ADVANCES IN ADDITIVE MANUFACTURING OF LIGHT METALS

COM00171: Grain Refinement and Microstructural Homogenization of Additively Manufactured Al Alloys for Better Corrosion Performance

Abstract: Additively manufactured (AM) aluminum alloys lack isotropic corrosion response ideal for most structural applications due to their inherent microstructural inhomogeneities at different orientations. In this talk, two methods of microstructural refinement and homogenization applicable to AM fabricated Al alloys will be discussed and compared. The first method is based on introducing ceramic nanoparticles as grain refining agents to the feedstock metal powder. For this method, the addition of TiB_2 nanoparticles to the structure of A205 alloy (an Al-Cu-Mg-Ag alloy) fabricated through laser powder bed fusion (L-PBF) technique is discussed. For the second method, thermomechanical processing of AM fabricated parts by applying post-printing friction stir processing (FSP) will be deliberated. As a solid-state surface modification technique, FSP can be applied on the as-printed components to modify the surface microstructure and ultimately improve their surface properties, i.e. wear and electrochemical properties. In this talk, the microstructural evolution and the resultant corrosion performance of FSPed L-PBF fabricated AlSi10Mg are discussed. The effectiveness of these two methods towards the degree of grain refinement and microstructural homogeneity and their contributions to corrosion properties of both alloys will be elucidated.

Ali Nasiri, Dalhousie University; Mehran Rafieazad, Memorial University of Newfoundland; Mohsen Mohammadi and Parisa Fathi, University of New Brunswick

COM0056: Deformation Mechanism, Microstructure Characterization and Fracture Analysis of Horizontally and Vertically Printed Electron Beam Melted Ti-6Al-4V Alloy under High Strain Rate Compressive Loadings

Abstract: This study focuses on the effect of building direction on the deformation behavior, microstructural evolution, dynamic mechanical properties, and fracture surface of severely deformed electron beam melted Ti-6Al-4V (EBM-Ti64) specimens under high strain rate compressive loadings. Utilizing optical and scanning electron microscopy, transformed α+β phases, columnar prior β-grain, and grain boundary-α along with the prior β-grain boundaries were detected in the as-built microstructure of horizontally and vertically built specimens; however, owing to higher cooling rate, vertically built specimen revealed finer microstructure and lower interlamellar spacing. High strain rate tests were conducted using a Split-Hopkinson Pressure Bar (SHPB) apparatus from the strain rate of 1150 s^{-1} up to failure, 2700 s^{-1} and 1900 s^{-1} in horizontal and vertical specimens, respectively. By increasing strain rate, specimens exhibited superior mechanical properties (yield and ultimate compressive strength). Besides, at each strain rate, vertically built specimens showed higher strength but lower strain. A finer microstructure with lower interlamellar spacing was obtained by strain rate increment. Moreover, microstructure fragmentation was detected in the deformed specimens. After the initial strain hardening drop at the first step of deformation, thermal softening governed strain hardening because of the temperature rise resulting from internal friction during dynamic deformation. The presence of shear strain localization, local softening, and thermomechanical instability, along with the temperature rise, led to the formation of adiabatic shear bands (ASBs). Because of the occurrence of dynamic recovery (DRV) and dynamic recrystallization (DRX) inside ASBs, these regions revealed a featureless microstructure. Continuing deformation caused void nucleation, growth, and rotation inside ASBs, leading to void coalescence cracks initiation and propagation in the case of more intense deformation. Fractographic observations showed smooth surfaces and dimples as a sign of ductile-brittle fracture. Elongated dimples proved the existence of shear stress along with the ASBs. It has to be mentioned that other deformation mechanisms such as twinning and pyramidal slip systems have considerable contribution during high strain rate deformation. On the other hand, basal and prismatic slip systems showed the least contribution in deformation. Moreover, compared to the extension twin system, contraction twinning contributed considerably as a deformation mechanism, notably as the strain rate increases.

Reza Alaghmandfard and Mohsen Mohammadi, University of New Brunswick

COM0081: Corrosion Performance of Laser DED TiC-Ni_3Al Cermet Coatings on D2 Tool Steel Substrates

Abstract: D2 tool steel is widely used in die manufacturing, where high wear resistance and contact strength are desired. Further development of such parts pertains to the extension of die lifetimes and in-situ repair of worn die surfaces. This can be achieved by the use of advanced surface engineering techniques, such as high-velocity oxyfuel (HVOF) and direct energy laser cladding (DED) based additive manufacturing. In the present study, improvements are being sought through the use of DED for the application of TiC-based cermet coatings onto high Cr-containing, cold work D2 tool steel substrates. The cermet composition is first applied onto the steel substrate by dip coating into a suspension of TiC-Ni_xAl_y-Ni; this provides a well-adhered, pre-placed feedstock material on the surface of the substrate, with a uniform thickness. Subsequently, laser DED is used to provide a bonded surface clad. The aqueous corrosion behavior of laser clad cermet coatings then was characterized by means of open circuit potential and potentiodynamic polarisation responses of the laser cladded coatings in artificial seawater. The clad surface was analyzed by optical microscopy, scanning electron microscopy, and energy-dispersive X-ray spectroscopy, to assess the elemental distribution and the morphologies of the interface and phases formed through the oxidation reaction.

Zhila Russell and Kevin Plucknett, Dalhousie University

COM00139: High-performance Titanium Matrix Composites Fabricated by Laser Powder Bed Fusion

Abstract: Metal matrix composites (MMCs) are considered engineering materials that bilaterally benefit from a hard reinforcement and a ductile matrix. Owing to their desired structural and functional properties, MMCs have found their way into a wide variety of technological fields such as aerospace, automotive, and biomedical industries. Laser powder bed fusion (L-PBF) is a widely used additive manufacturing (AM) process that utilizes a high-power laser beam as the heat source to selectively melt powders to fabricate parts. L-PBF has offered an exceptional opportunity to fabricate metallic parts with complex shapes, unique geometrical designs and mechanical properties. This unprecedented technology has also opened new windows to produce MMCs with improved functional and mechanical properties while reducing weight. This paper aims at utilizing the L-PBF process to fabricate high-performance TiB reinforced titanium matrix composites (TMCs). For this purpose, minor quantities of B4C, as the starting reinforcing agent, were added to the Ti-6Al-4V powder to produce a composite powder feedstock that meets the L-PBF process requirements. This powder was subjected to the L-PBF process to fabricate highly dense TMC parts. Results indicated that the obtained composites possessed superior hardness and strength, and wear resistance compared to the monolithic Ti-6Al-4V counterpart.

Eskandar Fereiduni, Ali Ghasemi, and Mohamed Elbestawi, McMaster University

COM00142: Sintering and Its Impact on Heat Transfer in EBAM

Abstract: Predicting the melt track shape in EBAM, and other AM processes, is vital for process control. Process parameters, such as layer height and line spacing, should be directly influenced by melt track shape. In EBAM, melt track geometry is a function of both beam parameters and heat transfer from the melt track into its surroundings. In EBAM, sintering occurs impacting heat transfer from the melt track and therefore its shape. This presentation discusses experiments investigating the sintering kinetics of EBAM Ti-6Al-4V powder and sintering's impact on thermal diffusivity. Laser Flash Analysis is used to determine the thermal diffusivity of sintered powders. MicroCT is used to investigate the structure of these powders. Discrete Element Heat Transfer is then used to predict the thermal diffusivity through simplified structures and the impact of various structural parameters on heat transfer is discussed.

William Sparling, Chad Sinclair, and Mark Martinez, The University of British Columbia; Stephen Corbin, Dalhousie University

COM0015: Effects of Cooling Rate on the Microstructure and Mechanical Properties of Additively Manufactured AlSi10Mg during Post-process Heat Treatment

Abstract: Traditional T6 heat treatment process for aluminum alloys involves water quenching specimens after both the solution treatment and artificial aging to preserve the evolving microstructures. In this study, the standard T6 heat treatment procedure has been modified to accommodate furnace cooling and air cooling after both solution and artificial aging heat treatments for additively manufactured AlSi10Mg alloy. Such a variation in the post process heat treatment can bring about differences in the microstructure in terms of distribution of Si and Fe-rich precipitates. Heat treated specimens are analyzed with optical and scanning electron microscopes to study the microstructures. Mechanical properties were invested by studying Vickers micro-indentation hardness. Finally, effort has been taken to correlate the mechanical properties with associated microstructural features obtained by various cooling rates. Traditional T6 heat treatment process for aluminum alloys involves water quenching specimens after both the solution treatment and artificial aging to preserve the evolving microstructures. In this study, the standard T6 heat treatment procedure has been modified to accommodate furnace cooling and air cooling after both solution and artificial aging heat treatments for additively manufactured AlSi10Mg alloy. Such a variation in the post process heat treatment can bring about differences in the microstructure in terms of distribution of Si and Fe-rich precipitates. Heat treated specimens are analyzed with optical and scanning electron microscopes to study the microstructures. Mechanical properties were invested by studying Vickers micro-indentation hardness. Finally, effort has been taken to correlate the mechanical properties with associated microstructural features obtained by various cooling rates.

Dolly Clement and Abu Syed Kabir, Carleton University

COM0049: Inter-vendor Study of Directed Energy Deposition Build Quality Using a Commercial Ti-64 Powder

Abstract: This research sought to compare the manufacturing capabilities of several vendors of directed energy deposition (DED) equipment in the context of additive manufacturing. Gas atomized Ti-64 powder was utilized in all instances as it maintains a high relevance to industrial practice and is readily applicable in DED processing. A single commercial lot of Ancor Ti-64 powder was secured for this purpose, characterized, and then distributed amongst multiple OEMs of DED equipment. Vendors were also given a 3D model and dimensioned drawing of the desired test build geometry. Upon receipt of the completed builds, dimensions of interest were measured using a 3D coordinate measurement machine and compared to the provided model. Builds were also compared based on a range of metallurgical assessments. These included the acquisition of data on hardness, density (MPIF Standard 42), and tensile properties (ASTM E8M). In addition, optical micrography, scanning electron microscopy, differential scanning calorimetry and x-ray diffraction were utilized to characterize microstructural features of each build.

Nick Gosse, Dalhousie University; Matthew Harding, Tronosjet Manufacturing Inc.; Paul Bishop, Dalhousie University; Ian Donaldson, GKN Sinter Metals LLC

COM0051: Laser Powder Bed Processing of Aluminum Powders Containing Iron and Nickel Additions

Abstract: The variety of aluminum alloys currently used in laser powder bed fusion additive manufacturing (PBF-AM) is limited, yet the demand for such materials is growing. The AM community is particularly keen on aluminum alloys that offer enhanced thermal stability. Traditionally, this trait has been instilled through transition metal additions that form stable aluminides. This project seeks to devise new PBF-AM materials in this context starting with a precursory study into the effects of iron and nickel additions. Here, gas atomized Al-1Fe and Al-1Ni (wt.%) powders were processed via PBF-AM over a range of volumetric energy densities achieved through systematic adjustments to laser power, scan speed, and hatch spacing. The microstructure (OM, SEM, EDS, XRD) and physical properties (hardness, density, surface roughness) of the products were characterized. Results indicated that Al-1Fe was more responsive to processing as it densified to 99.0% of full theoretical and had a hardness of 95 HRH. Conversely, Al-1Ni only reached 97.8% theoretical density and a peak hardness of 78 HRH. It was also more prone to solidification cracking. Energy density values of at least 32.5 J/mm^3 were necessary to achieve peak density and hardness.

