LMPC 2019

Liquid Metal Processing & Casting Conference 2019

September 8-11, 2019 • www.tms.org/LMPC2019

University of Birmingham Edgbaston Park Hotel and Conference Centre • Birmingham, UK

FINAL PROGRAM

SPONSORED BY: TMS the Materials Processing & Manufacturing Division, and the Process Technology and Modeling Committee.

SCHEDULE AT-A-GLANCE

All events will be held at the University of Birmingham Edgbaston Park Hotel and Conference Centre unless otherwise marked.

Sunday, September 8	Time	Location
Registration	5:00 PM - 7:00 PM	Fry Room Foyer, Ground Floor
Welcome Reception	6:00 PM - 7:30 PM	Fry Room, Ground Floor

Monday, September 9	Time	Location
Registration	7:00 AM - 6:00 PM	Fry Room Foyer, Ground Floor
Morning Refreshments	7:00 AM - 8:00 AM	Fry Room Foyer, Ground Floor
Exhibits/Posters Set-up	7:00 AM - 8:00 AM	Fry Room, Ground Floor
Welcome Remarks & Introductions	8:00 AM - 8:10 AM	Fry Room, Ground Floor
Keynote Speaker	8:10 AM - 8:55 AM	Fry Room, Ground Floor
Technical Sessions	8:55 AM - 11:55 AM	Fry Room, Ground Floor
Break & Exhibit Viewing	9:45 AM - 10:15 AM	Fry Room & Foyer, Ground Floor
Lunch	12:00 PM - 1:00 PM	Hotel Restaurant
Technical Sessions	1:15 PM - 5:05 PM	Fry Room, Ground Floor
Break & Exhibit Viewing	2:30 PM - 3:00 PM	Fry Room & Foyer, Ground Floor
Poster Session, Reception & Exhibit Viewing	5:15 PM - 6:30 PM	Fry Room, Ground Floor

Tuesday, September 10	Time	Location
Morning Refreshments	7:00 AM - 8:00 AM	Fry Room Foyer, Ground Floor
Registration	7:30 AM - 5:00 PM	Fry Room Foyer, Ground Floor
Technical Sessions	8:00 AM - 11:50 AM	Fry Room, Ground Floor
Break & Exhibit Viewing	9:15 AM - 9:45 AM	Fry Room & Foyer, Ground Floor
Lunch	12:00 PM - 1:00 PM	Hotel Restaurant
Technical Sessions	1:15 PM - 5:05 PM	Fry Room, Ground Floor
Break & Exhibit Viewing	2:30 PM - 3:00 PM	Fry Room & Foyer, Ground Floor
Conference Dinner	6:30 PM - 8:00 PM	Fry Room, Ground Floor

Wednesday, September 11	Time	Location
Morning Refreshments	7:00 AM - 8:00 AM	Fry Room Foyer, Ground Floor
Registration	7:30 AM - 4:30 PM	Fry Room Foyer, Ground Floor
Technical Sessions	8:00 AM - 11:50 AM	Fry Room, Ground Floor
Break & Exhibit Viewing	9:15 AM - 9:45 AM	Fry Room & Foyer, Ground Floor
Lunch	12:00 PM - 1:00 PM	Hotel Restaurant
Technical Sessions	1:15 PM - 4:15 PM	Fry Room, Ground Floor
Break & Exhibit Viewing	2:30 PM - 3:00 PM	Fry Room & Foyer, Ground Floor
Closing Remarks	4:15 PM - 4:20 PM	Fry Room, Ground Floor
Exhibit/Poster Removal	4:20 PM - 5:00 PM	Fry Room, Ground Floor

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WELCOME TO THE
2019 LIQUID METAL PROCESSING & CASTING CONFERENCE (LMPC 2019)!

On behalf of The Minerals, Metals & Materials Society (TMS), the Lead and Local Organizing Committees, and the Scientific Committee, we are pleased to welcome you to the 2019 Liquid Metal Processing & Casting Conference (LMPC 2019). For two decades this conference has served as an internationally respected forum for the exchange of ideas and developments in the field of the processing and use of liquid metals. The presentations will cover a wide range of aspects, and the conference publication contains complete coverage of the work discussed. The material in this meeting has direct relevance to current and future industrial applications in energy, environment, and aerospace as have the meetings held over the past years. The publication will join its predecessors in being a premier source of information for those areas of endeavor.

The meeting provides an opportunity for you to network with researchers and industrial users in the field. You will also be able to contribute in the on-going discussions during the technical presentations and the poster session. Social events have been organized for enjoying less formal interactions. We look forward to an exciting meeting of outstanding speakers, interactive poster sessions, and challenging discussions.

Welcome to Birmingham, and thank you for your participation in LMPC 2019!

ORGANIZING COMMITTEES

LEAD ORGANIZING COMMITTEE

- **Alain Jardy**, Université de Lorraine, France
- **Alec Mitchell**, University of British Columbia, Canada

LOCAL ORGANIZING COMMITTEE

- **R. Mark Ward**, University of Birmingham, UK
- **Nils Warnken**, University of Birmingham, UK

SCIENTIFIC COMMITTEE

- **Stewart Ballantyne**, MeltMet Technologies LLC, USA
- **Joseph J. Beaman**, University of Texas at Austin, USA
- **Jean-Pierre Bellot**, Institut Jean Lamour Nancy, France
- **Harald Holzgruber**, INTECO GmbH, Austria
- **Alain Jardy**, Université de Lorraine, France
- **Zhouhua Jiang**, Northeastern University, PRC
- **Koji Kajikawa**, Japan Steel Works, Japan
- **Abdellah Kharicha**, Montanuniversität Leoben, Austria
- **Matthew J. M. Krane**, Purdue University, USA
- **Henry Lippard**, ATI Allvac, USA
- **Alec Mitchell**, University of British Columbia, Canada
- **Ashish Patel**, TIMET, USA
- **R. Mark Ward**, University of Birmingham, UK

REGISTRATION

Your registration badge ensures admission to each of these events:

- Sunday evening welcome reception
- Refreshment breaks (Monday, Tuesday, Wednesday)
- Lunch buffet (Monday, Tuesday, Wednesday)
- Poster session reception
- Exhibit viewing coordinated with above refreshment breaks
- Tuesday conference dinner event*

**Please note that while one ticket for the conference dinner is included, registration was required for this event through the conference registration form.*

REGISTRATION HOURS

The registration desk will be located in the Fry Room Foyer on the Ground Floor.

Sunday	5:00 p.m. to 7:00 p.m.
Monday	7:00 a.m. to 6:00 p.m.
Tuesday	7:30 a.m. to 5:00 p.m.
Wednesday	7:30 a.m. to 4:30 p.m.

SOCIAL MEDIA

Please use the hashtag #LMPC2019 in reference to this event on social media.

INTERNET ACCESS

LMPC attendees receive free high-speed, wireless internet. To enter the WiFi, select the network "Edgbaston Park-Ask 4". You will then be prompted to enter your name and email. After entering these details, you will be logged on automatically.

TECHNICAL SESSIONS

All oral presentations will be on the ground floor in the Fry Room.

PROCEEDINGS

Conference registrants can access the proceedings in two formats:

- E-book, accessible from the proceedings page of **www.tms.org/LMPC2019**
- Soft cover printed book, available onsite

EXHIBITION HOURS

The exhibition will be located on the ground level in the Fry Room.

Monday, September 9	9:45 a.m. to 10:15 a.m. 2:30 p.m. to 3:00 p.m. 5:15 p.m. to 6:30 p.m.
Tuesday, September 10	9:15 a.m. to 9:45 a.m. 2:30 p.m. to 3:00 p.m.
Wednesday, September 11	9:15 a.m. to 9:45 a.m. 2:30 p.m. to 3:00 p.m.

TMS would like to thank the following Exhibitors and Corporate Sponsors for their generous support of the event:

SILVER SPONSORS

AMG ENGINEERING ald

ALD Vacuum Technologies GmbH is one of the internationally leading manufacturers of plants and systems for thermal and thermo-chemical treatment of metallic materials. Its core competencies are VACUUM METALLURGY and VACUUM HEAT TREATMENT.

The product range includes vacuum systems for melting, casting and remelting metal alloys (e.g. VIM, ESR, VAR), special coating systems for turbine blades in aviation, atomization systems for the production of high-quality metal powder (e.g. EIGA - VIGA), as well as heat treatment systems and services for hardening high-precision engine and transmission components and tools.

ALD employs about 500 people at its headquarters in Hanau, Germany, and about 900 people in more than 10 countries worldwide. ALD is part of AMG Advanced Metallurgical Group N.V., Netherlands, a public listed technology company with leading market position and approximately 3,300 employees.

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.

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TEL: (+1) 609- 561-7500
www.americanflux.net

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 2018, the Group generated sales of some €4.98 billion, operates 24 production sites and maintains subsidiaries and sales offices in 32 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.

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CONSARC Engineering Ltd are world leaders in the design, manufacture, installation and commissioning of vacuum and controlled atmosphere furnace equipment. Over fifty years of experience have gone into developing our vast thermal processing technology product range to process the most advanced materials for critical and demanding applications. Today, over half the vacuum or controlled atmosphere melting furnaces around the globe bear the Consarc name.

CONSARC is an Inductotherm Group company, a strategic part of one of the world's largest groups developing technologies for the melting and processing of high-performance metals and alloys. ISO 9001 certified, with operations worldwide, Consarc is well equipped to tackle furnace projects on a global basis.

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Thermo-Calc Software

Thermo-Calc Software is a leading developer of software and databases for calculation of phase diagrams and many other types of calculations involving computational thermodynamics and diffusion. Databases produced by the CALPHAD method are available for steels, slags, Ti-, Al-, Mg-, Cu-, Ni-superalloys, HEAs, refractory oxides and many more. **Thermo-Calc** is used for performing thermodynamic calculations and **DICTRA** is used for accurate simulations of diffusion in multicomponent alloys. **TC-PRISMA** simulates concurrent nucleation, growth, dissolution and coarsening of precipitate phases. Various software development kits are available. **TC-Python** for example enables Thermo-Calc to be called directly from your Python code.

