME TO TMS

The Minerals, Metals & Materials Society

DID YOU KNOW?

If you registered for LMPC 2017 at the nonmemberrate, your registration includes a TMS electronic membership through December 31, 2018.

WHAT CAN YOU DO WITH YOUR NEW MEMBERSHIP?

- **Read:** Access more than 20 journals published by TMS and Springer for free and explore online publication libraries available only to members
- **Network:** Join a TMS technical committee or connect with colleagues through the TMS Membership Directory
- **Advance Your Career:** Post your resume on the TMS Career Center or download the PE Exam Study Guide for Metallurgical and Materials Engineering
- **And Much More!**

Visit **members.tms.org** to view a complete listing of benefits available to you as a TMS member.

HOW CAN YOU ACCESS YOUR BENEFITS?

Following the meeting, you'll receive an e-mail from TMS with your member username and password. Once you receive this, you can log in to the "Access Member Benefits" section of the TMS website at members.tms.org.

QUESTIONS?

Contact our customer service representatives at any time at members@tms.org or by phone at 1-724-776-9000, ext. 241.

We're glad to have you as a member—welcome to TMS!

LMPC 2017

Liquid Metal Processing & Casting Conference 2017

TECHNICAL PROGRAM

www.tms.org/LMPC2017

Keynote Address

Monday AM | Room: Grand Ballroom
September 11, 2017 | Location: The Hyatt at the Bellevue

8:15 AM Introductory Comments

8:20 AM Keynote
Mary Lee Gambone[1]; [1]Rolls-Royce North America

Vacuum Arc Remelting

Monday AM | Room: Grand Ballroom
September 11, 2017 | Location: The Hyatt at the Bellevue

9:00 AM
Numerical Simulation of the Vacuum Arc Remelting Process with ANSYS Fluent: *Moritz Eickhoff*[1]; Antje Rückert[1]; Herbert Pfeifer[1]; Jürgen Tewes[2]; Thorsten Hoffmann[2]; Jutta Klöwer[2]; [1]RWTH Aachen University; [2]VDM Metals GmbH
The vacuum arc remelting process is used to improve both cleanliness and a controlled grain structure for high potential metals like Nickel based superalloys. A self-consuming electrode is continuously molten by electric arcs sparkling between electrode tip and metal pool. The liquid droplets fall from the electrode to the metal pool and resolidify because of the water cooled copper mould. The numerical simulation is done with ANSYS Fluent in combination with user-defined functions and coupling with ANSYS APDL. ANSYS Fluent models the flow field and temperature distribution in the ingot. The user-defined functions offer the possibility to model different heat transfer mechanisms in detail. The current density and Lorentz forces are calculated with ANSYS APDL and implemented as source terms. The model can be validated by the "macroscopic texture examination" an in-house development to determine dendrite growth directions on huge metallurgical samples.

9:20 AM
Application of a Photodiode Based Instrumentation to Study the Dynamics of the Electric Arc during Industrial Vacuum Arc Remelting of a Ti Alloy: *Pierre-Olivier Delzant*[1]; Pierre Chapelle[1]; Alain Jardy[1]; Julien Jourdan[1,2]; Yvon Millet[2]; [1]Institut Jean Lamour; [2]TIMET Savoie
We present an experimental investigation of the dynamics of the electric arc during industrial VAR melt of a Ti64 electrode that is based on the analysis of the luminous emission of the arc. The latter was recorded using four photodiodes placed inside the furnace above the annular gap between the consumable electrode and the crucible. From the quantitative comparison of the signals of the four photodiodes, we were able to determine the location of the arc luminosity centroid and to follow its motion as a function of time. A periodic (with period of the order of several tens of seconds) and asymmetrical evolution of the arc centroid position was observed with a strong correlation between the centroid motion and the evolution of the stirring current. Three different patterns of the arc centroid motion were identified during the melt.

9:40 AM
The Influence of Magnetic Stirring on the Measured Arc Behaviour during VAR of an Alpha-Ti Alloy: Bindu Nair[1]; Yvon Millet[2]; Julien Jourdan[2]; *R. Mark Ward*[1]; [1]University of Birmingham; [2]TIMET
The period and magnitude of the solenoid field used in the VAR of an ingot of an alpha-Ti alloy were varied over the course of the melt. 3-axis magnetic flux density sensors were placed around the outside of the furnace, and the measurements were interpreted to infer the location of the arc in 3d at each time instant. The results were compared with video and other furnace parameters which were recorded simultaneously, and the effects of the solenoid are presented and discussed. Complex behaviour was observed, with the arc centre moving freely in some cases and being confined to regions in others.

10:00 AM Break

10:40 AM
Exploration of VAR Argon-Filling Process for 300M Steel: Yuchun Zhang[1]; Rui Wang[1]; Xianchao Bai[1]; Xuehui Liu[1]; Zhouhua Jiang[2]; [1]Fushun Special Steel; [2]Northeastern University
The experimental research on argon filling during vacuum arc remelting (VAR) of 300M has been performed. The results showed that there was a significant influence on VAR process and the ingot quality. In the process of VAR, the yield of manganese increased when the pressure of argon filling increased. When the argon pressure was less than 50pa, the arc was stable, the pool was active, the yield of Mn in the ingot increased significantly in comparing with traditional process, the Mn difference in different positions of the same ingot decreased a lot, and the chemical composition is uniform. The metallurgical quality of the steel bars totally conforms to current technical specification.

11:00 AM
Investigation into the Spatio-temporal Properties of Arcs in Vacuum Arc Remelting Furnaces: *Matthew Cibula*[1]; Rigel Woodside[1]; Paul King[1]; [1]Ampere Scientific
The behavior of vacuum arcs during VAR processing is known to impact product yield and contribute to ingot defects. Ampere Scientific's VARmetric system has demonstrated non-invasive detection of the spatio-temporal properties of vacuum arcs, including the detection of side-arcing conditions, by utilizing measurements of the magnetic field external to the furnace. Here we present an analysis of spatio-temporal arc distributions measured by VARmetric on a production VAR furnace. Analysis of the arc over different timescales provides new insights into the operating characteristics of VAR furnaces, and on how power is transferred to the molten pool. For example, even under similar steady state operating conditions within a given melt, we have identified significantly different arc distributions, information that may be useful in further understanding the characteristics of the molten metal pool.

11:20 AM
Inclusion Transformation in Vacuum Arc Remelting: *George Shannon*[1]; [1]Carpenter Latrobe Specialty Steel
Inclusion content in a VAR electrode and the resulting ingot of a low alloy structural steel was analyzed using an automated scanning electron microscope. Center, mid-radius, and edge samples were examined from both the top and bottom ends in each case. It was observed that a drastic reduction in inclusion content occurs, however, this reduction does not place consistently between inclusion-forming elements. Volatile elements such as magnesium and calcium are removed moreso than very stable oxide-forming elements such as aluminum. Center and mid-radius samples were found to be cleaner than edge samples in both electrode and ingot cases. Inclusion sources in the teeming setup were identified and eliminated; this was based on electrode analysis, not ingot analysis, indicating that transformations during VAR may disguise inclusion origins.

11:40 AM
Titanium Melting with High Power Plasma Torch: *Henrik Franz*[1]; Ulrich Biebricher[1]; Radisav Dzombic[1]; Dieter Kaufhold[1]; Christoph Morche[1]; Robert Link[1]; Sergejs Spitans[1]; [1]ALD Vacuum Technologies GmbH
In this paper experimental results of melting tests with a newly-developed high power plasma torch are presented. Current-Voltage characteristics of the plasma torch and melting behavior at various operation pressures with different plasma gases (Helium, Argon) will be explained in detail. Most of those tests were performed in a water cooled copper hearth with Titanium as feedstock material. For comparison of heat distribution, and in order to reveal performance characteristics of the torch, tests with Graphite were conducted. With torch currents ranging from 2 to 6 kA, a broad operation window was examined and it will be shown how various operation parameters (e.g. torch standoff distance, torch current) impact on melting efficiency. Results from pool depth measurements at various torch currents and results of an online gas analysis performed by an RGA during those melting tests will also be presented.

Electroslag Remelting I

Monday PM	Room: Grand Ballroom
September 11, 2017	Location: The Hyatt at the Bellevue

1:30 PM
Management of Physical and Structural Homogeneity of Hollow Ingot by Electro Slag Remelting: *Leonid Levkov*[1]; Vladimir Dub[1]; Michael Kisselman[1]; Ivan Ivanov[1]; Dmitry Shurygin[1]; [1]Public Corporation Scientific and Production Association «CNIITMASH»
The results of theoretical and experimental studies that show the possibility of intensity control of heat transfer and rate of crystallization during the hollow ingots formation by ESR are presented. Development conditions of physical and structural heterogeneity in hollow ingots from alloyed steels are defined. Methods of management of these types of inhomogeneities in case of mutual moving ingot, electrode, crystallizer and using a low frequency AC are developed. The mathematical model of solidification process hollow ingots is offered, boundary conditions are defined. Experimentally confirmed adequacy of model for quality prediction of ingots. Results of development are used for hollow ESR ingots with an outer diameter 275-950mm at wall thickness up to 120mm, up to 7200mm long. It's shown that properties of metal completely correspond and even exceed requirements to pipes for thermal and nuclear power plants. That allows using these products in a cast condition.