Jon Hierlihy, Dalhousie University; Ian Donaldson, GKN Sinter Metals LLC; Mathieu Brochu, McGill University; Gregory Sweet and Paul Bishop, Dalhousie University

COM0064: Modification of Primary Si Morphology in Hypereutectic Al-Si by Rapid Solidification and Alloying

Abstract: By their microstructures, hypereutectic Al-Si alloys are natural in-situ composites which contain hard Si grains embedded in an Al-Si eutectic. This microstructure provides Al-Si with good wear resistance while maintaining some ductility. Size, distribution, and morphology of Si grains are all known to strongly impact the wear resistance of these alloys. Rapid solidification and alloying offer the potential to refine Si grains and modify their morphology and some work has been reported in the literature but with limited success. The present work explores the effects of combining rapid solidification and alloying for Si modification. Four alloys were evaluated: Al-40Si, Al-40Si-1.5Ce, Al-40Si-9.2Mg, and Al-40Si-2.75Fe-2.75Mn-1.5Sc. Al-40Si provides a baseline understanding of the effects of rapid solidification on hypereutectic Al-Si. Ce-induced modification demonstrate the effectiveness of a modification under limited diffusion conditions. Macroalloying with Mg and Fe, Mn, and Sc decreases the equilibrium primary Si content of each alloy as a way to enhance the modifying ability of rapid solidification. These alloys were produced by Impulse Atomization and characterized though Optical and Scanning Electron Microscopy. These techniques, combined with a heat transfer model, were used to correlate changes in microstructure to the corresponding cooling rates experienced during solidification.

Daniela Diaz, Abdoul-Aziz Bogno, and Hani Henein, University of Alberta

COM0085: On Corrosion Behavior of As-printed Laser Powder Bed Fused AlSi10Mg Alloy before and after Friction Stir Processing

Abstract: Friction Stir Processing (FSP) is known as a surface modification technique, commonly utilized to modify microstructural features and improve the mechanical performance of various engineering alloys. In this study, the FSP technique was applied on the side surface (parallel to the building direction) of a Laser-Powder Bed Fusion (L-PBF) fabricated AlSi10Mg alloy. In-depth microstructural analysis of L-PBF-AlSi10Mg parts before and after the FSP treatment was performed using optical microscopy and scanning electron microscopy (SEM) analysis. Due to the strong dependency of the corrosion properties on the part's surface quality and its superficial roughness, comparisons were made between the corrosion properties and electrochemical stability of the rough as-printed L-PBF-AlSi10Mg surfaces and their FSPed counterparts with as-processed surface condition. The corrosion performance of the surfaces was evaluated using anodic polarization testing and electrochemical impedance spectroscopy (EIS) in aerated 0.6 M NaCl electrolyte. The existing correlations between the surface roughness, microstructure, and the expected corrosion response of the L-PBF-AlSi10Mg before and after FSP are comprehensively elucidated.

Mehran Rafieazad, Memorial University of Newfoundland; Mohsen Mohammadi, University of New Brunswick; Adrian Gerlich, University of Waterloo; Ali Nasiri, Dalhousie University

ADVANCES IN MATERIALS MANUFACTURING V - DR. XINJIN CAO MEMORIAL SYMPOSIUM

COM00117: Is Powder Characterisation Important for Additive Manufacturing Processing?

Abstract: Metallic powders are one of the key starting materials for additive manufacturing. Powders can be produced using a wide variety of extrinsic (powder morphology, including particle size distribution and shape) and intrinsic (influence of the powder composition and microstructure) properties. The interactions between these characteristics are having a significant influence on the processability of these powders, either during laser powder bed fusion, electron beam melting and binder jet. The sensitivity between these interactions and the processing also varies from one metallic system to another. This presentation will highlight the knowledge acquired on powder behavior, characterisation and its influence over processability acquired over the last 10 year.

Mathieu Brochu, Eileen Ross Espiritu, Jose Alberto Muniz Lerma, and Mahmoud Osman, McGill University

COM00121: Evolution of Precipitates and Mechanical Properties in Al-Cu 224 Cast Alloys with Mg Additions

Abstract: Al-Cu 224 cast alloys are widely used as high-strength aluminum alloys in automobile industries. To further improve the mechanical properties of Al-Cu 224 alloys, the influence of Mg additions (0-0.36 wt.%) on the evolution of precipitates and mechanical properties under T7 has been investigated. Results showed that Mg has little influence on the formation of intermetallics during solidification but a remarkable effect on the θ'' and θ' precipitates during aging. The addition of Mg promoted the formation of θ' after T7, resulting in an increase in the number density and volume fraction of precipitates with increasing Mg. Meanwhile, the ratio of θ'/θ'' precipitates increased with the addition of Mg and the dominant precipitates became θ' when the Mg was higher than 0.24%. The evolution of precipitates resulted in different mechanical properties, in which the yield strength at room temperature was increased from 284 MPa in the base alloy free of Mg to 349 MPa in the alloy containing 0.24% Mg, but slightly decreased to 332 MPa with the further addition of Mg to 0.36%. The relationship between the microstructure and mechanical properties of experimental alloys was analyzed by quantifying the θ'/θ'' precipitates and using the strengthening models.

Peng Hu and Kun Liu, University of Quebec at Chicoutimi; Lei Pan and Francis Breton, Rio Tinto; X. -Grant Chen, University of Quebec at Chicoutimi

COM0013: The Influence of Base Metal and Filler Metal Composition on the Kinetics of Transient Liquid Phase Bonding of Superalloys

Abstract: The present work examines the influence base metal (BM) and filler metal composition have during the joining of Ni-based superalloys using Transient Liquid Phase

Bonding (TLPB). BM's explored included Ni200, IN600, IN625 and IN718 while FM's included BNi-2 and BNi-3, representing 8 different joint combinations. The initial boron uptake (IBU), BM dissolution and rate of isothermal solidification (IS) were determined using an in-situ cyclic DSC method as well as microstructural evaluation. It was found that the type of metal boride formed within the diffusion affected zone (DAZ) of the BM was strongly dependent on the BM composition. This in turn had a significant influence over the rate of IS. BM dissolution was dependent on both the BM and FM composition. BMs with the higher concentration of boride forming elements exhibited the highest rate of IS. BMs with a combination of Cr, Mo and Nb as boride forming elements had the shortest IS times due to an optimum combination of high IS rate and low base metal dissolution.

Eric Moreau and Stephen Corbin, Dalhousie University

COM00131: METTOP-BRX Technology – The Next Level of Tankhouse Technology at 420 A/m^2

Abstract: Whenever thinking about increasing tankhouse performance two major aspects has to be considered, the technological feasibility as well as the economical impact. For meeting the requirement of an increased current density leading to an increased productivity, Mettop has developed the METTOP-BRX Technology, which allows the introduction of fresh electrolyte between each pair of anode and cathode. Based on an example of a tankhouse with 500 000 t annual production, the economic benefits as well as the technological benefits will be summed up. Based in the concrete figures from many years of experience at Xiangguang Copper Co., Ltd and at Montanwerke Brixlegg AG the benefits of a METTOP-BRX Tankhouse compared to a conventional tankhouse are manifold: Better cathode quality Less portion of silver in cathode Possibility of usage of lower grade anodes Smaller tankhouse footprint Latest technology Lower CAPEX Lower OPEX All those given bullet points can result in savings of 60 Mio. US$ in CAPEX and 4 Mio Mio. US$ /year in OPEX when considering a green field project. It is intended with this paper to create a better understanding about the parallel flow technology and highlight the huge positive economic impact of a high current density tankhouse.

Andreas Filzwieser, Iris Filzwieser, and Martina Hanel, Mettop GmbH; S. Zhou, Shandong Xiangguang Group Co., Ltd.

COM00132: Development of Advanced E-waste Recycling Facilities

Abstract: In the past, metallurgical e-scrap recycling has been dominated by large copper recycling plants, as they offer the opportunity to add a certain amount of copper and precious metal-bearing e-scrap fractions to their raw material portfolio. However, their capacities are limited, and the world is faced with an increasing amount of e-scrap coupled with a trend of decreasing contents of precious metals and recyclables. This development has resulted in the demand for compact and flexible plants with low to medium capacities as stand-alone units close to pre-treatment plants. The HENRI MiniSmelter offers a state-of-the-art solution for compact metallurgical recycling—both as a green-field stand-alone solution and as a plant upgrade to expand the raw material portfolio. The system provides an efficient smelting and reduction process for a wide range of copper and precious metal-bearing materials—from high-value PCBs

to the lowest grades of shredder (light) fractions and dusts. This paper summarises the development, capabilities, options, and applications of the HENRI MiniSmelter concept. Furthermore, the steps, complexity, and challenges of developing a modern metallurgical recycling plant are explained. Finally, the economic feasibility of small to medium-sized e-scrap recycling projects is addressed.

Karl Büchner and Stefan Konetschnik, UrbanGold GmbH; Andreas Filzwieser, Mettop GmbH

COM00134: Optimization of Spark Plasma Sintering Process Parameters for Enhanced Fabrication of Mullite-Rich Tailings Reinforced Ti6Al4V Composite as Material for Design of Vehicle Brake Rotors

Abstract: Drawbacks like poor ductility during production of Ti6Al4V Based Composites (TBC) can be managed by fabricating the TBC with Spark Plasma Sintering (SPS) method. But the challenge of unpreserved bulk properties due to compromised interstitial elements often present itself. Hence, the need to optimize the SPS process parameters for more efficient and cost-effective process conditions. Thus, leading to the aim of this study, which is the optimization of SPS process parameters for the fabrication of mullite rich tailings reinforced Ti6Al4V composite (MRTRTC) as material for design of brake rotors. This aim was achieved by using the Taguchi Design of Experiment method (TDOEM) to design the optimization process. Sintering temperature, pressure, dwell time and heating rate were parameters considered. The admixed powders were consolidated according to the TDOEM using the SPS machine which was followed by characterization of sintered compacts using an optical microscope, Vickers hardness tester and Archimedes-based density tester. The results obtained showed the test condition for sintering MRTRTC are 1000°C, 30 MPa, 100°C min^{-1} and 10 min. These optimum test conditions shall be used to evaluate best composition of MRTRTC as material for design of brake rotors.

Pretty Linda, Daniel Okanigbe, Abimbola Popoola, and Olawale Popoola, Tshwane University of Technology

COM00135: Surface Boriding of TiC-316L Stainless Steel Cermets

Abstract: Due to excellent physical and chemical properties, especially wear resistance, cermets are used as bulk materials and coatings in a wide range of applications. A novel 'pack' boriding treatment is developed in the current work, for titanium carbide cermets prepared with a 316 stainless steel binder. Boriding was conducted in a commercial boron-containing powder-bed, between 950 and 1150°C. A continuous borided surface layer was developed, with formation of high hardness iron borides, although surface roughness is also increased. Boriding was shown to increase the cermet hardness and scratch hardness, highlighting the potential for using this surface treatment step for complex-shaped components.