Recently our **Process Metallurgy Module** was released, that is specifically developed for liquid phase processing of metals. With this module the liquid metal – slag – gas phase thermodynamics and soon also kinetics can be simulated all the way from hot-metal pretreatment (BOF-route) or scrap (EAF-route) to the final refined steel ready for casting.

WELCOME RECEPTION

The Welcome Reception will be held on Sunday, September 8, from 6:00 p.m. to 7:30 p.m. in the Fry Room.

POSTER VIEWING/NETWORKING RECEPTION

A Poster Session/Networking Reception is planned for Monday, September 9, from 5:15 p.m. to 6:30 p.m. in the Fry Room. Don't miss this great networking opportunity!

CONFERENCE DINNER*

The conference dinner will be held on Tuesday, September 10, from 6:30 p.m. to 8:00 p.m. in the Fry Room.

** Please note that while one ticket for the conference dinner is included, registration was required for this event through the conference registration form.*

ABOUT THE VENUE

The Edgbaston Park Hotel and Conference Centre is part of the University of Birmingham Group, and it is situated in a quiet spot on the edge of campus. Guests will enjoy complimentary wireless internet in all guest rooms, the hotel lobby, and public areas. Hotel guests have complimentary access to the University of Birmingham's Sport & Fitness club (which includes a pool, fitness classes, and squash and badminton courts). The hotel also features the 1900 Steakhouse Bar & Grill. Visit the housing and travel section of www.tms.org/LMPC2019 for more information on:

- A variety of local attractions and activities
- Additional hotel amenities

EMERGENCY PROCEDURES

The chances of an emergency situation occurring at LMPC 2019 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 Edgbaston Park Hotel and Conference Centre facility printed in this program (on page 27). 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.

In the event of an emergency, the firebell will ring, and all guests are asked to evacuate to the front of the hotel.

BADGES

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

REFUNDS

The deadline for all refunds was August 2, 2019. No refunds will be issued at the conference. Fees and tickets are nonrefundable.

EDGBASTON PARK HOTEL ACCESSIBILITY

TMS asks those requiring specific equipment or services to contact TMS Meeting Services at mtgserv@tms.org in advance. The Edgbaston Park Hotel and Conference Centre has a lift (elevator) so guests with disabilities can access all floors of the facility. The venue also has a number of disabled car parking spaces.

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.

TMS MEETINGS CODE OF CONDUCT

TMS is committed to providing a safe, inclusive, and welcoming environment and an experience that embraces the richness of diversity where all participants may exchange ideas, learn, network, and socialize in the company of colleagues in an environment of mutual respect. TMS does not tolerate harassment in any form and requires all participants to abide by the TMS AntiHarassment Policy and Meetings Code of Conduct in all venues, including ancillary events and social gatherings. Participants include, but are not limited to, attendees, exhibitors, speakers, members, guests, contractors, and TMS staff. TMS will communicate its AntiHarassment Policy and Meetings Code of Conduct to all service providers and venue leadership. To review the Code of Conduct, which includes a list of both expected and unacceptable behaviors, consequences for violating the code, guidelines for reporting unacceptable behavior, and an outline of incident investigation procedures, please go to www.tms.org/CodeofConduct.

The TMS Anti-Harassment 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 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.

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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.

SCHEDULE OF EVENTS

	Monday, September 9	Tuesday, September 10	Wednesday, September 11
Room	Fry Room	Fry Room	Fry Room
AM	Keynote Vacuum Arc Remelting 1	Electoslag Refining 2 Casting 1	Chemical Aspects 2 Processing 1
PM	Vacuum Arc Remelting 2 Electroslag Refining 1	Casting 2 Chemical Aspects 1	Processing 2
	Poster Session	Conference Dinner	
	Reception		

LMPC 2019

Liquid Metal Processing & Casting Conference 2019

TECHNICAL PROGRAM

The content in this technical program was generated on August 20. However, changes may still be implemented. Please refer to the online session sheets for the most up-to-date information.

Keynote Address

Monday AM
September 9, 2019

Room: Fry Room
Location: Edgbaston Park Hotel and Conference Centre

8:00 AM Introductory Comments

8:10 AM Keynote
Clean Metal – A Casting Perspective: *Nicholas Green*[1]; [1]University of Birmingham
Mechanisms of formation of exogenous oxide bifilms entrained during casting and their impact on component performance are widely accepted, demonstrated comprehensively and addressed in design codes for critical applications. Modelling transient liquid flows, predicting the formation and tracking of defects and prediction of material and component performance continue to pose significant challenges. The kinetics and thermodynamics of oxidation often result in bifilms captured in the liquid existing in a metastable state. Future challenges for improved understanding and control of liquid metal cleanliness will be explored with the objective of highlighting opportunities for design and development of more robust processes and components of assured reliability.

Vacuum Arc Remelting 1

Monday AM
September 9, 2019

Room: Fry Room
Location: Edgbaston Park Hotel and Conference Centre

Session Chair: Jean-Pierre Bellot, Universite de Lorraine-Institut Jean Lamour

8:55 AM
An Experimental Setup to Study the Influence of an External Magnetic Field on Arc Behavior: *Ashish Patel*[1]; Jeremy Sensenig[1]; [1]Timet
A bench top experimental setup was assembled to study arc behavior. The arc was formed using a welding power supply, and a graphite rod as an electrode. The graphite rod was connected to a linear drive for precise vertical positioning. A large grounded copper slug was used as base. A camera with appropriate filters was used for recording. The transverse magnetic field was generated by passing current through a coil; the magnitude and phase shift of the coil current was regulated using a microcontroller. The arc was observed to move in a direction perpendicular to the current and applied magnetic field. A parametric study on arc behavior by altering the nature of the magnetic field will be discussed.

9:20 AM
Investigations on Collective Motion of Cathode Spots in the VAR Process: *Abdellah Kharicha*[1]; Ebrahim Karimi Sibaki[1]; Menghuai Wu[1]; Andreas Ludwig[1]; [1]University of Leoben
The behaviour of the arc in the VAR process can be considered as the sum of the collective motion of the spots. The spots moves discreetly at high speed, but based on experimental observation the arc motion is continuous and much slower. The purpose of the present paper is to investigate numerically the movement of the many cathode spots in interaction through their self-magnetic field. The movement of the spots is assumed to be controlled by a combined stochastic-deterministic law using a retrograde Lorentz force. It is shown that the cathode spots randomly nucleate near the centre and then move towards the edge of the electrode. Many spots move collectively in the form of alignments of 3 to 7 spots. For large applied currents, the spots form a cloud that expands periodically in an anisotropic way.

9:45 AM Break

10:15 AM
Measurement of the Spatio-Temporal Distribution of Arcs during Vacuum Arc Remelting and their Implications on VAR Solidification Defects: *Joshua Motley*[1]; Kanchan Kelkar[2]; Paul King[1]; Matthew Cibula[1]; Alec Mitchell[3]; [1]Ampere Scientific; [2]Innovative Research LLC; [3]University of British Columbia
The behavior of vacuum arcs during VAR processing is known to impact product yield and contribute to ingot defects. For example, it has been shown that constricted arcs during the processing of segregation prone Nickel-based alloys can lead to defects in ingots. Despite this knowledge, the role of arc distributions in VAR processing has not been considered in controlling the furnaces. In addition, computational models of the process have typically assumed that the arc provides an axisymmetric, Gaussian heat input to the ingot, while acknowledging that this is the biggest unknown variable. Here we present the theory behind VARmetricTM and present analyses of the spatio-temporal arc distributions measured on a production VAR furnace. We then use the measured axisymmetric arc distributions to provide updated boundary conditions for solidification of the ingot to investigate the implications of the changing distributions on solidification and the relationship between arc distributions and defects.

10:40 AM
VT3-1 Titanium Alloy Ingot Solidification during VAR: *Evgenii Kondrashov*[1]; Kirill Rusakov[1]; Mikhail Leder[1]; Aleksandr Maksimov[1]; Lev Konovalov[1]; [1]VSMPO-AVISMA Corporation
A thermal model is developed for the ingot solidification during vacuum arc remelting (VAR) and is applied to calculate pool profiles for a VT3-1 alloy. The pool profiles are calculated for two remelting schedules, and the calculation results are compared with radiography data. The model calculation results are shown to agree satisfactorily with experimental data. Using radiography data, the authors calculated a morphological map for a VT3-1 alloy during VAR. The model is used in practice to develop conditions for the final remelting of a VT3-1 alloy to exclude the formation of segregation defects, namely, beta-flecks and macrosegregation.

11:05 AM
SOLAR Calculation of the Capacity of the Security System to Ensure the Extraction of Heat during Vacuum Arc Remelting (VAR): *Isabelle Crassous*[1]; [1]Framatome
VAR is used to produce reactive metals like titanium or zirconium. This technology is used by Framatome to produce zirconium alloys dedicated to nuclear and medical fields. The control of the process is essential to ensure quality through chemical homogeneity or security through the cooling system. For this reason, Framatome and the Institute Jean Lamour, have developed a specific code (SOLAR). The mathematical model is based on the solution of the coupled transient heat, momentum, and solute transport equations, under laminar or turbulent flow conditions, during the remelting and cooling of a cylindrical ingot. The specific case of a single melt M5Framatome ingot was studied: the evolution of the mold temperature is discussed during the process. The critical flow and the critical temperature defined by the free boiling theory are calculated and compared with the values calculated with SOLAR model. The corresponding results would be presented and discussed.