1:50 PM
Temperature Distribution in ESR Short Collar Mold: *Harald Scholz*[1]; Henrik Franz[1]; Ulrich Biebricher[1]; [1]ALD Vacuum Technologies
A crucial requirement for automated ingot withdrawal in ESR is a reliable level control of the slag pool within the mold. This paper describes how temperature measurement of the mold can be useful to learn about slag behavior underneath the electrode and top of the melt pool. In addition the withdrawal rates of the ingot can be controlled, thereby maintaining constant heat transfer rates in an industrial ESR furnace. The control of the temperature distribution in the mold wall helps to gain information on slag skin thickness, slag height and slag behavior on top of the ingot. According to the temperature measurements conclusions can be drawn on the process stability.The new additional feature on temperature control technology allows an insight into the thermal process of the refining slag and forming ingot.

2:10 PM
Effect of Impurities on Melting Point of ESR Fluxes: *Krzysztof Wroblewski*[1]; Carol Steinhauser[1]; James Fraley[1]; Jerry Fields[1]; Brent DiBiaso[1]; Stuart Rudoler[1]; [1]American Flux & Metal LLC
Several commercial models are capable of calculating reliable values of the liquidus temperature for multi-component fluxes. However, it is difficult to calculate such values over wide ranges of compositions, so several empirical equations are also being used for the estimation of both solidus and liquidus points, with Shridar and Mills model being one of the most popular in the field of ESR. In real world, ESR flux contains impurities that affect melting point but are not handled well by any of these approaches. In order to determine the effect of impurities, a high temperature melting point furnace has been built in our laboratory. Melting points of over 50 real compositions have been measured. Obtained results have been correlated with chemical analysis data, including both main components and impurities. Modified coefficients for the empirical model have been determined and are presented.

2:30 PM
Trace Element Control in Binary Ni-25Cr and Ternary Ni-30Co-30Cr Master Alloy Castings: *Martin Detrois*[1]; Paul Jablonski[1]; [1]US Department of Energy
Electro-slag remelting (ESR) is used for control of unwanted elements in commercial alloys. This study focuses on master alloys of Ni-25Cr and Ni-30Co-30Cr, processed through a combination of vacuum induction melting (VIM) and electro-slag remelting (ESR). Minor additions were made to control tramp element levels and modify the melting characteristics. Nitrogen and sulfur levels below 10 ppm and oxygen levels below 100 ppm were obtained in the final products. The role of the alloy additions in lowering the tramp element content, the resulting residual inclusions and the melting characteristics were determined computationally and confirmed experimentally. Additions of titanium were beneficial to the control of oxygen levels during VIM and nitrogen levels during ESR. Aluminum additions helped to control oxygen levels during remelting, however, aluminum pickup occurred when excess titanium was present during ESR. The usefulness of these master alloys for use as experimental remelt stock will also be discussed.

2:50 PM Break

3:30 PM
Improvement of the Carbide Morphologies by Controlling Metal Pool Profile in the Electroslag Remelting Process of High Speed Steels: *Li Wanming*[1]; Zhouhua Jiang; Ximin Zang[1]; Xin Deng[1]; Haiyang Qi[1]; Gang Wang[1]; [1]University of Science and Technology Liaoning; [2]Northeastern University
The carbide segregation of high-speed steels is a bottleneck problem for producing large cross-section high speed steels. Electroslag remelting is a predominant method for preparing high-quality high speed steels, but the metal pool profile of conventional stationary-mould ESR restricts its ability to control carbide segregation. In order to control carbides segregation, a shallow and flat metal pool will be achieved by using secondary aerosol cooling and mould shunt effect to make the high speed steel rapid solidification. The metal pool profile in ESR process was obtained by tungsten powder detection and high speed steel carbide quality was evaluated. Effects of the secondary aerosol cooling and mould shunt effect on the temperature field of ESR process were analyzed through numerical simulation. Experimental results indicate that the electroslag remelting withdrawal process with secondary aerosol cooling technology and mould shunt effect can significantly decrease the depth of metal pool.

3:50 PM

Industrial-Scale Validation of a Transient Computational Model for Electro-Slag Remelting: *Corey O'Connell*[1]; John deBarbadillo[1]; David Evans[1]; Ramesh Minisandram[2]; Richard Smith[3]; Jeffrey Yanke[3]; Eric Taleff[4]; Thomas Ivanoff[4]; Kanchan Kelkar[5]; William Hutchison[6]; Mark Benedict[7]; [1]Special Metals Corporation; [2]ATI Specialty Materials; [3]Carpenter Technology Corporation; [4]The University of Texas at Austin; [5]Innovative Research, LLC; [6]GE Aviation; [7]Air Force Research Laboratory

Under the auspices of the Metals Affordability Initiative (MAI), a collaborative team consisting of the U.S. Air Force, industry, software vendors, and academia was formed to produce and characterize commercial-sized ESR ingots for the purpose of validating a transient model of the ESR process. Trial melts for two rounds and one slab alloy 718 ingot were conducted, and the liquid metal pool was marked by nickel pellet additions to track its evolution. Full ingot cross-sections were evaluated by automated optical image acquisition, and image correlation techniques were used to estimate primary dendrite arm orientation and secondary dendrite arm spacing. The extent of chemical segregation was determined by X-ray fluorescence analysis at several locations within each ingot. Experimental results from the trials were used to benchmark the computational model in the commercial software package MeltFlow-ESR™.

4:10 PM

A Computational Model of the Electro-Slag Remelting Process with Power Interruption and Its Industrial Validation: *Corey O'Connell*[1]; David Evans[1]; Kanchan Kelkar[2]; [1]Special Metals Corporation; [2]Innovative Research, LLC

This paper presents a computational model for the analysis of an ESR process with power interruption and its application to industrial-scale processes. The model considers the electromagnetics, fluid flow, heat transfer, and phase change phenomena in the slag and ingot in five stages: 1) standard melting, 2) solidification of molten slag and metal pools during loss of power, 3) melting of the slag and ingot after power is recovered, 4) resumption of melting with the bulk of the slag not fully molten, and 5) resumption of standard melting. The model calculates the thermal history of the ingot during the entire process in a comprehensive manner. It has been applied to the analysis of industrial ESR processes for alloys 625 and 718. The results of the analyses illustrate the utility of the model for evaluating ingot quality when power is lost during the ESR process.

4:30 PM

The Sensitivity of an Electroslag Remelting Model to Uncertain Slag Properties: Alex Plotkowski[1]; *Matthew Krane*[2]; [1]University of Tennessee Knoxville and Purdue University; [2]Purdue University

In the numerical models of electroslag remelting (ESR), the values of many input parameters, particularly slag thermophysical properties, have significant uncertainty. This study examines the impact of these uncertainties on simulation output and on model validation efforts. Probability distributions describing the uncertainties in the solid slag skin thermal conductivity and the liquid slag thermal conductivity, specific heat, and electrical conductivity are propagated through a model of ESR transport phenomena and solidification using a reduced-order surrogate model. The slag property uncertainties have a significant effect on the output probability distributions of steady state electrode melt rates and sump depths. These wide probability distributions limit model validation with experimental results and more detailed model development may be not improve the ability to simulate real processes without a strong simultaneous effort to improve the quality of property data.

Poster Session

Monday PM — Room: Poster Area
September 11, 2017 — Location: The Hyatt at the Bellevue

P-1: The High Temperature Flexural Strength of Slag Skin in Electroslag Remelting Withdrawing Process: Ximin Zang[1]; Wanming LI[1]; Xin Debg[1]; Zhouhua Jiang[2]; Jianfei Ren[1]; [1]University of Science and Technology Liaoning; [2]Northeastern University

The slag skin is stretched and pressed at slag-metal interface in electroslag remelting withdrawing(ESRW) process. Slag skin cracking is one of the important reasons that lead to motlen slag and steel leakage. It is crucial to study the physicochemical prosperities of slags for obtaining high quality and smooth surface of ingot.The slag's melting temperature and viscosity were concerned in traditional ESR. In this paper, slag skin flexural strength test at a high temperature was carried out for three typical slags, which were 70%CaF2+30%Al2O3, 60%CaF2+20%Al2O3+20%CaO and 50%CaF2+20%Al2O3+20%CaO+7%SiO2+3%MgO.The slag was remelted into 40×40×160 mm sample bars, and the tests of bending strength were performed at 1000°C, 1050°C, 1100°C, 1150°C and 1200°C. The experimental results showed that the slag skin strength depends on mineral constituents and distribution in slag skin. High melting point, hardness mineral phase dispersion distribution was beneficial to improve the slag skin strength.