Danielle Griffin, Owen Craig, Marciel Gaier, and Kevin Plucknett, Dalhousie University; Hua-Tay Lin, Guangdong University of Technology

COM00138: Linear Friction Welding of Magnesium and Its Alloys: Overcoming Challenges

Abstract: In the aerospace industry, weight reduction is becoming increasingly important in tackling the challenges posed by climate change and aircraft fuel efficiency. Low-density magnesium (ρ=1.7 g/cm^3) can provide a definitive advantage by greatly reducing weight compared to other denser metals such as aluminum (ρ=2.7 g/cm^3) or titanium (ρ=4.5 g/cm^3). However, joining magnesium parts to magnesium and other metals is of paramount importance to ensure its widespread use from commercial aircraft seats to nano-satellite frames. Notably, magnesium poses liquid-phase joining challenges due to its low boiling point and high reactivity, which results in welding defects and poor strength. Friction stir welding, which is a solid-state welding technique, has been tested on different magnesium alloys to overcome these obstacles. However, this technique is limited to joining plate components, being difficult to apply to more bulky or complex shapes. Linear friction welding (LFW) is a solid-state technique capable of joining complex geometries; the process consists of joining two work-pieces by generating frictional heat between them and is a promising alternative for effective similar- and dissimilar-metal joining of magnesium. Our research aims at understanding the effect of LFW process parameters and alloying elements on the mechanical properties, ignition behavior and corrosion resistance of welded magnesium alloys. The study also involved an investigation of the microstructure of the welded region and its vicinity, taking into consideration the impact of various factors such as texture, second phase morphology and deformation. Magnesium-to-magnesium welding results in strong welded sections without a reduction in corrosion resistance. The welding of magnesium to aluminum poses some challenges due to galvanic corrosion and the formation of brittle second phases. This work is a part of an international collaboration between the National Institute of Advanced Industrial Science and Technology in Nagoya, Japan, the National Research Council Canada Aerospace Research Center and McGill University, Materials Engineering.

Luis Angel Villegas Armenta and Mihriban Pekguleryuz, McGill University; Priti Wanjara and Javad Gholipour Baradari, National Research Council Canada; Isao Nakatsugawa and Yasumasa Chino, National Institute of Advanced Industrial Science and Technology

COM00140: Overview of the Research and Development on Wire-Fed Electron Beam Additive Manufacturing in Aerospace

Abstract: Standing on the precipice of a technological revolution in the manufacturing industry, smart factories are poised to enable low-cost, on-demand and high efficiency production with the aid of disruptive innovations in the internet of things (IoT), condition sensing/monitoring combined with artificial intelligence, and metal additive manufacturing processes. Presently, the status-quo in research for metal additive manufacturing is centered on the fabrication of small parts with topology optimization performed for weight savings and performance using mainly laser powder-bed 3D printing technology. For production and repair of large parts, such as those that are likely to be used in aircraft engines, air frame structures or other large mechanical systems, the processing approach entails migrating to higher deposition rate 3D printing. In this regard, wire-fed electron beam additive manufacturing (EBAM) is gaining momentum as an enabling technology for the fabrication and repair of near net shape metallic parts through a rapid

layer-by-layer deposition process. Specific advantages of the EBAM process are the relatively large build envelop—that becomes infinite for in-space production—combined with the near 100% material efficiency of the wire-feed into the melt pool and high bulk material deposition rates of 200-600 mm^3/s depending on feature size and material. Post-deposition machining for finishing to the final geometry has indicated similar cutting forces and tool wear characteristics to conventional wrought metals, thus allowing ease of integration into existing factory environments. Work over the past 15 years on the EBAM process at the National Research Council of Canada (NRC) through its Aerospace Manufacturing Technology Center has strived to address the different underlying challenges presently facing the global scientific and research communities for introducing, producing and qualifying materials and structures fabricated through a hybrid additive-subtractive approach, as compared to a conventional subtractive methodology. This keynote overviews the technological developments to advance EBAM and covers the material characteristics (e.g. microstructure, residual stresses, distortion) and their linkages to mechanical performance under static tensile, cyclic fatigue and high cycle vibratory fatigue loading. The role of microstructural features on failure mechanisms will also be discussed based on fractographic and crack path analysis after tensile and fatigue testing.

Priti Wanjara and Javad Gholipour Baradari, National Research Council Canada

COM00141: Overview on Linear Friction Welding of Aerospace Titanium Alloys

Abstract: It is well known that titanium alloys possess high specific tensile strength and good fatigue properties at moderately elevated temperatures up to 500°C, but they remain notoriously expensive due, not only to the high cost of metal extraction, but also challenges (and thus cost) associated with their shaping, forming and machining. Unsurprisingly, numerous emerging manufacturing technologies for titanium alloys have been researched and developed to allow a reduction in the buy to fly ratio (i.e. minimized scrap). Amongst the different manufacturing advancements for titanium alloys, the development of cost-efficient joining technologies has been especially challenging for designing and net shape processing of load-bearing fatigue critical structures and assemblies. Though titanium alloys are weldable using most fusion-based joining processes, the high reactivity of titanium with atmospheric gases at elevated temperatures above 400°C, and especially in the liquid state, leads to the fusion zone being highly susceptible to solidification defects (e.g. gas porosity) and contamination by oxides/foreign particles from the environment that limit reliable metallurgical and mechanical performance, particularly vis-à-vis the stringent and safety critical requirements in the aerospace industry. The development of solid-state joining technologies, especially linear friction welding (LFW), for titanium alloys has significantly increased the capacity for advanced and precise assembly of complex geometries with high weld integrity and performance. The National Research Council of Canada (NRC) through its Aerospace Manufacturing Technology Center has been a key contributor to the global research and scientific developments on LFW over the past two decades. In this presentation, an overview of the processing developments on different titanium alloys (near-alpha, alpha-beta and near-beta) will be discussed alongside the key microstructural characteristics and performance responses. This presentation will also aim to provide a perspective on future areas for research development in this field.

Javad Gholipour Baradari and Priti Wanjara, National Research Council Canada

COM00150: A Brief Review of Ultrasonic Spot Welding of Dissimilar Lightweight Materials

Abstract: Lightweighting is one of the most effective strategies to reduce fuel consumption and harmful emissions in the automotive industry. It has been reported that the global automotive lightweight materials market is expected to surpass US$245 billion by 2026. Vehicle lightweighting can be achieved via stronger materials such as advanced high-strength steels or lighter materials such as magnesium (Mg) and aluminum (Al) alloys, along with essential manufacturing methods. Dissimilar welding between magnesium and other alloys represents a huge challenge, since intermetallic compounds (IMCs) may occur to potentially cause premature failure. Some emerging solid-state joining techniques, such as ultrasonic spot welding (USW), friction stir spot welding, have been developed to join light alloys. In this talk, a number of examples on the welding of dissimilar Mg-to-Al, Mg-to-steel and Al-to-steel via USW will be presented. The weld interface experienced dynamic recrystallization during similar welding, while an IMC layer or eutectic layer was formed during dissimilar welding, depending on material combinations and welding parameters. To diminish the occurrence of IMCs, a tin or zinc interlayer was used during dissimilar welding. It was observed that the tensile lap shear strength and fatigue life of the dissimilar welded joints were effectively enhanced. The evolution in the microstructure and texture as well as fatigue fracture mechanisms of the welded joints will also be presented.

Daolun Chen, Ryerson University

COM00159: High-Speed Nano-indentation Mapping of Additive Manufactured Titanium Alloys for Aerospace Application

Abstract: Throughout history, exploration of material properties at different length scales, both large and small, have fundamentally reshaped human understanding of the physical world and catalyzed industrial growth. Towards this vision, my seminar will focus on mechanical properties of materials in the size ranging from a few micrometers to about one hundred nanometers. I will first explain a well observed phenomenon – “smaller-is-stronger”. Then, I will share insights on mechanical characterization of emerging nanostructured refractory high-entropy alloys: I achieve mechanically strong (yield strength of ~10 GPa) and thermally stable (after annealing at 1100°C for 3 days) nanocrystalline alloys, surpassing conventional nickel-based superalloys and pure tungsten. In addition to small-scale mechanics, I will talk about my research on metal additive manufacturing (3D printing) techniques – selective laser melting in which fast melting and solidification of metal powder result in bulk components, as well as cold spray and RF Plasma spray. In closing, I will talk about future research directions of my group about the combinatorial development of structural materials.

Zhiying Liu, Haoxiu Chen, and Yu Zou, University of Toronto

COM00165: Hybrid/Tandem Laser-arc Welding of Thick Low Carbon Martensitic Stainless Steel Plates for Hydraulic Turbines Application

Abstract: The main objective of this research work was to understand the different challenges related to hybrid laser-arc welding (HLAW) of thick gauge section assemblies of low carbon 13%Cr-4%Ni martensitic stainless steel and develop a practical solution by adapting and optimizing this relatively new welding process in order to attain higher processing efficiency through a reduction in the number of welding passes necessary to fill the groove gap. Also a special focus was given to the development of the hybrid and tandem laser-arc welding techniques for the root pass. In this study, the processing methodology using the hybrid/tandem laser-arc welding technology was also adapted based on the thickness of the low carbon martensitic stainless steel plates, namely a single pass HLAW process for a 10-mm thick section and a multi-pass hybrid/tandem laser-arc welding process for a 25-mm thick section. After welding, the joint integrity was evaluated in terms of microstructure, defects and mechanical properties in both the as-welded and post-weld tempered conditions. The effect of different welding speeds on the as-welded joint integrity of the 10-mm thick and 25-mm thick assemblies was characterized in terms of the weld bead geometry, defects, microstructure, hardness, ultimate tensile strength and impact energy. All the welds met the specifications of ISO 12932 at a speed higher than 0.75 m/min. The ultimate tensile strength and Charpy impact energy values of the fully penetrated welds in the tempered condition were acceptable according to ASTM, ASME and industrial specifications, which show good potential for introducing hybrid/tandem laser-arc welding technology for the manufacturing of next generation hydroelectric turbine components.

Fatemeh Mirakhorli and Priti Wanjara, National Research Council Canada; Jean-Luc Fihey and Tan Pham, École de Technologie Supérieure

COM00166: Hybrid Additive/Subtractive Manufacturing of Maraging Steels

Abstract: This invited presentation will cover hybrid manufacturing of maraging steel produced in-envelop using laser powder-bed fusion (i.e. selective laser melting) processing with a sequential machining pass after every ten sintering layers, as well as final finishing of selected surfaces. As-built and machined surface roughness properties—measured with a profilometer (linear) and laser confocal microscopy (3D map)—are discussed in terms of typical linear/areal parameters. The influence of the laser power on the part density was measured using the Archimedes and pycnometry methods; furthermore, the distribution of pores was analyzed using X-ray micro-computed tomography (µCT). Mechanical stability assessment involved tensile testing to evaluate the mechanical response of maraging steel built by in-envelope additive/subtractive processing. Based on the findings, the presentation will discuss future areas for research and technology advancement for the application of hybrid manufacturing in the automotive and aerospace industrial sectors.