11:30 AM
Uncertainty in the Modeling of Nitinol Solidification in VAR: *Kyle Fezi*[1]; Matthew Krane[2]; [1]Fort Wayne Metals; [2]Purdue University
Nitinol's unique shape memory and super-elastic properties make it desirable for many biomedical, automotive, and aerospace applications, but are highly dependent on the Ni/Ti ratio and other outcomes of solidification behavior in VAR. A cost-efficient method to explore the processing parameter space is numerical modeling, but simulation results reliability is dependent on uncertainty in the model and the input data. The VAR process is modeled using the commercially available MeltFlow-VAR package. The sensitivity of the sump depth prediction to several input parameters, primarily material properties and boundary conditions, were analyzed. Level one sensitivity analysis determined which inputs had the most impact and level two analysis quantified sump depth uncertainty due to those parameters. Uncertainty in the thermal boundary condition on the ingot's sidewall was found to have a large influence on the sump depth, providing justification for an experimental program to more accurately measure heat loss during the process.

Vacuum Arc Remelting 2

Monday PM
September 9, 2019

Room: Fry Room
Location: Edgbaston Park Hotel and Conference Centre

Session Chair: Ashish Patel, Timet

1:15 PM
Numerical Investigation of the Vacuum Arc Remelting (VAR) Process: *Ebrahim Karimi Sibaki*[1]; Abdellah Kharicha[1]; Menghuai Wu[1]; Andreas Ludwig[1]; J. Bohacek[1]; Harald Holzgruber[2]; Bertram Ofner[2]; Alexander Scheriau[2]; Michael Kubin[2]; [1]University of Leoben; [2]INTECO
Nowadays, the Vacuum Arc Remelting (VAR) process is effectively utilized to manufacture Titanium-based alloys. A comprehensive CFD model is proposed to study the interaction between various transport phenomena (flow, heat, etc.) in the VAR. All elements of the process including the electrode, vacuum, Titanium-based ingot, and mold are taken into account. The electromagnetic field is calculated in the entire process. The flow filed in the melt pool is computed. Furthermore, the pool profile of the solidified ingot is calculated. The model enables us to compute the radiation heat transfer in the vacuum region where the amount of side-arcing is prescribed. The impact of side-arcing on the magnetohydrodynamics behaviour of the melt pool and consequently the pool profile of the ingot is analysed. Eventually, the model is validated against an experiment.

1:40 PM
3D Numerical Simulation of the VAR Consumable Electrode Melting Process: *Rayan Bhar*[1]; Alain Jardy[1]; Pierre Chapelle[1]; Vincent Descotes[2]; [1]Institut Jean Lamour; [2]Aperam Alloys Imphy
A 3D numerical model was set-up to simulate the formation and dynamics of the liquid metal film under the consumable electrode during VAR process. In the present paper the implementation of this model is described. It was developed using the open source computational fluid dynamics (CFD) software, OpenFOAM. The model solves coupled momentum and energy equations combined with a volume-of-fluid (VOF) method to track the liquid metal free surface. The melting of the electrode material is modelled with an enthalpy-porosity approach. The electric power supplied by the arc is supposed to be uniform and distributed between the electrode as well as the liquid bath. For a given electric arc power, the model quantitatively predicts the dripping and possible drip-shorts, hence the overall melt rate. Simulations are validated through comparisons with experimental data extracted from available literature.

2:05 PM
Feedback-based Control over the Spatio-temporal Distribution of Arcs during Vacuum Arc Remelting via Externally Applied Magnetic Fields: *Matthew Cibula*[1]; Paul King[1]; Joshua Motley[1]; [1]Ampere Scientific
Ampere Scientific's VARmetricTM measurement system for Vacuum Arc Remelting (VAR) furnaces passively monitors the distribution of arcs over time during VAR in real time. The arc behavior is known to impact both product yield and quality and can pose potentially catastrophic operating conditions. Arc position sensing with VARmetricTM enables a new approach to control the heat input to the melt pool. Transverse external magnetic fields are applied to push the arcs via the Lorentz force using feedback of the arc location to control the arc. This has been tested on Ampere Scientific's small-scale laboratory arc furnace with electromagnets used for control for up to 60 seconds while monitoring the arc location with VARmetricTM. The arc distributions are shown to be significantly different from the uncontrolled distributions with distinct thermal profiles at the melt pool. Alternatively, this type of control can be periodically applied to react to undesirable arc conditions.

2:30 PM Break

ElectroSlag Refining 1

Monday PM
September 9, 2019

Room: Fry Room
Location: Edgbaston Park Hotel and Conference Centre

Session Chair: Alec Mitchell, University of British Columbia

3:00 PM
Current Density and Electrode Tip Shape in an Electroslag Remeleting Process with Two-series Connected Electrodes: *Baokuan Li*[1]; Xuechi Huang[1]; [1]Northeastern University
An electroslag remelting process (ESR) with the two series-connected electrodes has the advantage of little inductance, lower power consumption and high melting rate, which is used to produce large-scale or rectangular ingot. A transient three-dimensional multi-physical field model has been developed to understand the two-phase flow and heat transfer of slag and liquid metal under the effect of electromagnetic field in ESR with the two series-connected electrodes. The consumable mechanism of electrode and examine the effect of operating parameters such as current density and immersion depth on the flow field and electrode tip shape. The results show the main part of current is through the slag cap and little enters into ingot in two series-connected electrodes ESR system. The maximum joule heat power density is located at the interface of slag and electrodes, and decrease with the increasing of the electrodes immersion depth. The averaged joule heat power density increases with reducing of slag cap thickness. The variation of electrode tip shape is connected with distribution of current density and heat-power density, and the consumable rate in electrode tip surface in slap cap is proportional to the local heat-power density.

3:25 PM
DNS and Engineering Modeling of the Electoslag Remelting Process: *Jeremy Chaulet*[1]; Abdellah Kharicha[2]; Bernard Dussoubs[1]; Sylvain Charmond[3]; Alain Jardy[1]; Stéphane Hans[3]; [1]Institut Jean Lamour; [2]Christian Doppler Laboratory for Metallurgical Applications of MHD; [3]Aubert & Duval
Electroslag remelting (ESR) is an extensively used process to produce metallic ingots with high quality standards. In order to investigate the possibly important impact of the behavior of liquid metal droplets in the slag on the solidification of the ingot, DNS and engineering modeling have been associated. At MU Leoben, several 3D simulations were performed to explore the effects of the electric current and electrode immersion depth on the dripping phenomena. Simultaneously a 2D multiphase model was used to estimate the distribution, speed, and overheat of the droplets entering the liquid pool. With adequate adaptations, the results given by this computationally cheap 2D model can fit the 3D results. The aforementioned results are then used to improve a 2D engineering model previously developed at IJL Nancy, aimed to help optimizing the operation parameters. For validation, several remelting experiments at industrial scale were performed under various geometrical and electrical conditions.

3:50 PM
Results of the New Generation ESR (Electro Slag Remelting) Unit with Rotating Electrode, Designed by SMS Mevac GmbH: *Cihangir Demirci*[1]; B. Mellinghoff[1]; J. Schlüter[1]; C. Wissen[1]; Martin Schwenk[2]; Dr. Ing[2]; Bernd Friedrich[2]; [1]SMS Mevac GmbH; [2]RWTH Aachen University
The increasing demands being made on the quality of special alloys means new ideas need to be found and incorporated into the ESR process. One of the new possible approaches is the use of a rotating electrode during the ESR process. To find out the influence of a rotating electrode during the ESR process, the atmospheric ESR unit at the institute IME/RWTH Aachen University was redesigned by SMS Mevac GmbH: its vertically-oscillating function has been changed to a rotating and vertically-oscillating function. This paper presents the results regarding the molten metal pool formation for better crystallization and the cleanliness of ESR ingots which have been remelted with rotating electrodes.

4:15 PM
Modeling Electrochemical Transport of Ions in the ESR Process: *Ebrahim Karimi Sibaki*[1]; Abdellah Kharicha[1]; Menghuai Wu[1]; Andreas Ludwig[1]; J. Bohacek[1]; [1]University of Leoben
Numerous electrochemical reactions were suggested for chemical elements such as S, O, Al, and Fe to describe metal refinement mechanisms in the ESR. Electrochemical (Faradaic) reactions take place within the slag bath or at slag-metal-gas-mold interfaces. Specifically, those reactions are carried out at the liquid film under the electrode tip as well as at the droplet-slag interface. We propose a model for Faradaic reactions at those interfaces as well as electrochemical transport of ions in the bulk of slag. It is found that the intensity of the flow filed and the strength of electric field in the bulk of slag can significantly impact Faradaic reactions and consequently efficiency of metal refinement. Impacts of electrode polarity and electro-migration of ions are analysed. Based on modeling results some explanations are suggested for theses phenomena in DC ESR: higher melt rate for positive polarity, and formation of FeO layer under electrode tip.

ElectroSlag Refining 2

Tuesday AM
September 10, 2019

Room: Fry Room
Location: Edgbaston Park Hotel and Conference Centre

Session Chair: Zhouhua Jiang, Northeastern University

8:00 AM
Effect of Rare Earth Magnesium Alloy on Microstructure and Mechanical Properties of H13 Steel: *Xing Li*[1]; Zhouhua Jiang[1]; Xin Geng[1]; Minjun Chen[1]; Shan Cui[1]; [1]Northeastern University
Rare earths and magnesium are common purifying elements in steel, but it is rarely reported that rare earths and magnesium are added to steel at the same time. In this paper, H13 steel and rare earth magnesium treated H13 steel were prepared respectively by using vacuum induction melting (VIM). After the same forging and heat treatment process, the microstructure and mechanical properties were investigated comparatively. The results show that rare earth magnesium alloy could purify the molten steel. The contents of O and S in H13 steel were significantly reduced. Furthermore, rare earth magnesium alloy promoted the precipitation of carbides in H13 steel and made the carbide distribution finer and more uniform. The tempering mechanical properties indicated that rare earth magnesium alloy improved the hardness, tensile strength and impact energy of H13 steel by different degrees.