P-2: Alloying Elements Loss Prevention and Surface Quality Improvement of As-cast Ingot Produced by Protective Atmosphere Drawing-Ingot-Type ESR: *Cheng-bin Shi*[1]; [1]University of Science and Technology Beijing

To meet the demands in providing stable drawing-ingot operation and sound surface quality of as-cast ingot, as well as prevent alloying elements loss, a series of special slags were developed for drawn-ingot-type ESR. Meanwhile, the influence of melting rate on surface quality of ingot was clarified. The application of the developed slags was examined in industrial practice. Increasing SiO2 addition strongly suppressed the crystallization, and reduced the liquidus temperatures of the slags. A small amount of SiO2 addition in slag improved surface quality of as-cast ingot and stable drawing-ingot operation, and prevented silicon loss in H13 die steel during drawn-ingot-type ESR. Compared with other melting rates, the melting rate of 400kg/h brought sounder surface quality of as-cast ingot. At melting rate of 400kg/h, small amounts of TiO2 and SiO2 addition in slag not only strongly prevented Ti loss in 825 superalloy but also improved the surface quality of ingot.

P-3: New Approaches to the Control of Chemical Homogeneity of Electroslag Remelting Ingots: *Leonid Levkov*[1]; Vladimir Dub[1]; Dmitry Shurygin[1]; [1]Public Corporation Scientific and Production Association «CNIITMASH»

A theoretical model of a molten slag as phase of variable stoichiometric composition and oxidation level (its parameter - equilibrium partial pressure of oxygen Po2) was considered. Based on these ideas for management of oxygen content and components possessing high thermodynamic affinity content in the metal to it a new control method at electroslag remelting process was developed. The model of oxygen behavior during electroslag remelting was developed. This model takes into account characteristics totality of thermodynamic (chemical composition of metal, input reductants, slag and its oxidation level) and kinetic (reaction surface of metal-slag interface, mass transfer rate in metal and slag). It allows predicting the concentration of oxygen, aluminum, silicon and titanium in ingots. For the first time presented the results of implementation of industrial technologies with differentiated slag deoxidation in production of solid and hollow ingots (mass from 20kg to 60tons) from low-alloy, high-chromium and titanium-alloyed steels.

P-4: Numerical Simulation of Electroslag Composite Roll with Different Power Supply Circuit: Xin Deng[1]; Yulong Cao; Ximin Zang; Zhouhua Jiang[2]; Wanming Li; Zhijun He; [1]University of Science and Technology Liaoning; [2]Northeastern University

A new technology of electroslag remelting for the production of composite roll is proposed. A three-dimensional finite element model was developed to simulate the current density, voltage distribution and temperature field for the new technology. Especially, three kinds of power supply circuit are used in the numerical calculation of the model for electroslag composite roll, meanwhile, the skin effect is taken into account in electric field model by thermoelectric coupling method. Numerical results show that the double power supply circuit has better the ability of controlling current distribution, and the slag temperature distribution can be adjusted by adding a reactor in one of the circuits, the skin effect becomes strong and the maximum current occurs at the surface of electrode, the surface temperature of the core prior to cladding is mainly determined by the structure of power supply circuit and input power, the high temperature area of liquid slag pool varies with the power supply circuit.

P-5: Potentials of the Acid Slag for ESR: Stanislav Davidchenko[1]; *Ganna Stovpchenko*[2]; Anatoliy Salnikov[1]; Lev Medovar[3]; Igor Logozinskii[1]; Alexander Kuzmenko[1]; [1]Dneprospetstal; [2]Elmet-Roll; [3]E.O. Paton Electric Welding Institute

Practice of the so known acid steel making processes has the really long history.There are many well known advantages of the acid steel making such as round shape non metallic inclusions or increased low cycle fatigue properties of acid Cr-Ni-Mo steel. Also known advantages and limitation of the acid ESR slag usage. Forecast of acid slag usage for the modern ESR practice to be given on the basis of the recent industrial tests with the different acid slag containing up to 70% SiO2.

P-6: A 2D Transient Model for the Multiphase Flow, Heat Transfer in Electroslag Remelting Process with Different Fill Ratio: Jia Yu[1]; *Fubin Liu*[2]; Zhouhua Jiang[2]; Kui Chen[2]; Huabing Li[2]; Xin Geng[2]; Yanwu Dong[2]; [1]Northeastern University ; [2]Northeastern University

A 2D axisymmetry transient model is established to simulate the fluid flow, heat transfer and the impact of fill ratios in electroslag remelting process with the same power input. The governing equations are discretized with the finite volume method and solved simultaneously. The motion of phase interface is tracked by the volume of fluid approach. The solidification is addressed by the enthalpy-porosity model. The simulation results indicate that the highest temperature is located below the edge of the electrode, and the superheat in metal pool is approximately 151 K. Two distinctly different vortexes within the slag bath promote the temperature filed more uniform. During a period of droplet dripping, the first droplet entering the metal pool takes approximately 0.98s. Besides, the maximum value of electromagnetic field variables decreases with the fill ratio increasing, meanwhile, the zone occupied by the counter-clockwise flow in slag expands as well.

P-7: Considerations for the Operation of a Small Scale ESR Furnace: *Paul Jablonski*[1]; Marion Cretu[2]; John Nauman[2]; [1]US Department of Energy; [2]Consarc Corporation

Vacuum induction melting (VIM), electro-slag remelting (ESR) and vacuum arc remelting (VAR) are all techniques used to make high quality ingots of complex chemistries. In some cases, all three are used, e.g., alloys for aerospace applications and increasingly those for fossil power applications under extreme conditions. As such, research on alloys of this class require access to a variety of melting capabilities. In this report we discuss our recent experiences with a laboratory scale (8in/450lb) combination VAR/ESR furnace. The focus will be on the ESR operation, especially startup, since this is the most difficult operation in our experience. The complication arises from the necessity of the two-melt-mode design which prevents the use of a clamped base plate. Base plate lifting can result in excess arcing and subsequent copper pickup from the crucible bottom. Starting compact design, criteria for enabling the ram drive, and experiences with differing alloys will be discussed.

P-8: Design of ESR Slags According to Requested Physical Properties, Part 3: Surface Tension: *Krzysztof Wroblewski*[1]; James Fraley[1]; Jerry Fields[1]; Brent DiBiaso[1]; Stuart Rudoler[1]; [1]American Flux & Metal LLC

In order to take full advantage of electroslag remelting, it is necessary to optimize the most important properties such as structure, chemical uniformity, and inclusion control by careful choice of remelt parameters and flux chemistry. Surface tension of molten slag controls the size of metal droplets formed in the process, which strongly affects chemical and thermal interaction between molten metal and slag. The surface tension component of multifunction G defining all six component slags of requested properties has been defined. Proposed brute-force algorithm for solving multifunction G is capable of producing results in reasonable time. Obtained results are in good agreement with physical properties of slags commonly analyzed in our laboratory.

P-9: Determination of Fluoride Content in ESR Flux by 19F TD-NMR: *Krzysztof Wroblewski*[1]; Paul Giammatteo[2]; Dennis Guralnick[3]; Carol Steinhauser[1]; James Fraley[1]; Jerry Fields[1]; Stuart Rudoler[1]; [1]American Flux & Metal LLC; [2]Cosa Xentaur Corporation; [3]Dana Scientific Co.

ESR flux is a fused mixture of calcium fluoride, lime, alumina, and other oxides which is used in metal refining to facilitate removal of impurities and prevention of oxide formation during production of high-quality alloys. Presently used analytical methods for measurement of fluorides in ESR flux are time consuming, and for this reason cannot be used for in-process applications. A quick method (less than 15 minutes, including sample preparation) for routine determination of fluoride contents using Time-Domain NMR has been developed. The method has been tested on several flux formulations and the results were as accurate and precise as those obtained using conventional technology.

P-10: ESR for Railroad Wheels and Rails: Ganna Polishko[1]; *Dmytro Kolomiets*[1]; Ganna Stovpchenko[2]; Lev Medovar[1]; Eugen Pedchenko[1]; [1]E.O. Paton Electric Welding Institute; [2]Elmet-Roll

Limitation of the further increase of the railroad wheels and rails workability to be discussed. To be presented observation of the metallurgical quality of ESR rails and wheels metal in compare with the metallurgiiucal quality of the routine railroad meetal manufacturing. Possibilities to utilize ESR for railroad wheels ans rails of the superior quality for most critical applications to be discussed as well. Technical and economical criteria of ESR utilzation for high speed rail road to be formulated and analized.