Sheida Sarafan, Priti Wanjara, Javad Gholipour Baradari, Fabrice Bernier, and Marjan Molavi-Zarandi, National Research Council Canada; Josh Soost, Matsuura Machinery, USA, Inc.

COM00167: Study on Precipitate Formation during Laser Powder Bed Fusion of Inconel 625

Abstract: An understanding of both the solidification microstructure and precipitate formation is critical for estimating the mechanical properties of Inconel 625 prepared by the Laser Powder Bed Fusion (LPBF) technique. In this study, the as-built microstructure of Inconel 625 has been characterized in terms of cell spacing, precipitate morphology and composition using optical and electron microscopy. It is found that the microstructure mainly consists of Nickel-Chromium (gamma-FCC) dendrites with a small volume fraction of precipitates embedded mostly into the interdendritic regions. Using transmission electron microscopy equipped with Energy-dispersive X-ray Spectroscopy (EDS) and Selected Area Diffraction (SAD) analysis, the phases found within the interdendritic regions are designated as γ" [Ni3Nb], NbC, and laves precipitates.

Pardis Mohammadpour and Andre Phillion, McMaster University

COM00169: A Multiscale Modeling Approach for Fast Prediction of Residual Stress during Laser Powder Bed Fusion

Abstract: Additive manufacturing (AM) is a layer-by-layer fabrication technology poised to bring about a revolution in the way products are designed, manufactured, and integrated. This technology has gained significant industry interest due to its ability to create parts consolidation and complex geometries with customizable material properties. Parts are fabricated directly from the three-dimensional digital model and their precise geometries and material distribution could result in higher performance than parts obtained using conventional manufacturing techniques. Among metal AM processes, laser powder bed fusion (LPBF) is the major technology as it represents around 80% of metal AM equipment installed globally. Although being formerly used to produce prototypes, LPBF is more and more foreseen to manufacture near-net-shape structural components with complex geometries. Nevertheless, there are still some technical barriers and challenges for the production of metallic parts. The build-up of residual stresses in a part during laser powder bed fusion provides a significant limitation to the adoption of this process. These residual stresses may cause a part to fail during a build or fall outside the specified tolerances after fabrication. Defect-free production of metallic parts using LPBF requires process optimization which consists of establishing a quantitative correlation between final part characteristics and process parameters to determine the optimum parameters in order to fabricate a fully functional mechanical component. Development of a numerical model to accurately predict the induced residual stresses and distortion during the LPBF process would be of great interest as it would allow to effectively investigate the influence of processing parameters on the quality of the parts. Additionally, a reliable numerical model can drastically reduce the expensive experimental costs associated with the number of tests, cut-ups, as well as manufacturing iterations required for the development of additive manufactured parts. In this invited presentation, we present ongoing activities at National Research Council Canada (NRC) to develop a high fidelity finite element (FE) model to simulate the build process and calculate the residual stress state and distortion for specimens built with a continuous scan strategy. The presentation will discuss a novel inherent strain (local-global) approach that has recently been developed to speed up the computations of LPBF simulation. The model was then validated by experimental results for distortion and residual stresses. Based on the findings from the thermomechanical simulations, there is a good agreement between X-ray diffraction measurements and 3D scanning data used to determine the residual stresses and distortions in the parts.

Marjan Molavi-Zarandi, Jean-Philippe Marcotte, Kalonji Kabaa Kabanemi, and Florin Ilinca, National Research Council Canada

COM00175: Comparison of Texture Development and Segregation in Ti-6Al-4V and In625 Alloys during High Productivity Wire Arc Additive Manufacturing Process

Abstract: Additive manufacturing is a promising process to produce nickel and titanium based alloys parts and builds in better economic way than the conventional industrial methods. Nevertheless, final properties in terms of microstructure, texture and residual stresses of additive manufactured part/build are different as compared to the conventionally produced methods (1). Numerous studies on Al-Li (2), In718 (3,4), and Mg (5) alloys show microstructure heterogeneities during welding and additive manufacturing processes. Although, they are not well reported/explained for the high deposition rates in WAAM process. In present investigation, the samples of In625 and Ti-6Al-4V alloys were produced by WAAM process with high deposition rates (>600 cm^3/h). Where, processing parameters were controlled to promote structural transition zones. The experiments show that while periodic columnar to equiaxed transition is observed within In625, no evidence of it was found in Ti-6Al-4V. Mechanism at the origin of such structural transition related to processing parameters and the metallurgical difference of both alloys was investigated and presented in this work.

Ilia Ushakov, Satyaveer Dhinwal, and Dominique Daloz, Institut Jean Lamour - Université de Lorraine; Guillaume Cadoux, Prodways Rapid Additive Forging

COM00176: Critical Assessments of Some Common Assumptions in the Use of Concentration-dependent Interdiffusion Coefficients Obtained by Standard Analytical Methods

Abstract: Ranging from diffusion-based advanced materials processing techniques, such as, surface alloying, sintering, and bonding, to diffusion-controlled phase transformations that influence materials microstructure and properties, reliable use of concentration dependent interdiffusion coefficient, D=F(C), to predict and/or understand materials behaviour is fundamentally crucial. The common standard analytical methods that are used to determine D=F(C) in binary alloy systems include Boltzman-Matano (BM), Sauer- Freise (SF), Hall, Sarafianos, and Wagner procedures. Moreover, the D=F(C)s obtained by these methods are used in the computation of atomic mobilities for diffusion analyses in multi-component systems. The use of D=F(C)s obtained by these standard analytical methods in several practical applications have been predicated on some major assumptions that have not been adequately scrutinized. One of these assumptions is that solute concentration is mainly dependent on a single variable, l, the ratio of distance to the square-root of time, which is known as the Boltzmann's parameter, and as such, the D=F(C) is time independent. Secondly, it is generally assumed that the D=F(C) obtained under the condition of constant surface concentration, which is the prevailing condition during the determination of D=F(C) by the standard analytical methods, is applicable for cases that involve a time-varying surface or solute-source concentration e.g., during homogenization processes. A third assumption is that the standard D=F(C)s can be used to analyze or model multi-stage processes, where a non-uniform solute distribution pre-exists in a material prior to a

diffusion treatment at a given temperature, e.g., multi-stage heat treatments, sintering, bonding and coating. Unfortunately, proper verification of the validity of these key assumptions can not be performed by analytical approach, systematic numerical analyses are imperative. In our work, we used the Leapfrog/Dufort-Frankel's explicit scheme to develop a numerical diffusion model, which we coupled with a numerical inverse simulation technique to compute D=F(C)s from experimental concentration profiles to verify these assumptions. The results of the study, which unveil invalidity of the assumptions, and the implications on the use of D=F(C) obtained by the standard analytical methods to produce reliable theoretical predictions and analyses of diffusion effects, will be presented and discussed.

Olanrewaju Ojo, University of Manitoba

COM00178: Bifilm Revolution: Our First Glimpse

Abstract: The observation by Xinjin Cao of the formation of intermetallic phases on the outer, wetted interfaces of oxide bifilms has led to major breakthroughs in the understanding of a number of metallurgical mysteries. The new understanding included the apparent brittleness of beta-Fe particles and Si phases in Al-Si alloys, and the mechanism for the dramatic change of structure from 'unmodified' primary Si to 'modified' fine eutectic Si by additions of Na or Sr. The great loss of ductility following turbulent handling of liquid Al alloys is also explained, as is the ease of nucleation of gas or shrinkage porosity in castings. The unsatisfactory nature of vacuum melting and casting of many metals, including steels, is also explained for the first time, and the extreme dangers from the unreliability of vacuum arc remelted steel is uncovered. Following Cao's confirmation of the existence and importance of the bifilm defect created during casting, the prospect of reliable metals, metals we can trust, is for the first time a reality.

John Campbell, University of Birmingham

COM0041: Effects of Asymmetric Rolling on Spark Plasma Sintered Preforms Fabricated from Aluminum 2219 Powder

Abstract: The effects of asymmetric rolling (ASR) on a prealloyed (PA) 2219 powder metallurgy (PM) alloy processed through spark plasma sintering (SPS) have been studied. The prealloyed powder was first consolidated through SPS and subsequently through ASR using rollers of the same diameter but different velocities. The rolled products exhibited microstructures that were clearly pore free. This was corroborated by density measurements which indicated that all ASR products achieved full densification. This implied that ASR was an effective means of eliminating the usual residual pores found in spark plasma sintered preforms. In addition, significant gains in tensile properties were noted in ASR products processed through T1 and T87 tempers. Aluminum oxides which apparently assume the shape of a continuous film in spark plasma sintered preforms were discretized through the ASR process. Obviously, this led to significant improvements in tensile properties especially the ductility. The microstructure of PA2219 exhibited aluminide phases identified through TEM/EDS analysis, which included $Al_{4.8}Cu_{3.8}$ Fe $Mn_{0.4}$, Al_3Cu_2, $Al_{5.3}Cu_{3.3}$Fe $Mn_{0.25}$ $Zr_{0.1}$, and $Al_2CuFe_{0.26}Mn_{0.1}Zr_{0.06}$.

Mark Amegadzie and Paul Bishop, Dalhousie University; Ian Donaldson, GKN Sinter Metals LLC

COM0044: Deep Cryogenic Treatment as the Next Processing Step in the Steel Industry

Abstract: Steel industry and the research of new steel processing schemes plays an important role in the development and production of tools used in everyday life. The post-production heat treatment play an essential role in tailoring various material properties to the needs of various applications. However, limitations in terms of simultaneous improvement of several material properties is in many cases a difficult challenge and require special heat treatment procedures. One of these procedures is deep cryogenic treatment (DCT), which has become increasingly more interesting for the application in various industries. DCT has been researched for a substantial time, however only lately DCT has been conservatively applied to improve properties of steels. During DCT the material is exposed to temperatures below –160°C, normally to the temperature of liquid nitrogen (–196°C). The treatment is used to transform austenite in daughter phases (mainly martensite) and consequently to change properties of the steel. DCT has been reported to change properties of steels such as corrosion and wear resistance, hardness, toughness, better machinability etc. The treatment has been also shown to increase precipitation of carbides and refinement of carbide formation in a more even manner. The benefits of DCT are not only the changing properties, but also the procedure allows replacement of 2-3 cycles of tempering when using DCT, which reduces productions costs. The issues with DCT are the unsystematic research and contradicting results that give no persuasive answers to the successfulness and applicability of DCT for industrial application. For this reason, the undertaken study has considered a range of steels from high-speed steels, tool steels and stainless steels, which are commonly used in various industries, in order to attain a clear understanding of DCT and its implication on material properties. Selected groups of steel were systematically investigated for the influence of DCT on their microstructural, mechanical, and tribological properties with respect to their processing history and compared with reference samples prepared with conventional heat treatment. The study provides systematic data of DCT influence on the properties of selected steels showing that DCT is evidently an effective method for applications used in industry. However, its effect differs depending on the steel composition and selected heat treatment upon which DCT is applied.