8:25 AM
Experimental Study on Alloying Additions in Electro Slag Refining: *Harald Scholz*[1]; Thomas Kilzer[1]; Gerhard Brückmann[1]; Henrik Franz[1]; [1]ALD Vacuum Technologies GmbH
Electro Slag Refining can be carried out under vacuum, atmospheric or elevated pressure using atmospheric composition or inert gas. Process parameters like electrode sizes, slag systems and the working pressure can be adapted to the necessities of the process to influence the final ingot quality. In pressure ESR gases like Nitrogen can be easily added to the final ingot via feeding of nitrogen containing elements and decreasing the immersion of the electrode in slag. In addition the slag can be de-oxidized to maintain the refining capability of the slag. As a next step the alloying of certain elements during ESR can be done considering the melting temperature of slag. A feasibility analysis was carried out allowing the addition of vanadium oxide and de-oxidation agent at the same time during the ESR process in order to increase the vanadium content in the final ingot.

8:50 AM
Effect of the Al2O3-content in the Slag on the Chemical Reactions and Non-metallic Inclusions during Electro-slag Remelting: *Reinhold Schneider*[1]; Manuel Molnar[2]; Gerald Klösch[3]; Christopher Schüller[3]; [1]University of Applied Sciences Upper Austria; [2]K1-MET GmbH; [3]voestalpine Stahl Donwawitz GmbH
The effects of Al2O3-contents between 0 and 33% in the remelting slag was investigated on the example of a ball bearing steel and the use of an experimental ESR-plant. Thereby changes in the chemical composition of the materials (electrode versus ingots) and in the remelting slag during remelting, as well as the amount and composition of the non-metallic inclusion (NMI) prior and after remelting were investigated. Changes in the chemical composition can largely be explained by equilibrium reactions between the slag and the metal, thereby low Al-contents in the remelted materials could only be achieved with lowest Al2O3-contents in the slag. Furthermore, higher Al2O3-contents in the slag also lead to higher oxygen and sulfur contents in the steel as well as higher amounts of NMI after remelting. The composition of the NMI changed from alumina-type for high Al2O3-contents to spinel-type and other mixed oxides at low Al2O3-contents.

9:15 AM Break

Casting 1

Tuesday AM
September 10, 2019

Room: Fry Room
Location: Edgbaston Park Hotel and Conference Centre

Session Chair: Harald Holzgruber, INTECO Special Melting Tech GmbH

9:45 AM
A New Approach to the Requirements of Casting Factors in Investment Cast Aluminium Alloys: *Roger Lumley*[1]; [1]AWBell Pty Ltd
A study was conducted with aluminum investment castings manufactured from A356-T6 and 357-T6 alloys, to develop a fundamentally derived quality model based on the true-stress / true-strain behavior observed during tensile testing. Tensile elongation and tensile strength of alloys are particularly sensitive to the presence of casting defects, that cause unstable plasticity. As a result, these properties together are useful measures of casting quality. It will be shown how the quality model employed may be used to develop both material and processes, and then to assign casting factors based on a physical basis. The methodology presented may also be used by suppliers to prove the capability and statistical reproducibility of products or processes. Examples will be provided as to how the methodology has been successfully applied to production aerospace components designed to be classified with Casting Factors approaching 1.0.

10:10 AM
Numerical Prediction of the Interfacial Heat Transfer Coefficient for Permanent Mold Casting of Mg-Al Alloys: *Muhammad Umer Bilal*[1]; Norbert Hort[1]; [1]Helmholtz-Zentrum Geesthacht
Most Mg alloys are based on the Mg-Al system and casting is the commonly used production process for these alloys. Apart from many governing factors, a parameter of prime importance for the numerical simulation of casting is the interfacial heat transfer coefficient (IHTC). Principally, it quantifies the heat flux between casting and mold. The study aims towards finding the unknown boundary temperatures and flux from the experimental temperature measurements using the inverse methodology. The IHTC was predicted for a variety of Mg-Al alloys, which were cast using permanent cylindrical mold. Unidirectional heat flow was ensured in order to replicate the experimental conditions for solving the one-dimensional transient heat equation. The numerically determined mold temperature was in good agreement with the experimentally measured values. Moreover, the heat transfer behavior across the interface depicted in the form of IHTC is discussed, also various empirical and numerical aspects of the method are highlighted.

10:35 AM

Influence of Gap Formation and Heat Shrinkage Induced Contact Pressure on the Development of Heat Transfer in Gravity Die Casting Processes: *Thomas Vossel*[1]; Björn Pustal[1]; Andreas Bührig-Polaczek[1]; [1]RWTH Aachen University

Anticipating the processes and parameters involved for accomplishing a sound metal casting requires an in-depth understanding of the underlying behaviors characterizing a liquid melt solidifying inside its mold. With heat balance and thermomechanical effects as two essential aspects of the casting process, numerical simulations can be used as a tool to predict the advancing solidification and the occurring stress-strain formation. A manifold of parameters gets incorporated in such simulations with some parameters being hard to define in advance. The heat transfer serves as a primal example for such an estimated parameter. This paper evaluates different approaches to estimate the heat transfer coefficient for A356 gravity die casting and will discuss the significance of not treating heat transfer as a pure function of temperature or time but as an effect-driven variable that has to be adjusted locally due to the possibility of local gap forming and heat shrinkage induced contact pressure.

11:00 AM

Ancillary Processes in Casting Manufacturing Introducing Risks in Production: *Oscar Caballero*[1]; Xabier Esquisabel[1]; [1]Industria De Turbo Propulsores S A

Manufacturing of castings in the aerospace industry is tightly controlled. Process parameters are fixed and customers and producers agree not to modify them for the benefit of having stable processes that always achieve the same quality on products and do not introduce scatter in mechanical properties or other characteristics of the parts. However, manufacturing constraints and other needs make some changes happen during regular production. As long as the changes affect identified critical parameters, these are of course thoroughly assessed to evaluate their effect on the final parts. However, in some occasions, changes in ancillary processes that are not expected to have any influence or risk on the final parts are introduced with no further evaluation. Unfortunately, these assumptions are not always correct. The case of plasma torch cutting for removing gating system in castings is presented here. Changing the gas caused some trouble on the final parts.

11:25 AM

Formation of Central Semi-macro Segregation and its Minimization by Soft Reduction during the Continuous Casting of Heavy and Wide Slab: *Min Jiang*[1]; En-Jiao Yang[1]; Zhi-Gang Xu[1]; Xin-Hua Wang[1]; [1]University of Science and Technology Beijing

Formation of semi-macro segregation in heavy and wide slab was discussed in present work. Central segregation in slab was composed of independent semi-macro spots. It increased with the rise of super heat and was more concentrated because of well growth of column grains. By comparison, well-developed equiax grains helped to scattered such semi-macro spots. However, with the use of soft reduction, central segregation peaks were lower at higher super heat, implying that the segregation was more effectively minimized under developed column grains. The relationship between central semi-macro segregation and solidification microstructure was discussed. Moreover, effect of solidification microstructure on the efficiency of soft reduction was elucidated. Based on these findings, continuous casting process of the heavy and wide slab was improved and quality of the cast products were greatly enhanced.

Casting 2

Tuesday PM
September 10, 2019

Room: Fry Room
Location: Edgbaston Park Hotel and Conference Centre

Session Chair: Alain Jardy, CNRS / IJL Dept. SI2M

1:15 PM

Investment Casting of High Reactive and High Melting Metals using Calcium Zirconate Crucibles: *Florian Bulling*[1]; Ulrich Klotz[1]; Claudia Legner[1]; F. König[1]; Lisa Freitag[2]; C. Faßaue[2]; Christos Aneziris[2]; Stefan Schafföner[3]; [1]fem Research Institute for Precious Metals and Metals Chemistry; [2]TU Bergakademie Freiberg; [3]University of Connecticut

In the past investment castings of highly reactive metals were performed by vacuum arc remelting (VAR) to avoid contaminations caused by the crucible material. Especially titanium and its alloys require a very high stability of the refractory elements related to the melt components. In this work we describe the development of CaZrO3 crucibles for investment casting with vacuum induction melting (VIM). Casting trials were conducted with tilt-/ centrifugal-/ and electric arc casting machines. To investigate the reactivity and thermal resistance of the refractory material alloys of Ti, Pt, CoCr and Zr were tested with different casting parameters. In this context influence of pre-casting evacuation, super heating and dwell time of the melt were examined by chemical analysis, metallographic examination and mechanical testing. In comparison to other refractory crucibles a lower contamination of the cast product by the crucible material could be achieved, which resulted in beneficial mechanical properties.

1:40 PM

Effect of Oxygen Atmosphere in High Pressure Die Casting Melt Holder Crucible on Metal Quality and Cast Part of AlSi9Cu3: *Irem Sapmaz*[1]; Omer Vardar[2]; Asim Zeybek[1]; Gökhan Tekin[1]; Muhammet Uludag[3]; [1]Yesilova Holding; [2]Can METAL, Yesilova Holding; [3]Bursa Technical University

Even though cold chamber die casting is the most suitable method for casting Al-Si based alloys, they tend to react with oxygen atmosphere on holder crucible. Reacting with oxygen causes formation of oxide film layer and this layer can break easily while the melt is being picked up from crucible and it triggers the initiation of bifilms during solidifying. In this work, the comparison of the metal quality of molten aluminum alloy that obtained from the crucible and the solid part that obtained from the same melt after casting will be investigated. Cast samples will be produced for before and after degassing processes. X-Ray radiography will be used for viewing porosities. Metal quality will be defined and bifilm index will be measured by Reduced Pressure Test (RPT). As a result, the effect of cold chamber die casting method on the metal quality will be revealed.