P-12: High Nitrogen Martensitic Stainless Steel 30Cr15Mo1N Manufactured by PIM-ESR Duplex Process: Hao Feng[1]; *Zhouhua Jiang*[1]; Huabing Li[1]; Fubin Liu[1]; Weichao Jiao[1]; Yu Han[1]; Hongchun Zhu[1]; [1]Northeastern University

High nitrogen martensitic stainless steel (HNMS) has been paid extensive attentions due to its excellent performance. In this paper, 30Cr15Mo1N HNMS with nitrogen content higher than solubility at atmospheric pressure was manufactured by pressurized induction melting (PIM) and N_2-protective electroslag remelting (ESR) duplex process. Firstly, the 30Cr15Mo1N ingot was melted using PIM, and nitrogen alloying was carried out under high nitrogen pressure to obtain high nitrogen content (higher than 0.5 wt.%). Then, the ingot was remelted using ESR under N_2 atmosphere. Simultaneously, nitrogen was released because of the low nitrogen pressure during ESR. However, partial nitrogen was preserved owing to the relatively high remelting and solidification rate. The results indicated that the sulfur content was reduced efficiently, and inclusion distribution was improved greatly. And 30Cr15Mo1N HNMS (nitrogen content higher than 0.2 wt.%) with high hardness, toughness and corrosion resistance can be manufactured using PIM-ESR duplex process.

P-13: Differences in Inclusion Morphology between ESR Remelted Steel With and Without Tracer in the Process Slag: *Ewa Sjöqvist Persson*[1]; Alec Mitchell[2]; Pär Jönsson[3]; [1]Uddeholms AB; [2]University of British Columbia; [3]KTH Royal Institute of Techology
This study presents results on inclusion morphology in tool steels, intended to investigate inclusion behavior during ESR remelting. In order to optimize process routes for different steel grades, it is important to understand the origin of the inclusions in ESR materials. In a larger study comparison has been made between electrodes, ESR ingots of different ingot sizes and furnace types and conventional casted ingots. In this study ESR ingots from the same electrode heat have been remelted using a process slag with and without a tracer. The results explain the connection between the inclusions in the electrode, the inclusions in the ESR ingot and the process slag.

P-14: Effect of Magnesium on the Cleanliness and Inclusions of Low Alloy Ultra-high Strength Steel: *Gong Wei*[1]; Pang Sheng[1]; Wan Wan[1]; Li Yang; [1]Northeastern University, China
Based on the low alloy ultra-high strength steel, the effect of magnesium on the cleanliness and inclusions in steel is discussed. The experimental results show that the total oxygen content in steel is decreasing with the increasing of magnesium content in steel, which can be reduced from 0.0024% in contrast sample to 0.0004%. And with the magnesium was added into the steel, the quantity and average diameter of inclusions in steel are gradually decreased, furthermore, the average space between inclusions is enlarged. Mg can give priority to the metamorphoses of oxide inclusions in liquid steel and subsequently metamorphic sulfide inclusions. Then with the addition of magnesium, the magnesium content in inclusions is increasing. The inclusion composition changed the sequence of Al2O3→MgO•Al2O3-MnS→MgO•Al2O3-MgS-MnS→MgO-MgS.

P-15: Study of Volume Deficit in Aluminium Alloy Casting: *Laxminarayana Pappula*[1]; Syed Hussainy[2]; Viquar Mohiuddin[2]; Sundarrajan Srinivasan[3]; [1]Osmania University; [2]Muffakham Jah College of Engineering and Technology; [3]Vishnu Educational Development and Innovation Center
Volume deficit in LM6, LM9 and LM24 cast aluminium alloy has been studies in the current presentation. The volume decreases during solidification and it leads to shrinkage defect. The influence of modulus of casting, orientation of casting in mould,shape of casting, riser aspect ratio, alloy, feed volume requirements and modulus extension factor has been studied on shrinkage defects. Casting yield studies and feeder safety margins are also studied. It is observed that volume deficit is sensitive to alloy, shape of casting, orientation of casting in mould and size of casting. The yield of casting is increased from 42% to 77% by using riser sleeves. The feed safety margins obtained are more than 15% the height of riser.

P-16: Experimental and Simulation Studies on Temperature Distribution of Manufacture Bimetallic Composite Material by Liquid-solid Bonding Method: Yulong Cao[1]; *Yanwu Dong*[1]; Zhouhua Jiang[1]; Zhongtang Cheng[1]; Fubin Liu[1]; Xin Geng[1]; [1]Northeastern University
Bimetallic composite materials have been given more and more attention because of their superiority in playing the advantages performance of the internal and external materials at the same time. In the study, a high chromium cast steel/carbon steel bimetallic composite material was fabricated by liquid-slag bonding method. In this experiment liquid metal of high chromium cast steel melted by VIM was casting into a cylindrical cast iron mold with a carbon steel bar in the center. A numerical model was built to predict the temperature distribution along the high chromium cast steel/carbon steel interface in real time by using the birth and death elements. Validation of the numerical model was conducted experimentally by measuring the temperature of the carbon steel and molds at some study points during the pouring and solidification process by thermocouples. A good agreement between the numerical and experimental results has been obtained.

P-17: Effect of Top Slag and Bottom Blowing Argon on Nitrogen Content and Inclusions in Cr12 steel in Vacuum Induction Melting: Leizhen Peng[1]; *Xin Geng*[1]; Zhouhua Jiang[1]; Fubin Liu[1]; [1]Northast University
For enhancing the properties of the Cr12 steel, the refining methods of adding top refining slag and bottom argon blowing were adopted in vacuum induction melting (VIM) process. The experiments were conducted in the 50kg vacuum induction furnace. The OLYMPUS-DSX 500 optical microscope and Image-Pro-Plus 6.0 software was used to statistically figure out the number and size of inclusions, a direct-reading spectrometer of ARL 4460 was applied to analyze the amount of alloying elements and a gas analyzer of LECO TC-500 was used to analyze the nitrogen content. The results show that there is no apparent effect of top refining slag on inclusions removal, which can cause lower nitrogen removal rate, while the effect of bottom argon blowing on the amount of inclusions and nitrogen removal is good. The denitrification coefficient, km =0.0066 cm/s in the case of bottom blowing argon compared with km =0.0054 cm/s in the conventional VIM process is a little higher.

P-19: Inclusions, Microstructure and Carbides of D2 Cold Work Die Steel Prepared under High Pressure: Changyong Chen[1]; Zhouhua Jiang[1]; *Yang Li*[1]; Wei Gong[1]; Cheng Wang[1]; [1]Northeastern University
The effect of pressure and magnesium on the solidification structure and primary carbides in D2 cold work die steel were investigated. The steel were smelting under high pressure from 0.5 MPa to 1.0 MPa with different magnesium. Results shows that the as-cast microstructure was greatly refined, and the network eutectic carbides in the as-cast steel were interrupted with the size reduced sharply at the same time. Furthermore, the transformation behavior and mechanism of carbides in forged and annealed steel was studied. The energy dispersive spectrometer, X-ray diffraction and the quantitative chemical examined method were carried. Meanwhile, the evolution of carbide under different temperatures and aging times were thermodynamically calculated by Thermo-Calc software. The results are as follows. The primary carbides and morphology, size and distribution are improved after the hot-forging operation. According to the calculated results, the carbides in the hot-forged and annealed steel are M7C3, M23C6 and M6C.

P-20: Effect of Al–Mg Alloy Addition on the Cleanliness and Inclusions in H13 Die Steel during ESR Process: Hao Wang[1]; Jing Li[1]; *Cheng-bin Shi*[1]; [1]University of Science and Technology Beijing
The effect of Al–Mg alloy addition on the cleanliness and inclusions during electroslag remelting of H13 die steel with two levels of oxygen content was investigated. The results show that the oxygen content pick-up and silicon loss of remelted ingot were avoided, and sulphur content was further decreased. After Al–Mg alloy addition during protective gas electroslag remelting (P-ESR) process. The oxygen content of consumable electrode (15 × 10-6) was invalid to be reduced. The oxygen content of consumable electrode (80 × 10-6) was reduced to 40×10-6 after P-ESR process, the oxygen content could not be reduced further in the Al-Mg addition trial. CaS content of complex inclusions were decreased significantly after P-ESR process. The type of inclusions was not changed during P-ESR process with Al–Mg alloy addition, except the increase in the concentrations of CaS in individual inclusion.