Matic Jovicevic-Klug, Patricia Jovicevic-Klug, and Bojan Podgornik, Institute of Metals and Technology

COM0054: Evaluating the Solid-State Sintering of a Metal Injection Molded Nickel-Based Superalloy under Different Sintering Atmospheres

Abstract: Metal injection molding (MIM) is a net shape manufacturing technique that can effectively produce complex parts while reducing material waste and manufacturing costs. MIM has been successfully applied to nickel-base superalloys (NiSAs) in the aerospace industry, however their high temperature properties remain limited. Sintered MIM NiSAs generally exhibit fine-grain microstructures, which have reduced creep resistance compared to the coarser grain structures found in cast NiSAs. Additionally, due to the use of fine pre-alloyed powders in the MIM process, carbon and oxygen can react with alloying elements such as Al, Ti, and other refractory metals (RMs) to form carbide and oxide phases which can restrict both grain growth and densification. In the present work, the sintering behaviour of a MIM NiSA is evaluated under different sintering atmospheres and peak temperatures. Dilatometry and differential scanning calorimetry techniques are employed to assess sintering densification and liquid fraction, respectively. Optical microscopy and SEM-EDS of the sample microstructures revealed that RM-rich oxides and carbides form at the prior particle boundaries, restricting grain boundary mobility. Samples sintered in the solid state did not exhibit grain growth regardless of the sintering atmosphere, while samples sintered at supersolidus temperatures experienced rapid grain growth upon reaching a critical liquid fraction which was influenced by the furnace atmosphere.

Addison Rayner and Stephen Corbin, Dalhousie University

COM0075: Surface Modification of an Industrially Processed 2xxx Series Aluminium Powder Metallurgy Alloy via Ultrasonic Pulsed Waterjet Peening

Abstract: The automotive industry is constantly devising approaches to mitigate against climate change by reducing vehicular emissions. One way by which this can be achieved is ‘light-weighting’, replacing ferrous components with lighter alloys, such as those based on aluminium. This reduces the net vehicular weight and in turn increases fuel economy. Aluminum powder metallurgy (PM) has proven to be a cost-effective means of production, since the process offers advantages such as effective material utilization, near-net shaped products, and high production rates. Meanwhile, most components fabricated through Al-based PM find applications in services where they are usually susceptible to fatigue failure. In an attempt to improve the mechanical properties, surface modification techniques such as laser and shot peening can be used to suppress the initiation of fatigue cracks and increase wear resistance. Whiles these peening technologies have proven viable, a more eco-friendly, cheaper and cleaner approach, known as ultrasonic pulsed waterjet (UPWJ) peening is being developed. The objective of this work is to study the effects of UPWJ peening on an industrially processed aluminum PM alloy, reinforced with AlN. Here, the effect of UPWJ exposure time on the microstructure, surface profile and residual stress were analyzed using optical microscopy, confocal laser scanning microscopy, scanning electron microscopy and X-ray diffraction.

Mark Amegadzie, Eric Moreau, and Kevin Plucknett, Dalhousie University; Bryce Christensen and Ian Donaldson, GKN Sinter Metals LLC; Andrew Tieu and Mohan Vijay, VLN Advanced Technologies Inc.

COM0078: Deep Cryogenic Treatment of Titanium-based Alloys

Abstract: Deep cryogenic treatment (DCT) is a process that involves cooling materials to extremely low temperatures, for extended isothermal holds, in order to modify physical properties in a positive manner. DCT has been successfully applied to a variety of ferrous alloys, invariably enhancing hardness and wear properties. In contrast, only limited studies have been conducted applying DCT to titanium alloys. In the present work, DCT has been used to treat both commercially-pure titanium (CP-Ti) and an aerospace-grade titanium alloy (Ti-6Al-4V). The

DCT process steps involved cooling the titanium materials to –196°C, at a controlled rate, and then holding at this temperature for a fixed period of time (either 10, 24, or 72 hours), before returning to room temperature. Treated samples were then investigated in terms of their microstructures, mechanical behaviour, and aqueous corrosion resistance (in 3.5 wt.% NaCl solution). It was found that DCT yields subtle changes to the microstructure and certain tensile properties, however these changes are very small for both alloys, and there were no significant changes observed in their hardness. Conversely, measurable improvements in corrosion resistance were noted, especially for the shorter duration DCT schedules (10 or 24 hours). It is consequently demonstrated that DCT can provide beneficial effects when used for titanium-based systems.

Theodore Street, Zhila Russell, Danielle Griffin, and Kevin Plucknett, Dalhousie University; Jack Cahn, Deep Cryogenics International

COM0089: Spark Plasma Sintering of Metal Matrix Composites with an Aluminum 2618 Matrix System

Abstract: In this study, metal matrix composite (MMC) materials were produced through spark plasma sintering (SPS). In doing so, 2618 (Al-2.3Cu-1.6Mg-1Fe-1Ni-0.2Si) aluminum alloy powder was coupled with various concentrations of AlN and SiC particulates and sintered at temperatures that ranged from 450°C to 550°C. The density, hardness, microstructure, and 3-point bend properties were then investigated. The final density increased with sintering temperature and effectively full densification was achieved in most systems provided they were sintered at 550°C. Portions of the coarser particulates contained internal porosity that prevailed after SPS and reduced the final density realized. Internal porosity was not apparent in the 3 μm SiC particulates and although this phase self-concentrated into small clusters, the majority of these were fully infiltrated by the FA2618 matrix during SPS. Three-point bend tests indicated that UBS and ductility typically deteriorated as the concentration of ceramic increased. However, the extent of the decline was influenced by the choice of ceramic. Overall, the MMC that contained 10 v/o 3 μm SiC offered the best balance of density, hardness, and bend properties.

Xuegang Wang, Shandong Jianzhu University; Ian Donaldson, GKN Sinter Metals LLC; Randy Cooke, Gregory Sweet, and Paul Bishop, Dalhousie University

COM00116: Effect of T5 Heat Treatment on Al-7Si-Mg Alloys Printed by Laser Powder Bed Fusion Process with Different Printing Layer Thickness

Abstract: Laser powder bed fusion (LPBF), one of the additive manufacturing methods, is praised to be used for the component production in the aerospace, medical, and automobile industries, due to its design flexibility and the potential to achieve excellent mechanical properties. Even though LPBF is approaching mainstream fabrication, some knowledge gaps related to heat treatment response of such parts remains to be elucidated. The present study deals with the relation between T5 heat treatment of A357 alloy as a function of the printing layer thickness. Firstly, powder characterizations will be presented to validate the quality of A357 powder for LPBF. Secondly, T5 age hardening curves with different temperatures up to 24 hours

will be presented. The combination of microstructure evaluation and micro-hardness were used to ascertain the interactions between cycle and printing layer thickness.

Chin Chieh Cheng, Jaskaranpal Dhillon, Zhen Li, and Mathieu Brochu, McGill University

COM00120: Localized Surface Modification of High Strength Aluminum Alloys Using Cold Spraying and Friction Stir Processing

Abstract: Repair methodologies for cold-worked aluminum alloys are very limited due to strength degradation that occurs during the process. Though friction stir processing (FSP) is a well-documented repair methodology for various alloys, it causes recrystallization in the microstructure of cold-worked aluminum alloys, negatively affecting their mechanical properties. This study presents a novel approach for surface repairs of high-strength aluminum alloys without negatively affecting the material strength. Low-pressure cold gas dynamic spraying (150 psig) was used to fabricate aluminum-alumina metal matrix composite (MMC) coatings on 5052-H32 Al alloy. The coatings were fabricated from custom mechanical powder blends with varying concentrations of the Al and Al_2O_3 powder, up to a maximum of 75 wt.% Al_2O_3. The coatings (~1.5 mm thick) were then friction stir processed using a cylindrical tool with rotational and traverse speeds of 1200 RPM and 9 mm/s respectively. Optical microscopy, scanning electron microscopy (SEM), and image analysis were conducted to quantify the Al_2O_3 concentration in the coatings and analyze the difference in microstructure between the as-sprayed and post-FSP coating samples. The Al_2O_3 content in the coating matrix increased as the Al_2O_3 content in the powder blend increased, producing a maximum of 33 wt.% Al_2O_3 in the coating fabricated from the powder blend containing 75 wt.% Al_2O_3. Vickers hardness, abrasion and tensile testing were performed on both the as-sprayed and post-FSP coatings. The coating hardness increased with increasing Al_2O_3 content, yielding a maximum of 73 HV for the as-sprayed 33 wt.% Al_2O_3 coating. The increase in hardness was attributed to the decrease in mean free path between the Al_2O_3 particles. The coating wear rate decreased with increasing Al_2O_3 content, from 97×10^{-5} mm^3/N-m for the as-sprayed pure Al coating to 73×10^{-5} mm^3/N-m for the as-sprayed coating with 33 wt.% Al_2O_3 reinforcement. The elastic modulus and ultimate tensile strength achieved a maximum of 45 GPa and 162 MPa respectively, for the as-sprayed coating with 33 wt.% Al_2O_3. Therefore, increasing the hard, reinforcing particle content improved the hardness, wear, and mechanical properties of the coatings. Additionally, the hard particle redistribution and refinement that occurred during FSP led to further improvements in hardness, wear, and mechanical properties. These results suggest that hybridization of cold spray with FSP to produce MMC coatings can be an effective method for high-strength surface repairs of aluminum alloys.

Wania Jibran and Andre McDonald, University of Alberta; Priti Wanjara and Javad Gholipour Baradari, National Research Council Canada

COM00123: Analysis of Inconel 625 Fabricated through Laser Powder Bed Fusion

Abstract: Additive manufacturing offers advantages over traditional manufacturing techniques that are ideal for the aerospace industry. The standards for certification in this industry are significant, therefore a better understanding of the effects of additive manufacturing on the properties of components is required. A study was conducted, focusing on a single alloy and process that provide important advantages for the aerospace industry: Inconel 625 superalloy (IN625) and Laser Powder Bed Fusion (LPBF). The effect of LPBF processing parameters on the mechanical properties and porosity of printed IN625 were initially investigated. Seven different manufacturing parameters associated with Renishaw RenAM 500Q machine were employed. The preliminary results indicate that an increase in laser power, hatch spacing, and exposure time leads to lower porosity (higher relative density) of the printed sample. All the samples generated a hardness of approximately 28 HRC. To further improve the tensile strength, three different heat treatment schedules normally employed to conventionally formed IN625 were analyzed. It can be concluded that heat treatment at 670°C for 10 hours provided the highest hardness of the three, about 32 HRC. The data from this work can be used in designing the manufacturing parameters and heat treatment schedule of IN625.

Jonathan Lewis and Clodualdo Aranas, University of New Brunswick; Matthew Harding, Tronosjet Manufacturing Inc.

COM00127: Modelling Thermal Conductivity of Spark Plasma Sintered Al-Ni Alloys

Abstract: High strength, low density Al-Ni alloys show promise as high thermal/electrical conductivity materials for demanding thermal/electrical applications in lighting, automotive and consumer electronics. Spark plasma sintering is a rapid manufacturing route that can provide high density alloy mixtures within short time periods. This research focused on determining the thermal conductivity of Al-Ni spark plasma sintered alloys using eddy current electrical conductivity measurements and finite element simulations. The results indicate that increasing Ni content in the Al-Ni alloys reduces thermal conductivity but that finite element simulations can provide estimations of thermal conductivity within 2-3 W/mK to eddy current derived values. Therefore, simulations can be used to estimate thermal conductivity of spark plasma sintered samples and possibly extended to more complex alloy microstructures with multiple phases and irregular phase morphologies.