2:05 PM

Identification of Relevant Parameters for a Gap and Pressure Dependent Heat Transfer Model for Different Cooling Conditions in Gravity Die Casting: *Nino Wolff*[1]; Mahmoud Ahmadein[2]; Björn Pustal[1]; Andreas Bührig-Polaczek[1]; [1]RWTH Aachen University; [2]Tanta University

Local heat transfer in gravity die casting is of great importance for precision in terms of distortion, properties and quality of the castings due to localized variance in gap thickness or contact pressure. Experiments were carried out casting an A356 aluminum alloy in a steel mold at different initial temperatures, while the remaining process parameters were kept constant. During solidification, the temperature gradients at the interfaces between casting, mold and core are experimentally determined. The size of the air gap forming and the contact pressure acting on the core are measured as well. The experimental results are used to derive correlations related to the heat transfer coefficient at the interface, the thickness of the air gap and the contact pressure.

2:30 PM Break

Chemical Aspects 1

Tuesday PM
September 10, 2019

Room: Fry Room
Location: Edgbaston Park Hotel and Conference Centre

Session Chair: Matthew Krane, Purdue University

3:00 PM
Liquid Metal Flow Studied by Positron Emission Particle Tracking: *Agnieszka Dybalska*[1]; Adrian Caden[1]; David Parker[1]; John Wedderburn[1]; William Griffiths[1]; [1]University of Birmingham
To improve the properties of castings a new technique to observe fluid flow and study the motion of oxygen-bearing inclusions has been developed. The new technique, Positron Emission Particle Tracking (PEPT), enables a single radioactive tracer particle moving inside a liquid metal casting to be tracked with an accuracy of some millimeters, which depends on the liquid metal and mould material properties. These novel experiments give promising results to observe the liquid metal flow and locate the tracked particle in the cast metal. Experiments have shown that various particle sizes can be used to observe the liquid metal flow if the particle has sufficiently initial radioactivity. The different types of particles are considered and the radioactivity of them is compared in terms of usability for the tracking in the aluminium fluid flow.

3:25 PM
Slag-metal Interactions in the FeMn Tapping Process: Interfacial Properties and Wetting: *Sergey Bublik*[1]; Sarina Bao[2]; Merete Tangstad[1]; Kristian Einarsrud[1]; [1]Department of Materials Science and Engineering, NTNU; [2]Metal Production and Processing, SINTEF Industry
FeMn-alloys are produced by transforming ore and carbon materials into FeMn and slag at high temperatures in a furnace. Entrainment of FeMn in slag during tapping reduces the yield. Entrainment and subsequent separation are strongly influenced by slag-metal interfacial properties. In the current work, interfacial properties, including the contact angle, in the FeMn-slag graphite system have been investigated using the sessile drop technique at temperatures above 1300 ˚C. Two experimental configurations are proposed: (a) slag and metal placed beside each other on graphite; and (b) slag placed on top of the metal layer, which is in contact with graphite. Results demonstrate that the contact angle between slag and metal is 55-60˚ at temperatures from 1310 to 1350 ˚C and slag-metal weight ratio around 0,25. In addition, wetting properties are considerably influenced by the variation of slag-metal weight ratio in the range from 0,25 to 1,50 and only marginally by temperature.

3:50 PM
Calculating Steel Making and Steel Refining Processes using Thermo-Calc's New Process Metallurgy Module and the CALPHAD Database TCOX9: *Nicholas Grundy*[1]; Andreas Markstrom[1]; Lina Kjellqvist[1]; Ralf Rettig[1]; Johan Jeppsson[1]; Johan Bratberg[1]; [1]Thermo-Calc Software
Computational thermodynamics is a powerful tool widely applied in materials science, e.g. for alloy design. Thermodynamic databases developed through the CALPHAD approach usually give reasonable predictions of thermodynamic properties as well as the phase equilibria of corresponding multi-component systems. A thermodynamic database, TCOX, has been developed for calculating thermochemical interaction between liquid steel and slag. With the TCOX database an attempt is made to develop an internally consistent database for oxygen-containing systems. Today the TCOX database includes the major alloying elements in steels as well as the important slag elements. Additionally, a graphical interface for steel/slag calculations that is easy to use and suitable for the steel industry has been developed. Such an interface, together with the TCOX database, is a powerful tool for controlling complex metallurgical processes, for example desulphurization, dephosphorization or ladle refining, and in the development of new steel grades.

4:15 PM
Dissolution Rate of Carbon in Liquid Metal: Hamideh Kaffash[1]; *Merete Tangstad*[1]; [1]Norwegian University of Science and Technology
In this paper carbon dissolution studies were carried out on four carbon materials, viz. graphite, commercial charcoal and two metallurgical cokes, coke A and coke B. The rate of carbon dissolution into molten Fe-85%Mn at initial stage at 1550˚C, were determined. Characterization of the substrates was accomplished using proximate analysis, surface topography and XRD. The results showed that coke A and coke B had the highest overall dissolution rate and the dissolution rate constant was determined to be 6.73×10-2 cm/s and 5.94×10-2 cm/s respectively The dissolution rate constant for graphite was 3.52×10-2 cm/s and 1.47×10-2 cm/s for charcoal. Within poorly ordered carbon materials (charcoal and cokes) crystallite size and surface roughness seemed to be dominant factors affecting the dissolution rates. The dissolution mechanism was found to be both mass transfer and interfacial reaction.

4:40 PM
Surface Tension, Viscosity and Specific Heat Capacity of Ni-based Superalloys MC2, LEK94 and CMSX-10 in the Liquid Phase Measured in the Electromagnetic Levitator (EML-ISS) on Board the International Space Station: *Markus Mohr*[1]; Rainer Wunderlich[1]; Hans-Jörg Fecht[1]; [1]Ulm University
Nickel-based superalloys combine high temperature strength, creep resistance and toughness, and hence find application in turbines for land-based power generators as well as in aircraft engines. The used casting process is time consuming and costly, making it necessary to perform supporting simulations of the heat and material flow in the melt. This models require good input data of thermophysical properties in the solid and liquid phase.Measurement of surface tension, viscosity and specific heat of liquid metals is challenging, due to the melts high solution reactivity. The method of choice is electromagnetic levitation, a containerless method. However, gravitational forces have to be absent to obtain a spherical droplet with controlled fluid flow conditions. We will present and discuss measurements of surface tension, viscosity and specific heat capacity, performed in the Material Science Laboratory Electromagnetic Levitator (ISS-EML) on board the European Space Laboratory Columbus in the international space station (ISS).

Chemical Aspects 2

Wednesday AM
September 11, 2019

Room: Fry Room
Location: Edgbaston Park Hotel and Conference Centre

Session Chair: Henry Lippard, ATI Specialty Materials

8:00 AM
Electromagnetic Filter Priming (EMFP) of Ceramic Foam Filters (CFF) for Liquid Aluminium Filtration: *Robert Fritzsch*[1]; Ragnhild Aune[2]; [1]Pyrotek, EMP Technologies Limited; [2]Norwegian University of Science and Technology
Electromagnetic (EM) fields can influence the behavior of liquid metals. EM fields have now been successfully applied to prime commercial scale grade 30 to 80 Ceramic Foam Filters (CFF). The required properties of the EM fields in such a system are different from existing systems. Similar physics are applied, i.e. Lorentz forces induced by time varying EM fields; however, in the present system the forces are used to overcome the metal surface energy for filter priming.This study presents results from 23 inch full scale industrial priming trials, using moderate preheated single to triple 23 inch CFF's from grade 30 to 80 avoiding thermal shock. The influence on priming of the CFF structure, and the resulting improvements in filter productivity and reliability are discussed. The results obtained utilize Finite Element Modeling (FEM). Estimated filtration efficiency of different filter types are presented as functions of velocity and thickness.

8:25 AM

Wettability of Molten Fe-Si-B Alloy on Graphite, Al2o3, and h-BN Substrates: *Jianmeng Jiao*[1]; Bettina Grorud[1]; Jafar Safarian[1]; Merete Tangstad[1]; [1]Norwegian University of Science and Technology

Fe-26.38Si-9.35B alloy (numbers in mass %) is of interest as a phase change material (PCM) because it exhibits high thermal conductivity, moderate melting point, high latent heat, and low cost. This study offers valuable insights into the contact angles of molten eutectic Fe-26.38Si-9.35B alloy on various substrates using the sessile drop method. Moreover, the reactivity has been investigated by examining the cross-sections between Fe-26.38Si-9.35B droplets and substrates with a scanning electron microscope (SEM). The purpose of this study is to find a proper refractory material for the new Fe-26.38Si-9.35B PCM. These wetting tests confirm that the contact angle between molten Fe-26.38Si-9.35B and Al_2O_3 is about 112\176. Molten Fe-26.38Si-9.35B spreads over the graphite plate and the contact angle is estimated to be 31\176 and a continuous silicon carbide (SiC) layer is formed between the molten Fe-26.38Si-9.35B and graphite. Interestingly, three melting/solidification cycles have been performed on hexagonal boron nitride (h-BN) substrate at the temperature range of 1100-1550 \176C. The contact angle is observed to be 142\176 in the first cycle, 105\176 in the second cycle, and 130\176 in the third cycle. This study contributes to our understanding of the wettability properties of molten Fe-26.38Si-9.35B alloy on various substrates.

8:50 AM

Mass-Spectrometric Study of Thermodynamic Properties of CaO–TiO2 Melts: *Sergey Shornikov*[1]; [1]Vernadsky Institute of Geochemistry of RAS

The oxide activities in the CaO–TiO2 melts were determined by Knudsen effusion mass-spectrometric method in the temperature range 2241-2441 K. The experimental data allowed to calculate the partial and integral thermodynamic characteristics (Gibbs energies, enthalpies and entropies of melt formation). The obtained data are compared with those available in the literature.