Static Casting

Tuesday AM Room: Grand Ballroom
September 12, 2017 Location: The Hyatt at the Bellevue

8:15 AM Introductory Comments

8:20 AM
Investigation on the Solidification Behavior and Microstructure of Superalloy Inconel 718 Prepared by Permanent Mold Casting: Yahui Liu[1]; Maodong Kang[1]; Yun Wu[1]; Junwei Yu[1]; Shuxian He[1]; Jun Wang[1]; [1]Shanghai Jiao Tong University

Continuous improvement of the engine operating temperature requires more excellent superalloys. A new method was investigated to improve the microstructure of polycrystalline superalloy by permanent mold casting. Physical experiment and numerical simulation were employed to understand the relationship between cooling condition and microstructure evolution. The results revealed the significant refinement of grain and precipitation in the entire casting. Both the large cooling rate and thin-walled structure caused the small scale of dendritic secondary arm spacing and precipitation. Fine precipitates on grain boundaries (GBs) promoted the serrated GBs while developed precipitates promoted smooth GBs. Niobium segregation resulted in tiny MC carbide and Laves, but not acicular δ. The coating was trapped in casting to form surface layer while the carbon diffusion from iron mold to casting formed the subsurface carbon-rich layer.

8:40 AM
Interdendritic-melt Solidification Control Technique and Its Influence on the Porosity Reducing and Stress Rupture Life at intermediate temperature of a Ni-base Superalloy: *Liang Zheng*[1]; Guoqing Zhang[1]; Dominik Daisenberger[2]; Zhou Li[1]; Chengbo Xiao[1]; [1]Beijing Institute of Aeronautical Materials; [2]Diamond Light Source

The interdendritic-melt solidification control (IMSC) technique was developed to manufacture equiaxed superalloy in order to reducing porosity of castings. The effect of IMSC process on the micro-porosities and stress rupture properties at 760°C/662MPa of IN792 alloy was investigated compared with conventional investment casting (CC). The microstructure and minor phases of alloys were characterized by optical metallography and synchrotron XRD. In addition, the fracture surfaces of stress ruptured IMSC and CC test bars were observed by scanning electron microscopy. The results indicate that the large size MC carbides, brittle plate-like η phase and large amount of porosity existed on the fracture surface of fast withdrawal rate IMSC alloy which result in low stress rupture life of the alloy. However, proper process parameter of IMSC can produce castings with much reduced porosity, equivalent stress rupture properties at intermediate temperature and higher stress rupture life at elevated temperature compared to conventional investment casting.

9:00 AM
Microstructure Evolution during the Stir Casting of a Graphene-Magnesium Alloy Composite: *Pavan Penumakala*[1]; Gokul Nanda[1]; Sujith Ravindran[1]; Suresh Kurra[1]; [1]BITS Pilani- Hyderabad Campus

Magnesium alloys are extensively used in automotive applications because of low density. However, their mechanical strength is lower compared to other lightweight materials. In recent times, graphene is used as an ideal reinforcement for increasing the strength of these alloys. In this present study, a composite material is fabricated using stir-casting method by reinforcing graphene in a magnesium alloy. The graphene particles are introduced into the molten magnesium alloy and stirred using a mechanical stirrer under argon atmosphere and allowed to solidify in a crucible. The grain size and the graphene distribution of the as-cast sample is examined using scanning electron microscope. The grain refinement if any, when compared to the pure magnesium alloy is also examined. Numerical simulations are carried out to find the parameters that influence the grain refinement and graphene distribution. The influence of process parameters such as particle size and the stirring speed is investigated.

9:20 AM
Evaporation of Cu and Sn in Ferrous Scrap Mixed with Hot Metal: Fahmi Tafwidli[1]; Sung-Hoon Jung[1]; *Youn-Bae Kang*[1]; [1]Pohang University of Science and Technology

Cu and Sn are known as typical tramp elements in ferrous scrap which cause degradation of steel properties during hot processing. As a method to remove Cu and Sn from liquid iron melts, in the present study, Cu and Sn evaporation from liquid Fe-C-S alloys representing hot metal mixed with ferrous scrap was elaborated. In the regime of chemical reaction at the surface as a rate controlling step, a series of kinetic investigation were carried out in order to elucidate evaporation reaction mechanism by employing gas-liquid reaction in levitation/semi-levitation technique. A wider C content (0 to C saturation) and a wide temperature range from 1240 to 1500°C were employed. Experimental results showed that increase of temperature and C content increased the evaporation rate. A kinetic model was developed, and it is shown that the newly developed model could explain the newly obtained experimental data obtained in the present study.

9:40 AM
A New Technology for Large Scale Electromagnetic Levitation Melting and Casting of Metals. Part I: Simulation: *Sergejs Spitans*[1]; Henrik Franz[1]; Egbert Baake[2]; [1]ALD Vacuum Technologies GmbH; [2]Institute of Electrotechnology, Leibniz University

A 3D numerical model for the molten metal free surface flow in an alternate EM field has been developed by means of coupling between Lorentz force recalculation in ANSYS and transient two-phase turbulent flow calculation in FLUENT. The developed numerical model has been successfully validated for the case of induction furnace with cold crucible, levitation melting in horizontal field and conventional levitation melting with aluminum samples up to 20 g.The model has been used further for design and optimization of a novel two-frequency levitation furnace that is able to melt aluminum samples up to 500 g in experiments. Observed instabilities taking place at a certain parameter range have been understood and explained using numerical approach. Application of the two-frequency levitation melting technology for metals with high melting temperatures (e. g. titanium) is discussed.

10:00 AM Break

10:40 AM
A New Technology for Large Scale Electromagnetic Levitation Melting and Casting of Metals. Part II: Experiments: *Egbert Baake*[1]; Sergejs Spitans[2]; Henrik Franz[2]; [1]Leibniz Universität Hannover; [2]ALD Vacuum Technologies GmbH

A new technology for large scale electromagnetic (EM) levitation melting and casting of metals will be presented. In conventional axisymmetric approaches for EM levitation melting the charge weight is rather limited because the required EM forces vanish on the symmetry axis and therefore leakages of the molten metal can be avoided only by the melt surface tension. The new solution is based on the application of two EM fields of different frequencies, whose field lines are horizontal and reciprocally normal in order to realize an EM lift force in the molten charge also on the axis. Therefore, the weight of the levitated charge can be increased and the charge can be leakage-free melted. The applicability and the scale-up of this approach was experimentally and numerical investigated. The realization of EM confinement, e.g. for controlled casting has been ensured by a water-cooled protective coil.

Continuous Casting and Melting

Tuesday AM Room: Grand Ballroom
September 12, 2017 Location: The Hyatt at the Bellevue

11:00 AM
Generation of Al-3.7mass%Fe Hypereutectic Alloy Wires with Unidirectional Morphology Using the Ohno Continuous Casting Process: *Takuma Sawaya*[1]; Genjiro Motoyasu[1]; Hiroshi Soda[2]; Alexander McLean[2]; [1]Chiba Institute of Technology; [2]University of Toronto
Unidirectional solidified Al-3.8mass%Fe hypereutectic alloy wires 6 mm in diameter have been produced by the Ohno Continuous Casting (OCC) Process at casting speeds of 50~ 500 mm/min. The effects of casting speeds on cast structure and crystal orientation of the wires have been studied. At lower casting speeds, the cast structure consisted of primary phase (FeAl inter-metallic compound) and eutectic areas. However, at casting speeds above 200 mm/min, this inter-metallic primary phase was no longer observed, but instead a-aluminum dendrites (primary crystals of hypoeutectic compositions) were present as the primary phase. It was also found that at lower casting speeds, the crystal orientation of cast wires in the casting direction tended to be [111], while at casting speeds above 200 mm/min, the crystal orientation tended to be [101] and the cast structure contained Z3 coincidence boundaries.

11:20 AM
Numerical Simulation of Adding Steel Strip Process in Continuous Caster: *Zhongqiu Liu*[1]; Ran Niu[1]; Xianglong Li[1]; Baokuan Li[1]; [1]Northeastern University
Adding steel strip into continuous casting mold is a technique to increase the ratio of equiaxed grain and result in decreasing the centerline segregation in continuous casting process. A mathematical model was developed to investigate the coupled fluid flow, heat transfer and phase change in adding strip process. A generalized enthalpy-based method is implemented to describe the phase change behavior in the system. Both The forced convection and the thermal buoyancy are considered. Results indicate that some hot melt would firstly solidified to form a sheath onto the cold strip after the strip just be added into the mold, and then the sheath and original cold steel strip would melt gradually due to the effect of superheat of melt. The effect of strip thickness, superheat of melt and adding speed of steel strip on the melting behavior of the strip and solidification behavior of slab has been evaluated.