Pradeep Bhagtani and Mehkansh Sharma, University of Guelph; Lukas Bichler, University of British Columbia-Okanagan; Alexander Bardelcik and Abdallah Elsayed, University of Guelph

COM0016 Roll Compaction of Ti-6Al-4V and Ti-5Al-2.5Fe Strips with Titanium Sponge Powder

Abstract: Direct powder rolling (DPR) is a process wherein metallic powders are first compacted into a porous sheet or strip. This strip is then sintered to allow the individual particles to bond and fuse together. The third step is to cold roll this porous, sintered strip to reduce its thickness and further increase its denisty. In the case of Titanium and its alloys, the availability of a low-cost powder feedstock, in conjuntion with the DPR porcess, is a potential way to produce a lower-cost Titanium sheet or foil for a range of industrial applications. To date, the DPR process applied to Ti powder has not produced a sheet with mechanical properties necessary for widespread comercial use. This has limited the use of Titanium in many

applications. In this work, roll compaction, sintering, and cold rolling methods are being developped which are capable of producing dense, commercially pure CP-Ti, Ti-6Al-4V and Ti-5Al-2.5Fe alloys. Mixtures of CP-Ti grade 3 sponge fines are blended with Al:V master alloy powder or Al and Fe elemental powders. The evolving density and microstructure of the Ti strips as a function of the degree of cold roll reduction, roll force and number of annealing steps is a particular focus of this presentation. If successful, the DPR process under development could increase the use of Ti as a light metal in the Canadian aerospace and automotice industries, facilitating weight reduction, lower fuel economy, and ultimately a reduction in greenhouse gases.

Shannon Clemens and Stephen Corbin, Dalhousie University

COM00168: Solidification Behaviour and Kinetics of Transient Liquid Phase Sintered MAR-M247 Nickel Superalloy Using a BNi-9 Filler Alloy

Abstract: Transient liquid phase sintering has become the go-to alternative to welding in the repair of critical hot section turbine engine components used in industrial gas turbine engines. Much of the existing literature on this industrial process has focused on systems where the nickel superalloy is in bulk form. In this study, the solidification behaviour and process kinetics of powder-based nickel superalloy repair processes were investigated both experimentally and computationally. The use of differential scanning calorimetry, scanning electron microscopy, along with computational evaluation via Thermo-Calc software allows for the characterization of the powder couple. We show the evolution of both thermal events and microstructure under various bonding temperatures, isothermal bonding times, and powder ratios. These results provide insight into the solidification behaviour and process kinetics for a MAR-M247/BNi-9 powder couple.

Coleton Parks and Andre Phillion, McMaster University

COM0034: Laser and Wire Direct Energy Deposition of Inconel 718: Lack of Fusion Origin and Process Interruption influence on Microstructure

Abstract: Series of deposited walls of Inconel® 718 on stainless steel plates were carried out with different process parameters (laser power, advance speed, hatch spacing and wire feeding rate) using coaxial laser and wire process. Firstly, the impact of these parameters on the presence of defects such as lack of fusion, encountered in DED laser and wire technology are discussed; and the effect of grinding and repairs during deposition process interruption is also investigated. We show that lacks of fusion are mainly influenced by heat input. This led to the deposition of a 20×50×200 mm dense wall, where no lacks of fusion were validated using X-ray radiography (as deposited / machined surface) and metallographic investigations. Inclusions were found and their origin is attributed to the wire state, and grinding effect during process stops led to no defect input.

Ivan Cazic, Institut de Soudure - Université de Lorraine - Université de Luxembourg; Maxime Schmitt and Maxime El Kandaoui, Institut de Soudure; Julien Zollinger and Benoit Appolaire, Institut Jean Lamour - Université de Lorraine; Peter Plapper, Université du Luxembourg

COM0073: Material Characterization Comparison of D2 and H13 Tool Steels Manufactured using Directed Energy Deposition

Abstract: This research focuses on the material characterization of Directed Energy Deposition (DED) processed D2 and H13 tool steels by varying the scanning speed and powder feed rate, with the remaining system parameters fixed. DED 'clads' of D2 and H13 were deposited onto annealed (wrought) D2 and H13 substrates, respectively. The results of printed D2 and H13 were compared when the selected process parameters were the same, and the starting powder characteristics are similar. Single clad tracks and rectangular samples were manufactured for this study. For the single clad samples, dilution depth, height, and width were investigated using confocal laser scanning microscopy (CLSM), optical microscopy (OM), and scanning electron microscopy (SEM). Multi-layered rectangular samples were printed to analyze the microstructure, which was examined using CLSM, OM, and SEM. Fundamental mechanical properties have also been measured. From this study, the alloys showed similarities in the printed samples, but the influence of varying scanning speed and powder feed rate were less obvious.

Owen Craig, Samer Omar, and Kevin Plucknett, Dalhousie University

COM0079: Advanced Surface Modification of Titanium Alloys Using Ultrasonic Pulsed Waterjet Peening

Abstract: Surface peening has been used as a viable method of treatment for titanium-based alloys across a variety of applications. In the present study, the effect of a novel ultrasonic pulsed water jet peening (UPWJ) technology has been assessed for surface modification of both Ti-6Al-4V and commercially-pure Ti alloys. The influence of UPWJ on residual stress, surface roughness and microstructure is investigated. These materials were considered primarily in wrought form, though initial studies on laser powder-bed fusion additively manufactured Ti-6Al-4V will also be discussed. The waterjet treatment was conducted on the surface by applying different UPWJ conditions, while keeping the other processing parameters constant. Initial microstructural characterization was conducted on peened and unpeened samples using laser confocal microscopy, scanning electron microscopy, X-ray diffraction, as well as hardness and tensile tests. The influence of UPWJ peening on fatigue strength of the samples is also being evaluated under fully reversed cyclic loading and compared to the properties of the unpeened counterparts. Based on the obtained results, UPWJ may serve as a potential method for surface modification of engineering components.

Paria Siahpour, Mark Amegadzie, Eric Moreau, and Kevin Plucknett, Dalhousie University; Andrew Tieu and Mohan Vijay, VLN Advanced Technologies Inc.; Bryce Christensen and Ian Donaldson, GKN Sinter Metals LLC

COM0091: Thermal Stability and Hardness of Electroformed Nickel-Cobalt Sheet Metal

Abstract: A novel electroformed nanocrystalline nickel-cobalt (n-NiCo) sheet was recently developed for commercial use as surface mount technology stencil sheets. To explore a broader range of potential industrial applications for this n-NiCo sheet material, detailed material characterization analyses in terms of microstructure, mechanical, and thermal stability were performed. The as-received material with a grain size of 18 ± 5 nm exhibited enhanced hardness (5.21 GPa) compared to polycrystalline NiCo (3.14 GPa). Annealing treatment result revealed that the n-NiCo was stable up to 200°C for at least 1 hour and the onset of abnormal grain growth was observed when the material was annealed to 250°C. The material shows a regular Hall-Petch to inverse Hall-Petch transition in the grain size range of 20–46 nm. Overall, the material has improved mechanical properties compared to the conventional polycrystalline NiCo counterpart which indicates as a promising alternative for industrial applications.

Jonathan Kong, Michael Sabatini, Leo Monaco, Jane Howe, and Uwe Erb, University of Toronto; Jonathan McCrea, Integran Technologies Inc.

COM0093: On the Hardening and Subsequent Tempering of a Wire Arc Additive Manufactured 420 Martensitic Stainless Steel

Abstract: The impact of hardening-tempering heat treatments on the microstructure and mechanical properties of a wire arc additive manufactured 420 martensitic stainless steel was studied with the purpose of ensuring a fully martensitic microstructure in the as-quenched condition, and obtaining an optimum secondary hardening in the tempering cycle. Microstructure of the as-printed part was composed of residual δ-ferrite embedded in a martensitic matrix. Among the studied austenitizing temperatures, including 1050, 1150, and 1300°C (for 30 min followed by air-quenching), a fully martensitic microstructure was obtained from austenitizing at 1150°C, while undesired phases, such as Cr-rich carbides and δ-ferrite, were revealed at 1050 and 1300°C, respectively. Although two-hour tempering at 200 and 300°C was found to be insufficient for triggering the secondary hardening, increasing the tempering temperature to 400°C resulted in the formation of carbides with an optimum size and distribution, leading to increased microhardness value. On the contrary, intergranular segregation and coarsening of carbides at higher tempering temperatures of 500 and 600°C reduced the microhardness. The results of uniaxial tensile tests also confirmed that tempering at 400 °C results in the optimum combination of ultimate tensile strength and ductility.

Alireza Vahedi Nemani, Mahya Ghaffari, and Ali Nasiri, Dalhousie University; Salar Salahi, Memorial University of Newfoundland

COM0094: Effects of Columnar Grain Growth and Inhomogeneous Microstructure on the Anisotropic Mechanical Properties of a Wire Arc Additive Manufactured pH 13-8Mo Martensitic Stainless Steel

Abstract: Precipitation hardened martensitic stainless steels (PHMSS) with a reasonable weldability and superb combination of strength and corrosion resistance are appropriate candidates for wire arc additive manufacturing (WAAM) with various applications in marine, petrochemical, and aerospace industries. The present study aims to investigate the impact of microstructural heterogeneities and columnar grain structure on the anisotropic mechanical properties of a wire arc additive manufactured PH 13-8Mo component. The macrostructure of the deposited part was characterized by large columnar primary δ-ferrite grains elongated preferentially parallel to the building direction during the non-equilibrium solidification process,

resulting in anisotropic ductility along the horizontal and vertical directions of the fabricated wall. Moreover, the complex thermal history experienced by different deposited layers during sequential heating and cooling cycles, associated with the nature of the WAAM, led to the formation of inhomogeneous microstructural features through the building direction, including different volume fractions of δ-ferrite and retained austenite. The results of mechanical tests revealed an increasing trend in the microhardness and ultimate tensile strength from the bottom to the top of the component, correlated to the lower volume fraction of δ-ferrite and retained austenite in the top regions of the WAAM part.