9:15 AM Break

Processing 1

Wednesday AM
September 11, 2019

Room: Fry Room
Location: Edgbaston Park Hotel and Conference Centre

Session Chair: Abdellah Kharicha, Montanuniversität

9:45 AM

Reduction of Explosion Frequency and Severity during BOF Charging and Blowing: *James Sundal*[1]; [1]JS Metallurgical, LLC

One of Russia's largest integrated steel mills employed the services of JS Metallurgical, LLC to study and assist in remedying frequent BOF explosions which had plagued the producer for many years. Some of the more severe past explosion events had caused significant equipment damage, production downtime, and personal injury to employees. JS Metallurgical, LLC was invited to visit the plant in two stages; the first to asses the issue and provide guidance to process improvements, and the second (several months later) to evaluate the effectiveness of changes made by the plant. This study involves scrap management and preparation, materials quality and handling, environmental factors, process design, and materials chemical transformation and interaction with hot metal.

10:10 AM

Numerical Modelling and Optimization of the Electrode Induction Melting for Inert Gas Atomization (EIGA): *Sergejs Spitans*[1]; Henrik Franz[1]; Egbert Baake[2]; [1]ALD Vacuum Technologies GmbH; [2]Institute of Electrotechnology, Leibniz University

Electrode Induction Melting Inert Gas Atomization (EIGA) is one of the leading processes for manufacturing of high-quality titanium, zirconium, niobium and precious metal alloy spherical powders for use in aerospace, medical, energy, chemical, electronic and other industries. To study the EIGA process a numerical model for the electrode induction melting has been developed by means of coupling between the Lorentz force and Joule heat calculation in ANSYS and a transient heat transfer, melting and turbulent free surface flow calculation (including droplet detachment) in FLUENT. Parameter studies revealing the impact of the induction coil design and process conditions on the electrode melting behaviour (melting stability and regime, droplet size and superheat) will be presented. Finally, using numerical modelling we have successfully tailored our EIGA systems for atomization of new refractory materials with especially high melting temperatures like Tantalum (3017 °C, Ø40mm) and ensured the further scale-up of established process (Ti-6Al-4V, Ø150mm).

10:35 AM

Thermo-hydrodynamic Modeling of the Plasma Arc Melting Cold Hearth Refining Process (PAMCHR): Léa Décultot[1]; Alain Jardy[2]; Stéphane Hans[1]; Emiliane Doridot[1]; Jerôme Delfosse[3]; Fabienne Ruby-Meyer[4]; *Jean-Pierre Bellot*[2]; [1]Aubert & Duval; [2]Institut Jean Lamour; [3]Safran Tech; [4]MetaFensch

In order to set up a titanium alloy recycling route in Europe, UKAD, a joint-venture between Aubert & Duval and UKTMP, ADEME and Crédit Agricole Center France, created the company EcoTitanium. The recycling is performed thanks to the PAMCHR process with the aim of producing aeronautical titanium alloy ingots. The research work is focused on the refining hearth stage, a very important step where low and high density inclusions have to be removed. A 3D numerical simulation of the thermal and hydrodynamic behavior of the liquid metal bath has been set up based on Ansys-Fluent CFD software. Thermal and shear effects of the plasma jet on the turbulent flow have been modelled together with the transient displacement of the torches. A comparison between the results obtained experimentally and numerically is carried out in order to validate the numerical model, both for a pilot furnace, and the industrial EcoTitanium furnace.

11:00 AM

Defect Curing using Plasma Arc for Continuously Cast Steel Slabs: *Ki Hyeon Moon*[1]; [1]Posco

Although many kinds of countermeasures have been applied to reduce the surface defects during continuous casting of slabs, limit has been always met not to completely remove the casting defects. In this paper, a new trial is introduced to cure surface defects and consequently to improve the surface quality for cast slabs. Plasma torches were applied to cure the defects, especially corner cracks at the slabs. Melting and solidifying moments were observed, and micro structures were examined during and after plasma curing. Also mechanical properties were evaluated after the hot rolling. By examining the micro structure, it was found that the cracked part was completely melt and solidified without any defect. The mechanical properties such as tensile and bending strength were almost same as those of no-crack part.

11:25 AM

Modelling the Cold Crucible Pouring Dynamics: *Valdis Bojarevics*[1]; Kyriacos Pericleous[1]; [1]University of Greenwich

The paper uses the mathematical modelling technique to investigate cold crucible operation with a non-consumable nozzle made of copper segments. The combination of two coils, one for the main crucible and the other for the nozzle with different power supplies, requires to superpose the effects of the two independent AC electromagnetic force fields. This leads to complex transitional flow structures and turbulence of the melt, contributing to the melt shape dynamics and the heat loss to the walls to satisfy the narrow balance between the thin solidified protective layer while avoiding the blockage of the outflow if the nozzle is frozen. The sensitivity of the outflow to the nozzle diameter is investigated. The beneficial features of the cold crucible melting to purify the melt from particulate contamination are explained using the particle tracking during the pouring process.

Processing 2

Wednesday PM
September 11, 2019

Room: Fry Room
Location: Edgbaston Park Hotel and Conference Centre

Session Chair: Mark Ward, University of Birmingham

1:15 PM
The Realization of a Dynamic Regulation Process for Nodularization and Inoculation of Ductile Iron: Dayong Li[1]; *Zhenyu Xu*[1]; Xuliang Ma[1]; Dequan Shi[1]; Guili Gao[1]; Peihong Zhang[1]; [1]School of Materials Science & Engineering, Harbin University of Science and Technology
Nodularization and inoculation are the two necessary processes for the production of ductile iron. Due to the uncertainty of the metallurgical state of the base iron, fixed nodularization and inoculation often lead to "over-nodularization" or "under-nodularization". In order to avoid "over-nodularization" or "under-nodularization", the authors designed and trial-produced a dynamic control system for the nodularization and inoculation. Based on monitoring the main chemical composition, oxygen content, sulfur content and melt temperature and evaluating the nodularized and inoculated performance of the base iron, the addition amount of nodulizer and inoculant can be given. After nodularization and inoculation, the nodularization and inoculation effects are detected by the rapid analysis equipment in front of the furnace, unqualified melts shall be fine-tuned or rehandled. Through the simulation test in the casting production practice workshop of the school, the experimental results preliminarily show that this method can effectively control the nodularization and inoculation process of ductile iron.

1:40 PM
Alloy Grain Refinement by Means of Electromagnetic Vibrations: *Kyriacos Pericleous*[1]; Valdis Bojarevics[1]; Georgi Djambazov[1]; Agnieszka Dybalska[2]; William Griffiths[2]; Catherine Tonry[1]; [1]University of Greenwich; [2]University of Birmingham
A tuned electromagnetic induction coil generates ultrasonic pressure waves is an alloy melt. Under acoustic resonance conditions cavitation of dissolved gases is observed leading to microstructure refinement, dispersion of added particles and degassing. The method is an alternative to the immersed sonotrode technique but offers several advantages. Being contactless, it can be applied equally to high temperature or reactive melts, avoiding contamination due to probe erosion; consequently, it is maintenance free. The consequent induction stirring means that larger volumes of melt can be treated (a major limitation of the traditional method), as the liquid is forced to pass repeatedly through zones of cavitation activity. The coil configuration used depends on application. Here, a top conical coil immersed in aluminium melt (contactless due to EM repulsion) was used. Simulations of sound, flow and EM fields are given, compared with experiments and indicating strong stirring, evidence of cavitation and grain refinement.

2:05 PM
Plant Design Aspects and Attainable Ingot Quality of Most Modern Super Alloy Production Plants: *Michael Kubin*[1]; S. Ressi[1]; Alexander Scheriau[1]; Harald Holzgruber[1]; [1]INTECO Melting and Casting Technologies GmbH
High performance material such as nickel base alloys are usually produced via the route VIM-ESR and/or VAR. Due to the complexity of these alloys special requirements on the furnace design and the process parameters has to be taken into account. This paper gives a brief overview of the basic principles of each process and the overall plant design highlighting the main features of VIM, ESR and VAR furnaces. Results will be given regarding the attainable ingot quality with respect to the chemical composition of VIM ingots as well as a comparison of the achievable macrostructure of ESR and VAR ingots.

2:30 PM Break

3:00 PM
Electrolytic Production of Silicon using Liquid Zn Alloy Cathode in Molten $CaCl_2$: *Kouji Yasuda*[1]; Akifumi Ido[1]; Takeyuki Shimao[1]; Rika Hagiwara[1]; Toshiyuki Nohira[1]; [1]Kyoto University
A new electrolytic production process for solar-grade Si has been proposed utilizing a liquid Si-Zn alloy cathode in molten $CaCl_2$. The process consists of three major processes: electrolysis, precipitation, and refining. One of the advantages of the process is the attainability of high purity by application of a solidification refining from the liquid Si-Zn alloy. The residual zinc is easily removed afterwards due to its high volatility. To establish this process, the behavior of liquid Zn metal in molten $CaCl_2$ at 1123 K was investigated. Evaporation of Zn metal was largely suppressed by immersion into the molten salt, which enabled the use of a Zn electrode despite its high vapor pressure. Based on the results of cyclic voltammetry, the reduction of SiO_2 on a liquid Zn cathode was conducted by potentiostatic electrolysis at 0.9 V vs. Ca^{2+}/Ca. Precipitated Si particles were recovered in the solidified Zn matrix.

3:25 PM
A Novel Method for Measuring the Content of Aluminum Alloy Melt Inclusions: Xuliang Ma[1]; *Dayong Li*[1]; Chaowei Han[1]; Guili Gao[1]; Peihong Zhang[1]; [1]Harbin University of Science and Technology
The content of aluminum alloy melt inclusions has a vital effect on the properties of castings, so it is very important to detect inclusion content rapidly for ensuring casting quality. Many methods have been proposed, among them, the filtration method is widely used. In this paper, a novel method based on the theory of filtration to evaluate the content of melt inclusions by measuring the pressure at a certain time in the constant pressure has been proposed. The computer and ADAM modules are employed to develop an apparatus for detecting the content rapidly. To make simulation experiment by adding AlTi5B alloy into aluminum melt and measurement experiment of the unknown inclusion content of the aluminum melt, it is proved that this method and device can be used for evaluating the content of inclusions in aluminum alloy melt rapidly in front of the furnace and guiding the purification treatment of melt.