11:40 AM
A Thermal Model of Cored Wire Injection: *Edgar Castro-Cedeno*[1]; A. Jardy[2]; A. Carré[3]; S. Gerardin[3]; J.P. Bellot[2]; [1]Institut Jean Lamour - UMR 7198 CNRS Université´ de Lorraine, Laboratory of Excellence DAMAS -- Affival SAS; [2]Institut Jean Lamour - UMR 7198 CNRS Université´ de Lorraine, Laboratory of Excellence DAMAS; [3]Affival SAS
Cored wire injection is used to perform alloying additions during secondary steelmaking, presenting advantages such as higher yield over bulk additions. The wire consists of a casing wrapped around a core of powdered material, this setup delays the release of material into the melt. This work presents a 1-D finite volume numerical model aimed for the simulation of the thermal phenomena occurring during cored wire injection. It has been successfully validated from experimental from the literature. It is currently used as a design tool for the conception of new types of wire. A study where Al wire, single casing Al cored wire and double casing Al cored wire are compared has been set up. The effect of injection velocity was investigated. Characteristic melting routes for the three types of wires are identified and described. Results give guidelines on optimal ranges of injection velocities whichdelay the release of material.

Electroslag Remelting II

Tuesday PM Room: Grand Ballroom
September 12, 2017 Location: The Hyatt at the Bellevue

1:30 PM
The Development of an Integrated ESR Process Model: *A. Ballantyne*[1]; [1]MeltMet Technologies
One of the challenges in modelling the ESR process is that of specifying temperature dependent thermophysical properties. This is especially true of the ESR slag for which thermophysical properties may not be well defined and vary significantly with temperature. In addition, solution of the thermal model requires the specification of a set of boundary conditions which are usually defined as temperatures or heat fluxes rather than furnace operating parameters. This leaves a process engineer with the task of determining how these boundary conditions should be linked to melt practice variables. The objective of this paper is to explore the possibility of using a consolidated system approach combined with a slag heat balance to describe the ESR slag and to incorporate this simplified slag model into an ESR process model with inputs in the form of operating parameters. Preliminary results show promising potential and highlight the challenges for future model development.

1:50 PM
Effect of Remelting Atmosphere on the Oxygen Transfer during Electroslag Remelting Process: *Xuechi Huang*[1]; Zhongqiu Liu[1]; Baokuan Li[1]; [1]Northeastern University
A transient coupled model was developed to further understand the oxygen transfer in electroslag remelting (ESR) process. The effects of different remelting atmosphere on the oxygen transfer process were investigated. The electromagnetics, two-phase flow, heat transfer and mass transfer were simulated simultaneously. An innovative kinetic and thermodynamic model was adopted to assist in calculating the mass transfer rate. The gas phase was involved in atmosphere case while not included in inert gas protection one. The Lorentz force, Joule heating and mass transfer rate were incorporated into the momentum, energy and mass transfer equations as source terms, respectively. The reactions mainly occur at the slag/metal and slag/gas interfaces. The case of combination of inert gas protection and removal of oxide scale demonstrates a much higher deoxidation efficiency. The case under open atmosphere shows an increased oxygen content in final ingot. The model and simulations were validated well by laboratory experiments.

2:10 PM
Effect of an Innovative Electroslag Hot-topping on the Solidification of Large Ingot: *Baokuan Li*[1]; Neng Ren[1]; Zhongqiu Liu[1]; [1]Northeastern University
An innovative hot-topping system is designed to improve the quality of the solidification process of large ingot, where two series-connected graphite electrodes with the combination bar inside and pipe outside are used for electroslag heating. A finite element model has been developed to evaluate the effect of the new hot-topping system. The harmonic electromagnetic field is solved by the nodal-based method. Heat transfer is described by the enthalpy equation with a time-averaged Joule heating source loaded. Numerical results show the electroslag hot-topping can effectively control the temperature distribution of the steel ingot and improve the quality of the ingot. The uniformity of temperature along horizontal direction is significantly improved. Furthermore, some parameters, such as slag height and immersion depth, have been optimized to obtain homogenous Joule heating distribution and negative temperature gradient downward the ingot.

2:30 PM
An Analysis of Current Flow in ESR Slabs: *Ashish Patel*[1]; Corey O'Connell; [1]Timet
This paper takes a fundamental look at the current distribution within ESR slabs using an analytical solution to the magnetic diffusion equation. For slabs with large aspect ratios, it is reasonable to assume the current variation to be along the width and height of the slab. Appropriate interface boundary conditions are used to determine the current in the electrode, slag and ingot. Once the current distribution is determined, other parameters like voltage and joule heating within the slag are readily determined. To illustrate the industrial application of this approach, the estimated joule heating in the slag is correlated to the process data to estimate melt rate for a wide range of processing conditions. This estimated melt rate is, in turn, used as an input to a CFD model for determining trends in pool depth and centerline segregation tendency for a particular alloy of interest.

2:50 PM Break

3:30 PM
The Effects of Melt Current Frequency on Melt Pool Dynamics During Electroslag Remelting: *Andrew Elliott*[1]; Kanchan Kelkar; Craig Miller[1]; John Nauman[1]; Raymond Roberts[1]; [1]Consarc Corporation
The ongoing drive to increase the capacity of electroslag remelted ingots has resulted in novel power supply designs that can operate with balanced primary power load and at DC or lower AC frequencies on the melt power side. The frequency of the furnace melting power can have a significant effect on not just electrical efficiency, but also electrochemical aspects of the process and melt pool dynamics such as liquid metal flow patterns, pool size and shape, and cooling rate at the solidification front. The melt power frequency effect is explored via computational modeling across a range of ingot sizes, including more common ingot sizes around 1000 mm. Results indicate that the effects of AC melt power frequency on melt pool dynamics also depend strongly on ingot diameter and that the common line frequency melt power supplies may not provide optimal melting conditions.

3:50 PM
CFD Modeling of the Electrode Change during the ESR Process: *Ebrahim Karimi Sibaki*[1]; Abdellah Kharicha[2]; Menghuai Wu[2]; [1]University of Leoben, Austria; [2]Chair of Simulation and Modeling of Metallurgical Process, Univ. of Leoben, Austria
Nowadays, the electrode change technology is utilized in which a number of smaller electrodes are remelted to produce a large ingot (>100 tons). The entire electrode change procedure includes three steps. Firstly, the power is switched off when a preheated electrode is prepared to be immersed into the molten slag (~5 min). Secondly, the electric current flows again through the system to heat the electrode tip aiming at reaching the melting temperature (~10-15 min). Finally, the melt rate of electrode gradually increases to reach the target melt rate (~10-15 min). Here, a numerical investigation is performed in which the interaction between the turbulent flow, heat, and electromagnetism are modeled for a short collar mold ESR process (~2000 mm ingot). Impacts of the power and melt rate interruption on the flow and thermal fields as well as solidification of the ingot during the full procedure of the electrode change are analyzed.

4:10 PM
Numerical Simulation Approach for Modelling the ESR Process with a Rotating Electrode: *Christian Schubert*[1]; Antje Rückert[1]; Herbert Pfeifer[1]; [1]RWTH Aachen University
The electroslag remelting (ESR) process is used for the chemical refinement of high quality steel and titan- or nickel-based alloys, in which liquid metal droplets are refined by falling through a bath of molten slag. In recent years the theory, that a rotary movement of the electrode could further enhance the chemical refinement due to smaller liquid metal drop sizes and therefore enlarged reaction surfaces in the slag region, has been represented. Within a currently ongoing research project this theory will be investigated. This article focuses on currently existing numerical simulation approaches to model the ESR process utilizing a rotating electrode. Modelling the ESR process is quite multidisciplinary, since many different physical phenomena have to be considered. The different phenomena, including their common modelling approaches, will be described. In addition, an evaluation for practical application to overall process model implementation will be given.

4:30 PM
Enhancing the Electroslag Remelting Process: Development and Implementation of a Rotating Electrode Set-up: *Martin Schwenk*[1]; Bernd Friedrich[1]; [1]IME Process Metallurgy and Metal Recycling, RWTH Aachen University
The electroslag remelting (ESR) process has been investigated thoroughly over the last decades. Yet there is potential to improve the refining mechanisms during this process with a modification of the electrode movement. In this context the Institute for Process Metallurgy and Metal Recycling (IME), RWTH Aachen University is changing its static electrode set-up on its laboratory scaled open atmosphere ESR towards a rotating electrode. Significant improvement is expected concerning solidification structure, ingot quality and energy flow through altered fluid flow phenomena. Besides this, the objectives of this project are a better understanding of the electrodes molten metal film, attaining detailed knowledge in terms of droplet detaching from the electrode, investigation of the current flow through ingot and mould and an investigation about the behavior of nonmetallic inclusions. This paper provides an overview on the fundamental principles leading to the before mentioned assumptions as well as the current state of work.