Mahya Ghaffari and Alireza Vahedi Nemani, Dalhousie University; Salar Salahi, Memorial University of Newfoundland; Ali Nasiri, Dalhousie University

ADVANCES IN MINERAL PROCESSING: CHALLENGES AND OPPORTUNITIES

COM00112: Mercury Eradication for Chilean Small-scale Gold Mining by Smelting Gravimetric Concentrates

Abstract: Amalgamation to obtain gold from ore sources and gravimetric concentrates has been used by small-scale miners for more than one century in Chile. The process involves direct mercury handling and environmental damage by releasing metal particles into atmosphere and water. In accordance with Chile's commitments to develop responsible and sustainable mining and within the framework of the implementation of the Minamata agreement, national and regional institutions have made significant efforts to gradually reduce the use of large amounts of mercury in artisanal and small-scale gold mining. Nowadays, the participation of small gold miners, most of them located at the north of Chile, represents 3% of the national production. In this work, with the aim of finding a solution to eradicate the use of mercury during the process, improving environmental and operational health conditions, an alternative pyrometallurgical method suitable for small scale gold mining to produce Doré metal was investigated. Different kind of fluxes were tested at laboratory scale mixed together with gold gravimetric concentrate into an electric furnace in order to, find experimentally and corroborate thermodynamic equilibria, the best combination that allows generating two molten immiscible phases, a Doré metal that concentrates most of the gold, silver and copper, and a valueless and lower density slag where most of the impurities were distributed. The experimental tests were carried out at temperatures between 1273 and 1373 K and they considered; sodium carbonate, borax, silica, potassium nitrate and wheat flour, as main components to generate the suitable flux. After the pseudo-equilibrium, the crucible containing the molten sample was cold down under nitrogen atmosphere, cut and later on the two immiscible phases were analysed by using XRD and ICP to clarify the distribution of valuable metals. As a result of the study, the best condition that allows to maximize the recovery of gold and silver into the high market value metallic phase was determined. Temperature, type and amount of corresponding flux, and operation time were defined. In Chile there are no furnaces for melting gold gravimetric concentrates, first because of the technical challenges involved to build and to operate them, and second because of the lack of interest of large companies for creating functional prototypes that empower and promote independence for small-scale gold mining. Therefore, this research that allows to clarify the

develop of a new concentration method of gold from their mineral sources considering no use of mercury and the improvement of health, safety, environmental conditions and economic opportunities, represents a relevant and novel advance for the small-scale gold mining in Chile.

José Espinoza, Julio Ossandon, Leandro Voisin, and Camila Pizarro, University of Chile

COM00122: Modeling of a Continuous Bioreactor for a Two-step Pyrrhotite Tailings Treatment

Abstract: In Sudbury, Ontario, around 70-100 tons (dry weight) of pyrrhotite (Po, Fe_7S_8) tailings containing up to 1% Ni are stored under water in tailings ponds. With ongoing acid mine drainage (AMD) and growing cost to maintain those tailings facilities, the mining industry is seeking for a sustainable and economical treatment process. The present research is part of a collective effort led by an interdisciplinary University of Toronto team to develop such a process that produces stable elemental sulfur instead of sulfuric acid while recovering the valuable metal (Ni). This is proposed to be done in a two-stage process starting with an abiotic ferric leach of Po and a subsequent lixiviant (ferric ion) regeneration via microbially assisted oxidation of released ferrous ions. This work serves as the foundation to model the continuous biotic ferrous oxidation reactor, investigating the oxidation kinetics based on a modified Monod equation that's accurate for a high total Fe concentration. Batch and continuous bioreactor experiments were performed to construct and validate the model, with the aim to have a base for incorporating other process parameters into this predictive tool.

Heping Shen, Vladimiros Papangelakis, Elizabeth Edwards, and Krishna Mahadevan, University of Toronto

COM00126: Proposal of Novel Process for PCB Recycling by Using Roasting, Selective Crushing and Physical Separation

Abstract: Waste printed circuit board in electronic appliances contains considerable amount of valuable metals, such as copper, gold, etc., and at the same time, they also involves the elements, aluminum, bromine, antimony, etc., which cause operational problems in the subsequent copper or other non-ferrous metals smelting processes. In this study, we have proposed a pre-treatment process for concentrating such valuable metals and removing the smelting repellent elements. The process involves heating, roasting, sieving, selective crushing (mechanical and electric pulse disintegration), and physical sorting. We finally obtained the comprehensive copper/gold concentrates which involves 35-49 wt% grade of Cu with the recovery of 61-91%, 121-181 ppmw grade of Au with the recovery of 97-98 %, while the contents and mixture ratios of Al, Br, Sb were 2.6-3.4 wt% and 0.6-28, 0.3-0.4 and 3.2-3.8, and 0.02-0.05 and 3.3-4.1, respectively. We also found out the crushing and separation mechanism of each unit operation in the process.

Shuji Owada, Kazuma Tsutsumi, and Takahiro Ogawa, Waseda University; Takeru Sugisawa, Taiheiyo Cement Corporation; Yudai Fueki, Waseda University; Satoshi Kawakami and Shota Tahata, Dowa Eco-System Co., Ltd.

COM00129: A Comprehensive Methodology to Determine the Mechanism of a Flotation Reagent: Review of Existing Approaches and Critical Points

Abstract: Chemical reagents are at the heart of froth flotation and yet, many of them operate in complex and sometimes unclear ways. Determining their mechanism and their interactions with each other allows optimizing existing or planned processes by fine-tuning the amount of the reagents required to reach the desired result. This can also lead to a better application of the reagents by adapting them to the mineralogical composition of a targeted ore. This article should help ascertaining the important questions before starting the analysis of a reagent: where to start, what to look for and how to get there. It aims at presenting a complete methodology to determining the mechanism of a flotation reagent. This methodology is comprised of four simple steps, namely 1. Literature and critical points to be examined, 2. Design of experiments and associated statistical methods; 3. Performance analysis and parameters to be taken into account and 4. Fundamental investigations, e.g. typical analytical techniques applied to the analysis of the behavior of chemical reagents. Each step includes a review of common approaches and state of the art, as well as examples.

Nathalie Kupka and Martin Rudolph, Helmholtz Institute Freiberg for Resource Technology

COM00143: Recovery of REEs as Co-products from a Vietnamese Sedimentary Phosphate Ore by Flotation - Impact of Milling Conditions

Abstract: Vietnamese phosphate deposits are of marine sedimentary origin and one of the largest phosphate rock deposits of Southeast Asia. Lao Cai phosphate reserves have been estimated at about 526 million tonnes with hypothetical reserves of about 2.6 billion tonnes. Phosphate rock has been considered as a secondary rare earth elements (REEs) source due to REEs often found as tracers of geochemical processes in the crystal structure of phosphates via substitution of Ca. Although REE content in apatite is rather low, it is still relevant by total mass due to large tonnages of phosphate rock mined annually. This study presents the impact of milling conditions on particle properties, pulp/ froth properties; theirs influences on the flotation responses (grade, recovery, flotation kinetics and selectivity between apatite, REEs-bearing apatite and carbonate minerals). With a rougher flotation feed containing about 12 % P_2O_5 and 200 g/t REEs, the obtained recoveries were 88-93 % for apatite and 75-84 % for REEs. This indicated that REEs can be enriched by froth flotation via co-flotation of the REEs-bearing apatite or true flotation of rare earth bearing minerals. However, there was only 24-29 % of dolomite removed from a feed containing about 7.3 % MgO. Thus, the separation of carbonate from finely disseminated siliceous carbonaceous apatite ores is given to be challenging due to fine intergrowth and a significant amount of dolomite with similar flotation properties like apatite.

Huu Duong Hoang, Helmholtz Institute Freiberg for Resource Technology and Maelgwyn Mineral Services Limited; Adam Balinski, Nathalie Kupka, Robert Möckel, and Norman Kelly, Helmholtz Institute Freiberg for Resource Technology; Heinrich Sprenger, Maelqwyn Mineral Services Limited; Martin Rudolph, Helmholtz Institute Freiberg for Resource Technology

COM00151: Evaluating Forward Osmosis as a Process Intensification Strategy: The Solution to Pollution is Concentration

Abstract: "The solution to pollution is dilution", is a problematic old proverb of environmental management referring to the need to dilute waste streams to meet discharge limits. In many hydrometallurgical applications, the production of large amounts of aqueous waste is ultimately due to valuable components becoming too dilute to economically be extracted. However, we propose that, "The solution to pollution is concentration". Until now, concentrating industrial waste streams has involved expensive thermophysical processes, such as evaporation, which have both high operating and capital costs. By leveraging a novel membrane-based separation technology, known as 'Forward Osmosis' (FO), it is possible to extract large volumes of water from dilute waste streams while retaining nearly all the components in a reduced volume of now-concentrated aqueous phase. This route allows for reduced equipment sizes and/or higher throughput of material to any downstream unit process. The water extracted can then be recovered to be reused in the process, further reducing the cost and environmental impacts of the operation. In this work, we present a fast screening method to identify what types of aqueous effluents are amenable to FO. We explain the key elements in evaluating FO performance, including estimating stream volume reduction on real effluents. We also discuss some limitations of the FO approach related to scaling and pH.

Noel Devaere and Vladimiros Papangelakis, University of Toronto

COM00152: Nickel and Cobalt Concentrate Purification by Solvent-Impregnated Ion Exchange Resins: A Case Study

Abstract: Lewatit® ion exchange resins offer safe, efficient, economical and sustainable technical solutions in the field of hydrometallurgy. Our extensive product portfolio and application knowledge covers recovery and purification of a wide variety of metals e.g. base metals, gold, uranium, precious and platinum group metals and rare earth metals. Our selective resins are increasingly employed in various flowsheets, which are being developed for the production of the battery grade materials; lithium, nickel, cobalt and copper. In this paper we present the purification of nickel- and cobalt concentrates by the use of Solvent Impregnated Resins (SIR) Lewatit® TP 272 and Lewatit® VPOC 1026. SIR are macroporous crosslinked polymeric beads with a solvent extractant adsorbed and immobilized on the surface and within the pores. These resins can be thought of as having a liquid complexing agent dispersed in a solid polymeric medium. SIR combine the advantages of ion exchange resins (low capital cost, simple maintenance) with the unique and enhanced metal selectivity of solvent extraction. These materials possess different characteristics from standard ion exchange resins, because of their low density (lower than water) and the physical entrainment of functional groups. As result, the resins need to be operated at acidic pH values to avoid losses of extractant. Therefore we present in this paper a successful industrial application case of Lewatit® VPOC 1026 being used for zinc removal from cobalt concentrates in a refinery located in Canada. (Feed composition of average 35 g/L Cobalt with Zinc concentration ranging from historical 5 mg/L to current 40 mg/L average. Handling spikes up to 100 mg/L). Interestingly, we were able to optimize the operational parameters such as regeneration time. The reduction of regeneration time from 9.6 h to 4 h was achieved, which is crucial to design an economic process. Water wash steps were removed from the regeneration process to increase the life-span of the resin. Additionally, the acid concentration was reduced from 150 g/L to 100 g/L which allows significant savings on chemical costs. Furthermore, during preload the discharge solution is fed forward to batch PPT, with batches consistently meeting the low Zinc targets. An additional air displacement of the liquor leads to another saving. In conclusion we show that solvent impregnated resins are well suited for the purification of base metal concentrates. We show that this resin type has been successfully operated within an industrial setup since many years. SIR resins are interesting candidates for the purification and refining of battery chemicals such as Nickel and Cobalt. Solvent impregnated resins, cobalt and nickel concentrate purification, case study,

Naomi Sourour, Vale; Dirk Steinhilber, Zhendong Liu, and Wilson Nova Ruiz, LANXESS Corp.