Poster session

Monday PM
September 9, 2019

Room: Pre-Function Area
Location: Edgbaston Park Hotel and Conference Centre

P1: Characterization of Inconel-600 Produced via the Route VIM - VAR: Sajid Hussain[1]; *Michael Kubin*[2]; [1]Peoples Steel Mills Ltd.; [2]INTECO Melting and Casting Technologies GmbH
For certain applications Ni-base alloys have to be produced by applying two vacuum processes. The common practice is to produce an ingot in the vacuum induction furnace (VIM) which is then taken as electrode for a subsequent remelting operation under vacuum (VAR). This paper describes the production of an Inconel-600 which was produced at the special melting shop of People Steel Mills Ltd. After a short overview of the production capabilities detailed results will be given with respect to the internal as well as surface quality. For example the non-metallic inclusions across the cross section of the VAR ingots through Scanning Electron Microscopy were examined. The result shows a definite pattern of the distribution of non-metallic inclusions and carbide precipitation across the grain boundaries. Ultimately this paper highlights the differences in the achievable quality over the entire production route leading finally to a material with superior quality and enhanced properties.

P2: Effect of Slag Containing Rare Earth Oxide on Steel Cleanliness and Tensile Properties during Electroslag Remelting of AF-3 Steel: Haibo Cao[1]; *Yanwu Dong*[1]; Zhouhua Jiang[1]; Zhiwen Hou[1]; Kean Yao[1]; Shuyang Du[1]; Yushuo Li[1]; Fei Peng[1]; [1]Northeastern University
The effects of slag containing rare earth oxide under on non-metallic inclusions and tensile property during of the AF-3 steel by ESR were experimentally investigated. Specimens were taken at the electrode and each remelting ingot for analyzing the compositions, dimensions, and types of non-metallic inclusions. After hot rolling and sensitization treatment, electronic universal testing machine was employed to investigate normal and hot tensile performance. The results show that under simple nitrogen atmosphere combined with reduction treatment of slag containing rare earth oxide, oxygen content can be reduced from 76 ppm (electrode) to 29 ppm, 42 ppm and 51 ppm under different remelting conditions. Compared with the electrode, the content of the non-metallic inclusions was largely reduced. The results of tensile experiments indicate that the ingot under nitrogen atmosphere combined with slag reduction treatment has a better tensile performance.

P3: Effect of Vacuum on Oxygen Control during Electroslag Remelting of H13 Die Steel: Xuechi Huang[1]; *Baokuan Li*[1]; Zhongqiu Liu[1]; [1]Northeastern University
In order to decrease total oxygen content, vacuum electroslag remelting is developed. Vacuum refining is supposed to be conductive to deep degassing in steelmaking process, such as carbon monoxide. A transient model coupling the magnetohydrodynamic flow and heat transfer was therefore proposed to investigate the effect of vacuum on oxygen control during electroslag remelting process of H13 die steel. Oxygen transfer in ESR under Ar gas atmosphere and vacuum condition was discussed. A kinetic model based on the thermodynamic analysis was established to predict the thermochemical reaction rates. The result shows that the ingot remelted under vacuum condition has the lowest oxygen content, which indicates the carbon deoxidation occurs. Besides, the less heat loss under vacuum condition leads to a higher remelting rate, which shortens the reaction time that oxygen transfers from slag to steel. The calculated results agree well with the experiments.

P4: Effect of Yttrium on the Microstructure and Mechanical Properties of an Austenitic Hot-Work Tool Steel: *Chengbin Shi*[1]; Yongfeng Qi[1]; Jing Li[1]; Lan Peng[1]; [1]University of Science and Technology Beijing
The microstructure and mechanical properties of high-Mn austenitic die steel with yttrium addition were investigated with the help of optional microscope (OM), scanning electron microscope (SEM) and electron back scattered diffraction (EBSD). The microsegregation of alloying elements were analyzed by electron probe microanalysis (EPMA). The results showed that the microstructure were refined and mechanical properties were improved when the amount of soluble yttrium in as-cast ingot reached to 60×106. The secondary dendritic arm spacings and corresponding the size of primary carbides were reduced with increasing yttrium addition up to 60×106, but increased when excessive yttrium addition. The grain sizes decreased with increasing yttrium addition after heat treatment. The intragranular twin grain boundaries were increased with increasing yttrium addition, which resulted in the increasing in grain boundaries area ratio. Therefore, the strength and toughness of the steel were simultaneously increased due to the refined grains, reduced carbides and impeded movement dislocation.

P5: Microstructures and Mechanical Properties of AlMg5Si2Mn Experimental Alloy under Different Casting Processes: Shifeng Luo[1]; *Guangyu Yang*[1]; Shuxia Ouyang[1]; Wanqi Jie[1]; [1]Northwestern Polytechnical University
Microstructure and mechanical properties of AlMg5Si2Mn alloy were compared under permanent mold casting and high pressure die casting. The microstructure was composed of primary a(Al) grains, eutectic phase and Fe-rich phase for both alloys. However, compared to permanent mold casting, the primary a(Al) grains were more finer and the Chinese script morphology of eutectic phase disappeared under high pressure die casting. Due to the large different between these two alloys, the ultimate tensile strength and elongation of AlMg5Si2Mn alloy under high pressure die casting increased by 32% and 24% (255 MPa and 8.8%), respectively, when compared to that of AlMg5Si2Mn alloy under permanent mold casting. Furthermore, the SIMA method was further applied to AlMg5Si2Mn alloy under high pressure die casting to prepare the semi-solid slurry. The results showed that AlMg5Si2Mn alloy solidified under high pressure die casting can be used as the raw material for semi-solid slurry.

P6: Numerical Investigation on the Ingot Solidification with Different Solidification Paths and Permeability Models in Electroslag Remelting Process: *Jia Yu*[1]; Fubin Liu[1]; Zhouhua Jiang[1]; Ao Wang[1]; Wenchao Zhang[1]; Huabing Li[1]; Xin Geng[1]; [1]Northeastern University
A 2D transient axisymmetric model has been established to investigate the effects of solidification path and permeability model on ingot solidification in electroslag remelting process based on the volume of fluid (VOF) and dynamic mesh technique. The governing equations are discretized by means of the finite volume method (FVM). The modified heat capacity is employed including the change in enthalpy. The hypothetic linear dependence and the solidification path obtained from Thermal-Calc are incorporated into the model with User Defined Function (UDF) respectively. The Dracy's law is used to describe the flow in the mushy zone. Both the isotropy permeability and anisotropy permeability model are employed for comparison. The local solidification time (LST) is also predicted. The results could enhance the understanding of ingot solidification.

P7: Optimum Design of Refining Slag for 38CrMoAl High Aluminum Steel: *Taixu Xu*[1]; Zhijun He[1]; Jihui Liu[1]; Xiao Han[1]; Huan Zhang[1]; [1]University of Science and Technology Liaoning
In order to alleviate the nozzle clogging phenomenon of 38CrMoAl high aluminium steel and improve the production efficiency of continuous casting. This study combines orthogonal design with Factsage thermodynamic calculation to optimize the proportion of refining slag, and verifies it with actual smelting phase to find the best composition of refining slag. The experimental results show that CaO:65%, SiO2:1%, Al2O3:4%, MgO:4% slag system has the highest sulfur capacity, which is 5.665 E-2. The low melting point ratio range of refining slag is CaO:70%~75%, SiO2:1%~3%, Al2O3:6%~8%, MgO:4%~8%. Comparing the number, average area and particle size of inclusions in steel under different proportion refining slag smelting conditions, and considering comprehensively the melting effect and desulfurization performance of refining slag, the refining effect of refining slag component is the best with CaO=70%, SiO2=1%, Al2O3=6%, MgO=6%, CaF2=5%.

P8: Rapid Solidification and Microstructure Formation in Designed Ni-based Immiscible Alloys: *Jie He*[1]; X. Sun[1]; Y. Xi[2]; H. Ma[3]; L. Zhang[2]; H. Jiang[2]; J. Zhao[1]; M. Zhu[2]; H. Hao[2]; [1]Chinese Academay of Sciences; [2]Chinese Academy of Sciences; [3]Shenyang Aerospace University

In this work, a quaternary Ni–Cu–Nb–Ta system has been designed to obtain composite microstructures with spherical crystalline Cu-rich particles embedded in amorphous Ni-rich matrix and with glassy Ni-rich particles embedded in crystalline Cu-rich matrix. The alloy samples were prepared by using rapid quenching. The microstructure and related properties of the as-quenched alloy samples were characterized by X-ray diffraction, scanning electron microscopy, high-resolution transmission electron microscopy, and differential scanning calorimetry. It shows that the spherical crystalline Cu-rich particles are embedded in the amorphous Ni-rich matrix. The average size of the Cu-rich particles is strongly dependent upon the Cu content. The effect of the alloy composition on the behavior of liquid-liquid phase separation and microstructure evolution was discussed. The formation of structure with the glassy Ni-rich particles distributed in crystalline Cu-rich matrix and thereby the effect of the structure on the related properties were analyzed.

P9: Research on the Bonding Interface of Bimetallic Composite Roll Produced by a New Electroslag Cladding Method: Yulong Cao[1]; Guangqiang Li[1]; *Zhouhua Jiang*[2]; Yanwu Dong[2]; Yu Liu[1]; Qiang Wang[1]; [1]Wuhan University of Science and Technology; [2]Northeastern University

In the present study, a composite billet that consisted of a GCr15 steel as the composite layer and a 45 carbon steel as the roll core was produced by a new electroslag cladding method. Microstructure evolution at different radial regions of the roll core during the production process were discussed and the microstructure, elements diffusion, microhardness, tensile strength of the bonded regions were measured. The results illustrate that the bimetal materials achieves an excellent metallurgical bonding by the new method and the bonding interface isn't the weakest region during the loading process. Affected by the heat transfer from the high temperature slag pool, a high temperature austenitizing process and an obvious elements migration and diffusion phenomenon occur at the heat affected zone of the roll core which leads to a gradual change of the microhardness from the composite layer to the roll core.