4:50 PM
CFD Modeling of the Electroslag Rapid Remelting (ESRR) Process: *Ebrahim Karimi Sibaki*[1]; Abdellah Kharicha[2]; Menghuai Wu[2]; [1]University of Leoben, Austria; [2]Chair of Simulation and Modeling of Metallurgical Process, Univ. of Leoben, Austria
In the ESRR process, a T-shaped mold is used including a graphite ring that takes major amount of current through the mold. There are only a few reports available in the literature discussing about this topic. The research on the ESRR process is currently ongoing aiming to improve the design of the T-shaped mold, to decrease overall heat loss in the process, and to obtain a higher temperature at metal meniscus. In the present study, the electromagnetic, thermal, and flow fields in the whole process as well as solidification of the billet ingot (~ 200 mm) are modeled. Furthermore, the influence of current ratio (graphite to base plate) on the pool profile of the ingot is analyzed. The main goal is to obtain some fundamental understanding of the formation of melt pool of the solidifying billet ingot in ESRR process.

Vacuum Induction Melting

Wednesday AM Room: Grand Ballroom
September 13, 2017 Location: The Hyatt at the Bellevue

8:15 AM Introductory Comments

8:20 AM
Secondary Vacuum Induction Melting Technology of High Quality IN718C Superalloy: juntao li[1]; Jiantao Wu[1]; Ping Yan[1]; Xingfu Chen[1]; Zhen Wang[1]; Qiang Zeng[1]; Xiaofei Yuan[1]; [1]Central Iron and Steel Research Institute
IN718C superalloy is widely used as the structural components due to the superior castability, mechanical properties and low cost. The increasing size ,structural complexity, high metallurgical quality and performance of structural components demands higher pure master alloy. To meet the object, deoxygenation, denitrification and desulfuration technologies in VIM process of IN718C superalloy were investigated. The results indicated that the oxygen and nitrogen content in raw materials could be decreased obviously by controlling the composition of Fe-Cr-Ni intermediate alloy in the primary VIM preprocess. The following addition of rare earth elements and calcium slagging in the secondary VIM process further decreased the content of oxygen and nitrogen as well as the content of sulfur in master alloy. High quality IN718C superalloy was obtained by secondary VIM technology. The content of oxygen, nitrogen and sulfur decreased to 5ppm, 5ppm and 6ppm individually, the content of other trace elements were also decreased.

8:40 AM
Refractories for VIM Application: Selection Criteria and Wear Evaluation: *Christine Wenzl*[1]; Dean Gregurek[1]; Alfred Spanring[1]; Karl Budna[1]; Robert Drew[1]; Camilo Perez[1]; [1]RHI
Super alloy production (e.g. Ni&Co alloys as used in aerospace applications) typically involves vacuum induction melting (VIM). VIM metallurgy is mainly based on pressure-dependent reactions with the aim of obtaining a cast metal ingot to a defined metallurgical composition with reduced imperfections resulting from dissolved gasses and NMI's. Due to the process conditions, VIM creates different refractory challenges than encountered in other smelting processes in primary and secondary metal production: the refractories are subject to vacuum conditions and more severe decomposition by gas evolution, furthermore, alloy contamination by refractory components has to be avoided. Therefore proper refractory selection and design are crucial factors for an efficient VIM process. The present paper discusses RHI's lining solutions and also describes typical lining wear as encountered in VIM furnaces. Post-mortem studies are used to define the main wear mechanisms and consequently optimize the lining to give high product quality and efficient furnace operation.

9:00 AM
To be announced.

Inclusions

Wednesday AM Room: Grand Ballroom
September 13, 2017 Location: The Hyatt at the Bellevue

9:20 AM
Studies of Three Dimension Inclusions in from ESR Remelted Conventional Cast Steel: *Ewa Sjöqvist Persson*[1]; Andrey Karasev[2]; Pär Jönsson[2]; [1]Uddeholms AB; [2]KTH Royal Institute of Techology
This study presents two dimensional (2D) and three dimensional (3D) investigations of non-metallic inclusions in both an ESR remelted and a conventional common martensitic stainless steel. The study has been carried out to increase the knowledge of the inclusion behavior during ESR remelting. In order to optimize process routes for different steel grades, it is important to enhance the knowledge about the origin of the inclusions in ESR materials. The comparison has been made between ingot casted electrodes and ESR ingots of different ingot sizes and furnace types. In addition, scanning electron microscopes has been used in order to investigate the inclusions after electrolytic dissolution of steel sample and filtration. The results explain the differences between the inclusions in an ESR remelted ingot and a conventional casted ingot.

9:40 AM
Evolution of Non-metallic Inclusions due to Reduction of Slag and Refractory Components: Haoyuan Mu[1]; Richard Fruehan[1]; *Bryan Webler*[1]; [1]Carnegie Mellon University
Elevated levels of reactive elements in steels can lead to reactions with slags and refractories that modify the evolution of non-metallic inclusions during steel refining processes. Particularly important is dissolved Al in liquid steel which can reduce CaO and MgO. The Ca and Mg that are transferred to the liquid steel cause unintended changes to inclusion chemistry. The objective of this work was to evaluate the kinetics of inclusion modification by Ca and Mg. The results of laboratory-scale experiments showed that the rates were controlled by mass transfer of Ca and Mg from the slag/metal interface. The extent of Ca reduction and Ca modification of inclusions was significantly less than Mg modification. This was attributed to very low Ca solubility in liquid Fe and slow mass transfer rates. The results demonstrate the importance of reactions with slags and refractories in the evolution of inclusions, particularly in highly alloyed steels.

10:00 AM Break

10:40 AM
Influence of Alumina Shape on the Clustering of Alumina in Liquid Steel: *Muxing Guo*[1]; Lichun Zheng[1]; Annelies Malfliet[1]; Patrick Wollants[1]; Bart Blanpain[1]; [1]KULeuven
This work studied the effect of alumina inclusion morphology on its clustering behavior in molten iron. Alumina inclusions were extracted from iron samples taken at 1 min after Al addition. Dendritic, spherical, plate-like, faceted and clustered alumina inclusions were identified and their clustering degrees were measured. The clustering degree increases in the order of spherical, dendritic, plate-like and faceted inclusions. Based on calculation of the attractive force between two alumina particles with different shape combinations, i.e., sphere-sphere (S-S), sphere-plane (S-P), plane-plane (P-P), it was concluded that S-S type has the smallest attractive force and the shortest acting length; P-P type has the largest attractive force and the longest acting length. This explains that spherical inclusions have the lowest clustering degree. The lower clustering degree of plate-like inclusions, compared with faceted inclusions, is due to that molten iron wets plate-like inclusions better.

Titanium Processing

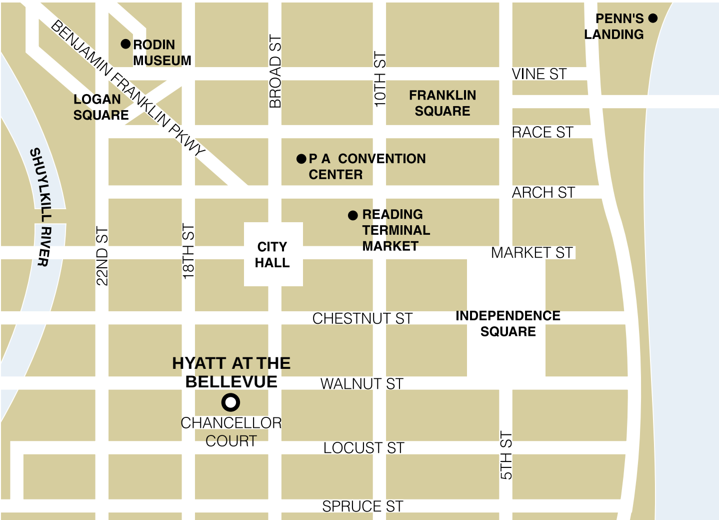
Wednesday AM Room: Grand Ballroom
September 13, 2017 Location: The Hyatt at the Bellevue

11:00 AM
Measurement of the Evaporation under Vacuum of Alloying Elements of Ti alloys and Assessment of the Activity Coefficients: *Jean-Pierre Bellot*[1]; [1]Institut Jean Lamour
Vacuum metallurgical processes are highly conducive to volatilization. In titanium processing, it concerns the alloying elements which show a high vapor pressure with respect to titanium matrix. An experimental approach using a laboratory electron beam furnace has been developed for the estimation of volatilization rates and activity coefficients. This innovative method is based on the deposition rate of metallic elements on Si wafers located at different angles above the liquid bath. We found that a deposition according to a cos2(theta) law describes well the experimental distribution of the weight of the deposition layer. Experiments performed with Ti64 provide values of the Al activity coefficient at T=1860°C in good agreement with the range reported in the literature. Additional volatilization experiments have been performed on Ti17, Ti1023 and Ti5553 and have provided the activity coefficients of Al, Cr, Sn, Fe at 1890 °C which are not reported in the literature.

11:20 AM
A Complete Recycling Circle for Precision Cast Low Pressure TiAl Turbine Blades: *Janik Brenk*[1]; Peter Spiess[1]; Marek Bartosinski[1]; Björn Rotmann[1]; Bernd Friedrich[1]; Rüdiger Tiefers[2]; Günter Hübner[2]; [1]IME - RWTH Aachen; [2]Access e.V.
Titanium based alloys gain a more and more important role in the manufacturing of aerospace turbine blades. In a modern aircraft turbine, all of the turbine blades and fans except the high temperature high pressure turbines are made out of Ti-based alloys. Due to the expensive primary Titanium production, an efficient recycling route for Ti-based alloys is crucial for decreasing the price of the whole turbine. Over the past decade, the IME has focused on the recycling potential of titanium aluminides (TiAl) used for low pressure turbine blades. To do so a full triple melt TiAl recycling route consisting of VIM, PESR & VAR was established at the IME. Even using ceramic crucibles in VIM it was possible to obtain a material which meets all specifications even the low limit for oxygen. This material can and will be directly reused for casting turbine blades.

11:40 AM
The Characteristics of TiAl Alloy Powders Fabricated by Cold Crucible Induction Melting and Argon Gas Atomization: *Na Liu*[1]; [1]Beijing Institute of Aeronautical Materials
The fine spherical TiAl alloy powders were produced by argon gas atomization of PSI's HERMIGA atomizers based on cold wall crucible induction melting, technology. The process of melting and atomization were studied. During melting, a skull forms at the bottom and the wall so the molted charge is always contained in a solid skull of the same composition. The powder particle size distributions are normal distribution, the powder particles are almost perfectly spherical, the gas content of the powder is low, among which oxygen concentration shows an increase with decreasing particle size, nitrogen content is basically constant for all size fraction. The microstructure of the powder exhibits cellular image resulted from rapid solidification.

NOTES

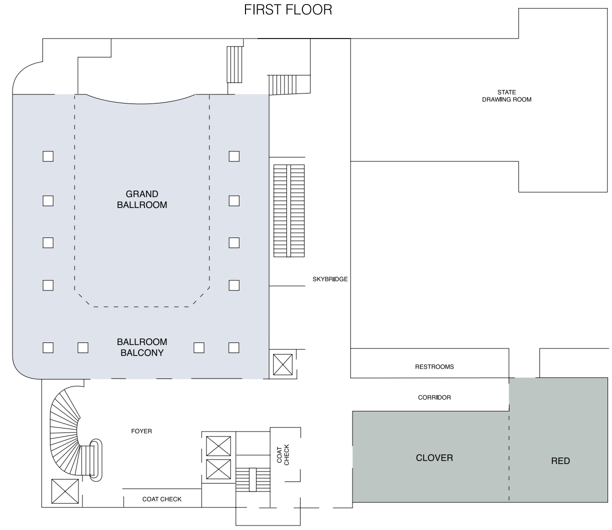


Hyatt at The Bellevue

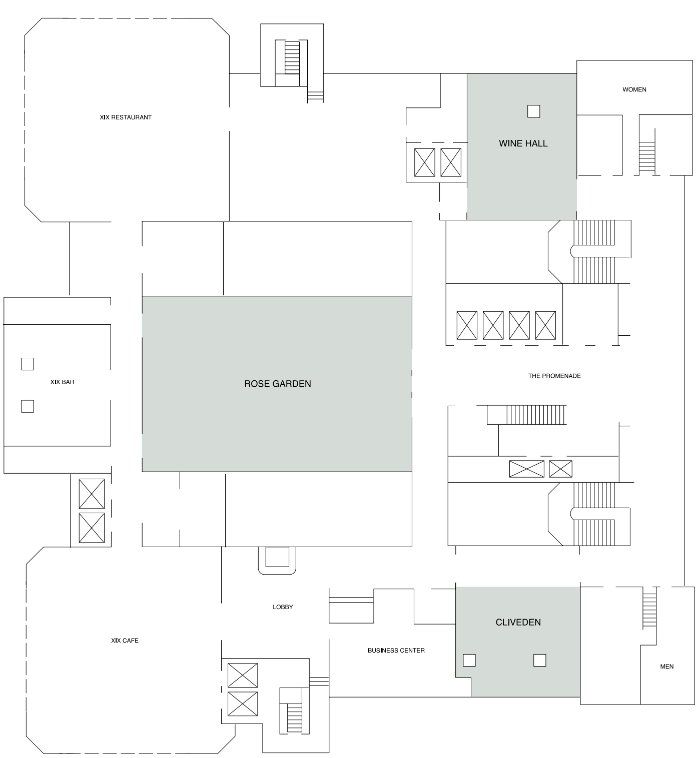
DIRECTIONS

From Philadelphia International Airport (8 miles): Follow I-95 North to Exit 17 — Broad Street / Route 611. Proceed north on Broad Street about 2 1/2 miles. Hotel is between Locust and Walnut streets. Use center lane and turn left into garage or driveway.

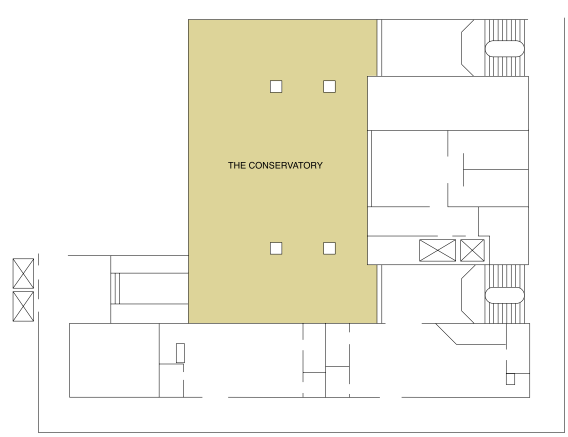
FIRST FLOOR



NINETEENTH FLOOR



TWELFTH FLOOR



SCHEDULE-AT-A-GLANCE

All events will be held at the Hyatt at The Bellevue unless otherwise marked.

As of August 11, 2017

Sunday, September 10		
Registration	5:00 p.m. to 8:30 p.m.	*Grand Ballroom Foyer, 1st Floor*
Welcome Reception	7:00 p.m. to 8:30 p.m.	*Conservatory, 12th Floor*

Monday, September 11		
Registration	7:00 a.m. to 5:15 p.m.	*Grand Ballroom Foyer, 1st Floor*
Exhibition Set-up	7:00 a.m. to 8:00 a.m.	*Grand Ballroom, 1st Floor*
Keynote Session	8:15 a.m. to 9:00 a.m.	*Grand Ballroom, 1st Floor*
Exhibition	8:15 a.m. to 6:15 p.m.	*Grand Ballroom, 1st Floor*
Technical Sessions	9:00 a.m. to Noon	*Grand Ballroom, 1st Floor*
Break	10:00 a.m. to 10:40 a.m.	*Grand Ballroom, 1st Floor*
Poster Session Set-up	10:00 a.m. to 10:40 a.m.	*Grand Ballroom, 1st Floor*
Lunch	Noon to 1:20 p.m.	*On Your Own*
Technical Sessions	1:30 p.m. to 5:10 p.m.	*Grand Ballroom, 1st Floor*
Break	2:50 p.m. to 3:30 p.m.	*Grand Ballroom, 1st Floor*
Poster Session & Reception	5:15 p.m. to 6:30 p.m.	*Grand Ballroom, 1st Floor*
Conference Banquet	7:00 p.m. to 9:30 p.m.	*Rose Garden, 19th Floor*

Tuesday, September 12		
Registration	7:30 a.m. to 5:15 p.m.	*Grand Ballroom Foyer, 1st Floor*
Technical Sessions	8:15 a.m. to Noon	*Grand Ballroom, 1st Floor*
Exhibition/Posters	8:15 a.m. to 5:10 p.m.	*Grand Ballroom, 1st Floor*
Break	10:00 a.m. to 10:40 a.m.	*Grand Ballroom, 1st Floor*
Lunch	Noon to 1:20 p.m.	*On Your Own*
Technical Sessions	1:30 p.m. to 5:10 p.m.	*Grand Ballroom, 1st Floor*
Break	2:50 p.m. to 3:30 p.m.	*Grand Ballroom, 1st Floor*
Social Activity: Phillies Baseball Game	7:05 p.m.	*Citizens Bank Park (ticket required)*

Wednesday, September 13		
Registration	7:30 a.m. to Noon	*Grand Ballroom Foyer, 1st Floor*
Technical Sessions	8:15 a.m. to Noon	*Grand Ballroom, 1st Floor*
Exhibition/Posters	8:15 a.m. to Noon	*Grand Ballroom, 1st Floor*
Break	10:00 a.m. to 10:40 a.m.	*Grand Ballroom, 1st Floor*
Poster Removal	10:00 a.m. to 10:40 a.m.	*Grand Ballroom, 1st Floor*
Exhibition Removal	Noon to 1:00 p.m.	*Grand Ballroom, 1st Floor*
Industrial Tours	Noon to 6:00 p.m.	*Bus departs from hotel lobby (ticket required)*