P10: Study on Centrifugally Cast Functionally Graded Al-Mg2Si In-Situ Composites: *Indrajit Chakrabarty*[1]; S. Ram[1]; K. Chattopadhyay[1]; [1]Indian Institute of Technology

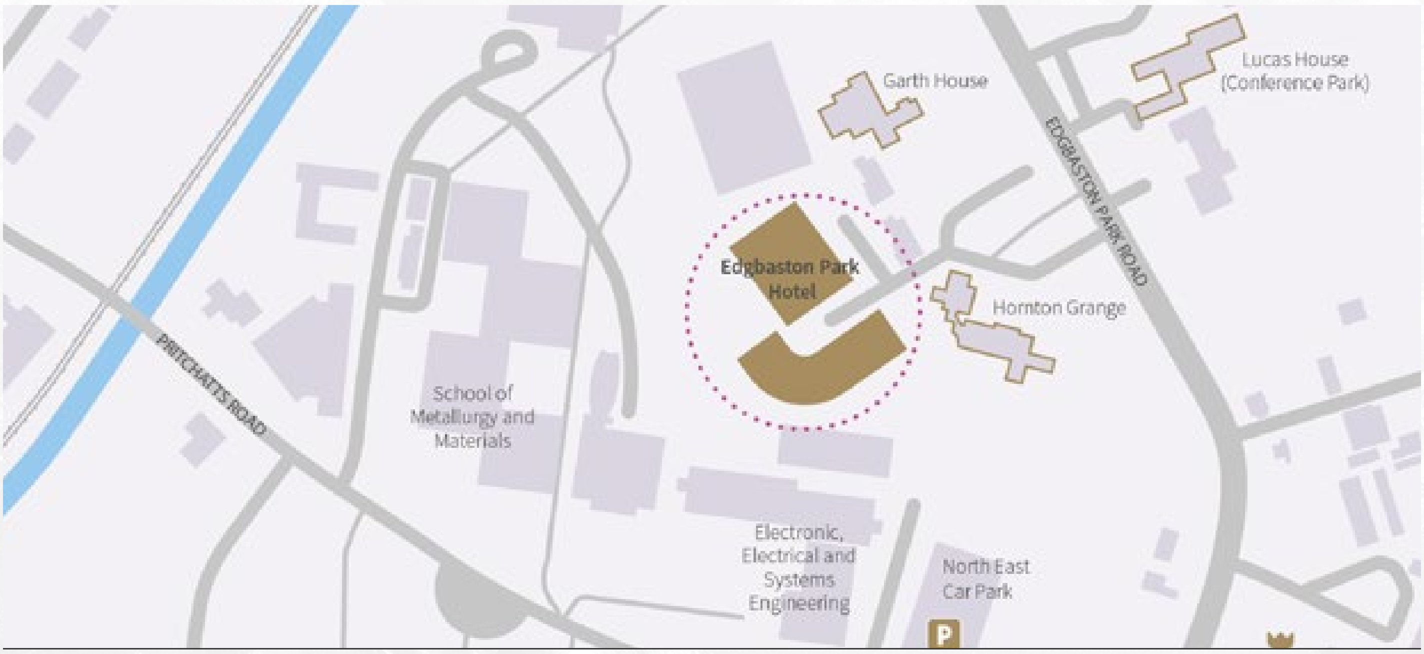
An attempt has been made to develop Al-Mg2Si functionally graded in-situ composites with varying percentage of Mg so that the volume percentages of Mg2Si are varied in the composites. Because of its lower relative density it will tend to migrate towards the core of the tubular product due to centrifugal force. The functionally graded composites have been characterized by optical, scanning and transmission electron microscopy and X-ray diffraction analysis for examination of matrix structure, reinforcement morphology and identification of phases. The distribution gradient along the cross-section in three zones such as surface, intermediate and the core have been studied. The hardness and high temperature tensile properties have been evaluated along the cross-section of cast graded composites

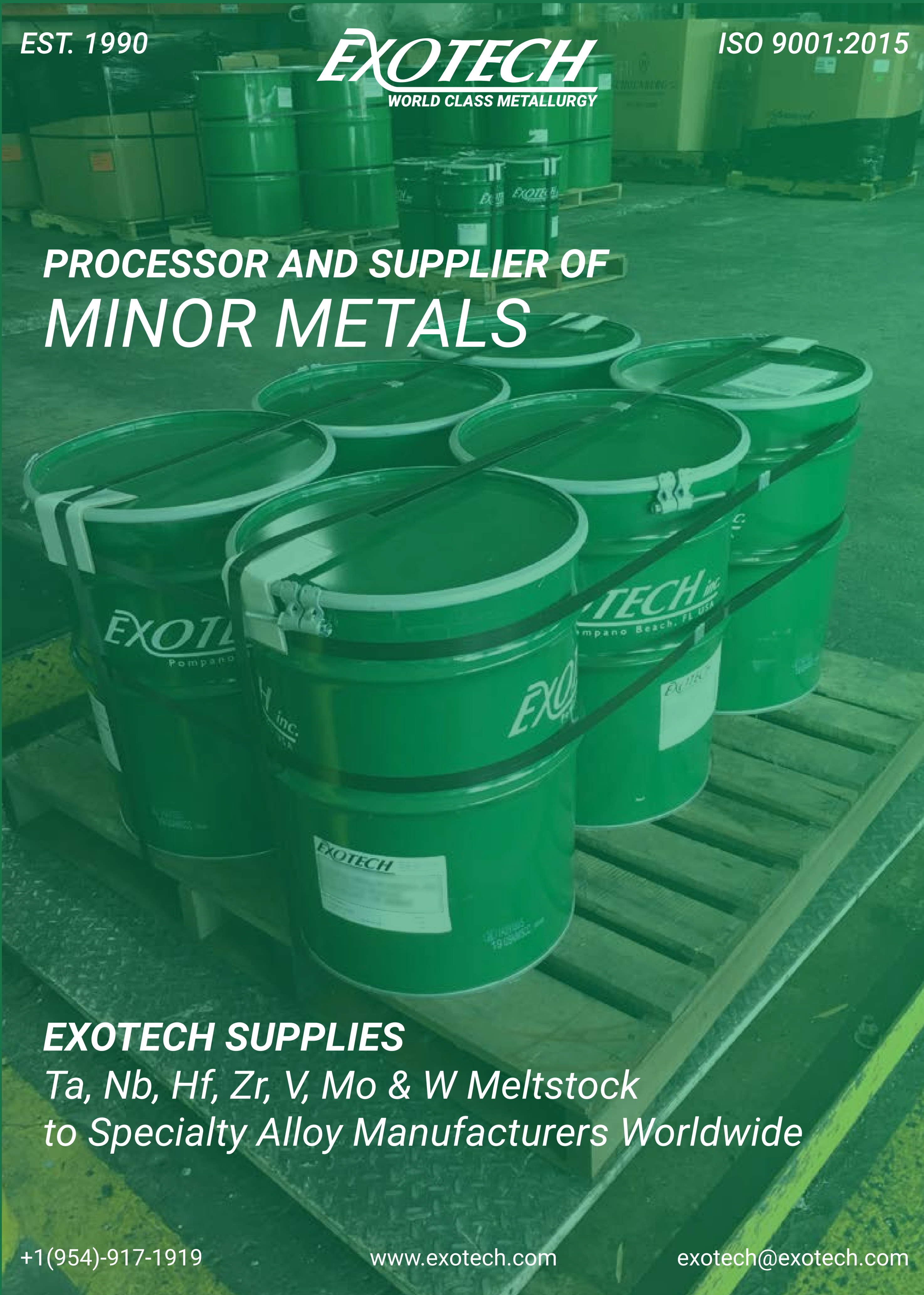
P11: Towards Prediction of the ESR Ingot Composition: *Ganna Stovpchenko*[1]; Lev Medovar[2]; Ludmila Lisova[3]; Iaroslav Gusiev[3]; Dmytro Kolomiets[3]; Artem Sybir[4]; [1]E.O. Paton Welding Institute ; [2]Elmet-Roll; [3]E.O. Paton Welding Institute; [4]National Metallurgical Academy of Ukraine

The new look to the electroslag remelting (ESR) process as a physicochemical system is proposed and grounded. The fundamental distinct of the ESR from any "batch" steelmaking processes (going in BOF, EAF, LF and VD/VOD etc.) is that a slag to metal ratio drastically changes while remelting and the slag bath is just slightly refreshing (to compensate losses for slag skin formation) without change of its mass. At the very beginning, the slag to metal ratio starts from infinity, and to the process, end approaches so known "slag consumption" value that usually makes 15-30 kg per ton. In traditional thermodynamic calculation the exact this value is used that unable predicting of the chemical composition on the height of the ingot. Besides, at all kind of the ESR processes, the physic-chemical interactions occur in two subsystems "gas - liquid slag" and "liquid slag - liquid metal", because the molten slag layer makes a border dividing the entire melting space. Irrespective of the ESR process organisation, gas atmosphere (vacuum, protective gases, open air or pressurized gas) has no direct contact with molten liquid metal that should be taken into account. Thermodynamic calculations and experimental investigations were performed to reveal the obstacles affecting active elements losses and connected changes in slag chemistry and properties. The procedure of physicochemical simulation of the complex interactions in the reacting system "gas-slag-metal" at the ESR was developed and verified. It allows predicting the changes in the content of elements on the height of ESR ingot as well as changes in slag composition while the ESR melting process in a protective gas.

GROUND FLOOR

LOCAL AREA MAP

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