COM00164: A Gravity Recoverable Gold Audit of Harte Gold Corp's Sugar Zone Mill in Northern Ontario

Abstract: An audit of Harte Gold's Sugar Zone mill was undertaken to evaluate the performance of the overall circuit with respect to gold recovery. The Sugar Zone mill achieves some the highest gravity recoveries amongst Ontario gold mines utilizing a gravity-flotation flowsheet with two Falcon semi-batch gravity concentrators processing the entire mill discharge and gravity concentrates being upgraded by a Holman shaking table for refining on site. Flotation concentrates are transported off site for smelting. A thorough sampling campaign was carried out in November 2019 and a series of Detailed Gravity-Recoverable-Gold (DGRG) tests and size-by-size gold assays were performed on the samples. Sugar Zone ore collected during the audit was determined to contain 71.4% gravity recoverable gold (GRG) which was found to be moderately coarse in comparison to other ores. The actual gold recovery at the plant was 95.0%, with 70.3% recovered to gravity bullion plus 24.7% to flotation concentrate. A proprietary mathematical model was used to benchmark the gravity circuit performance. The model was found to be in good agreement with the measured plant performance and suggested that the gravity circuit was operating well but less than ideal hydro-cyclone classification efficiency was allowing fine GRG to escape the grinding/gravity circuit. The model predicted that by improving the hydro-cyclone efficiency the gravity gold recovery rate could be increased form 70.3% to 72.8%. Finally, payment terms for gravity bullion and flotation concentrate were compared and a sensitivity analysis was completed to demonstrate the impact on concentrate grade dependent net payables.

Jonas Boehnke and Jeff Hanson, Harte Gold Corp.; Jonathan Tan and Danny Kwok, Sepro Mineral Systems Corp.

COM00172: MonoRoll Comminution Machine Achieves Grinding Efficiency Breakthrough

Abstract: The Conjugate Anvil Hammer Mill (CAHM) is a platform technology with two variants being developed in parallel. The variants are referred to as MonoRoll and CAHM. When used in series these machines could result in a simplified and more efficient comminution circuit. The MonoRoll is intended to replace the rod and ball mill grinding by substituting grinding media with a single patented hammer roll that allows for the two cylinders to rotate in a synchronized fashion and break particles in a thin (1-4 particles deep) bed. This paper focuses on the MonoRoll which has been retrofitted into a pilot-scale ball mill having a nominal 2000 kg/h capacity. The paper describes early testing results to date in both open-circuit and cascade operations. The open-circuit testing resulted in identifying a 30% solids ratio and 40 rpm mill speed as optimal operational conditions. The cascade circuit produced products similar to ball mill particle size distribution. The preliminary tests demonstrate a potential for significant improvement over conventional ball mills that are notoriously inefficient ore breakage devices.

Mohammad Mousaviraad, Sadaf Ghorbani, Rob Stephens, and Lawrence Nordell, Comminution & Transportation Tech. Inc.; Gillian Holcroft, Canada Mining Innovation Council (CMIC); Andreia Rosa and Anthony Lockhart, Corem

COM00173: Discrete Element Method (DEM) Modelling Key to Developing Energy-efficient Comminution Machines

Abstract: The Conjugate Anvil Hammer Mill (CAHM) is a platform technology where the patent-pending MonoRoll variant is intended to replace Rod and Ball mill grinding with a single, high mass hammer roll. The patented CAHM variant is intended to replace High-Pressure Grinding Rolls (HPGR) and SAG Mills. The paper describes how Discrete Element Method (DEM) modelling tools are key to ensuring the MonoRoll design creates optimal ore breakage performance. Specifically, DEM uses Klaus Schönert's thin-bed comminution principle to maximize energy efficiency by guiding theoretical comminution, wear, and power benefits. The optimal design, which enables the two cylinders to rotate in a synchronized fashion and break particles in a highly efficient thin particle bed, was the result of over 200 DOE simulations. DEM further supported Finite Element Analysis (FEA) analysis of component wear and stress. DEM modelling greatly accelerated the CAHM technology platform development from conceptual design, design optimization, detailed design, manufacturing, and testing the MonoRoll prototype in less than two years. This highly efficient technology development process showcases DEM's capability for drastically reducing design cycles that used to take decades to mature. This work is in collaboration with the Canadian Mining Innovation Council (CMIC) and many mining companies.

Mohammad Mousaviraad, Sadaf Ghorbani, Rob Stephens, and Lawrence Nordell, Comminution & Transportation Tech. Inc.; Gillian Holcroft, Canada Mining Innovation Council (CMIC)

COM00174: Cyanide Optimization and Control Philosophy at the Touquoy Mine

Abstract: Atlantic Gold's Touquoy Mine in Nova Scotia, Canada achieved commercial production in March 2018. Once the ramp up to design tonnage was achieved, process optimization was started. An overview of the process flow will be provided. The design consumption for cyanide at the Touquoy Mine was 0.52 kilograms of cyanide per tonne of ore processed. Focusing on the carbon in leach (CIL), gravity and elution circuits, the consumption was optimized to 0.18 kg/t without effecting recovery. This led to a significant reduction in operating costs. Finally, plant scale test work confirmed the balance of the recovery on cash flow. This paper will focus on the optimization process methodology and associated cost savings.

R. Payant, Mike Larter, E. Pushie, and Craig Hudson, Atlantic Gold Corporation

COM00179: Coarser Grinding: Economic Benefits and Enabling Technologies

Abstract: Coarser grinding and coarse particle recovery are receiving increased attention as a potential strategy for overcoming the multiple challenges that face the mining industry now and into the foreseeable future. Lower grade—normally harder—ores require the processing of larger ore quantities to achieve even the same production rate; necessarily increasing production costs. As dictated by the well known Comminution Laws, coarsening the final ground product size significantly increases throughput and reduces specific energy consumption and production cost. However, implementation of this coarser grinding strategy could be hindered by two key limitations. The first limitation is adequately controlling the final product size to enable more closely approaching process barriers in a safe manner. This requires an advanced process control system that can achieve the desired target size with low size variability. Lack of reliable online real-time particle size measurement has been a key limiting factor to achieving this goal. A new measurement technology developed by CiDRA overcomes this, making the grinding circuit better suited to implement a coarser grinding strategy. The second limitation is the potentially lower metal recovery in conventional froth flotation due to its limited ability to recover coarse particles. Although studies show that this recovery loss is often more than compensated for by increased throughput, operations have traditionally been averse to accept recovery loss. Along these lines, CiDRA is in the final stages of development of a radically innovative “bubble-less” separation technology—therefore very distinct from conventional flotation—with the capability of recovering particles across the entire size distribution, as produced by a grinding circuit operating in a “coarse grind” mode. This paper primarily addresses the first limitation. It presents a methodology for estimating the benefits of coarser grinding by using advanced process control enabled by a reliable online particle size measurement. Case studies and high-level control strategy are presented.

Joseph Poplawski, Robert Maron, Adam Jordens, Christian O'Keefe, and Henry Walqui, CiDRA Minerals Processing Inc.; Jaime Sepulveda, J-Consultants, Ltd.

COM00181: Circularity - A New Process Component

Abstract: We are a part of a society who wants whatever is new, the latest model. It could be a new phone, a new smart watch, new headphones, even though what we have works well. The current global population is 7.8 billion and over 5 billion of us have a mobile device. What may surprise many people is that cell phone production also results in the production of one-half tonne of tailings, 16 kg of CO_2 and 13,000 L of water. A cellphone is made from a variety of metals including aluminum alloys and other lightweight materials commonly found in the phone case, lithium cobalt oxide and carbon graphite used to make the batteries, and elements such as gold, copper, silver, platinum, tungsten, and various rare metals used in the circuitry. With the world population projected to reach 9.9 billion by 2050, an increase of more than 25%, the demand for cell phones could reach 42 million new phones/year. If current practices persist, this could result in the production of 21 million tonnes of tailings to satisfy people with a desire to have their first phone, and do not forget there are 5.25 billion people who currently have a phone and will want a new one when the next model becomes available. However, you may not be able

to have a new phone because we may not have the materials necessary to make one for the following reasons: Deposits of all minerals are getting harder to find. Residents do not want conventional mining in their backyard. ESG demands a totally new approach. But there are options, including circularity, a process to utilize 100% of the resource. Imagine a mine that does this by first separating and selling its precious metals, then crushes and ships the coarse mine waste in 60,000 tonne vessels to a construction project 2200 nautical miles away. The fine waste is then sold as volcanic Rock Dust, a soil amendment. Anaconda Mining inc. are amongst the first in the industry to develop and capitalize on this opportunity. These are options for conventional operations, but what about mining of other known, uneconomic zones or deposits that exist around the world? Novamera Inc. is developing and testing a new mining method called SMD (Sustainable Mining by Drilling) near the Anaconda Mining's site in Newfoundland. This new technology aims to lower cost, minimize dilution, lower energy consumption, and has a built-in requirement for progressive rehabilitation. We all have a key role to play in the pursuit of better resource management, a low-carbon future and increasing circularity of the economy.

Allan Cramm, Novamera Inc.

COM00184: Floatability of Sodium Jarosites with Sodium Dodecyl Sulfate

Abstract: Three sodium jarosite samples with varying content of silver were synthesized in an autoclave and their floatability was examined. Despite different silver contents—0% in baseline sodium jarosite, 3.5% in low-silver sodium jarosite, and 12.8% in high-silver sodium jarosite—no significant differences in zeta potential characteristics (pH 2-10) were observed between the samples, and their isoelectric point was found to be near pH 5. Hallimond tube flotation experiments were conducted at pH 3.5 and at pH 10 using dodecyl sulfate as a potential collector for the jarosite samples. Adsorption of dodecyl sulfate on the tested jarosites was also measured. It was found from the adsorption and flotation results that the floatability of jarosites with sodium dodecyl sulfate was possible at pH 3.5, but the minerals gave no measurable adsorption of the reagent at pH 10. As a result, flotation at pH 10 was impossible. It was proposed that poor flotation at pH 10 was a result of the formation of goethite-like layer on the jarosite surfaces. No systematic trends were observed as a function of the silver content.

Avery Payne and Marek Pawlik, The University of British Columbia

COM00186: Floc Volume Estimates from 2D Compared with 3D

Abstract: Flocs are porous, irregular, extended 3-dimensional (3D) structures comprised of fine particles and water. It is convenient to use 2-dimensional (2D) imaging modalities to measure flocs (e.g. photography in a settling column or under a microscope) but some spatial information is inevitably lost. In this paper, the measurement of 3D floc structure from X-ray computed tomography scans is described in the context of understanding more about the information loss that occurs when flocs are measured in 2D images. A comparison of several commonly used size and shape properties (mean diameter, aspect ratio, fractal dimension) were measured from 3D floc images and from 2D floc images obtained by the projection and cross-section of the 3D image from various viewing angles. This approach produces a series of measurements for each 3D floc, the analysis of which gives some insight into what is being measured when a 2D

imaging modality is used to characterize a sample of flocs. Further development of this approach is of practical significance to provide correction factors or methods to improve the data obtained from traditional 2D imaging modalities.

Ryan MacIver and Marek Pawlik, The University of British Columbia; Claire Chassagne, Delft University of Technology

COM0027: Characterization of Density-separated Mullite-rich Tailings from a Secondary Copper Resource: A Potential Reinforcement Material for Development of an Enhanced Thermally Conductive and Wear-resistant TI-6AL-4V Matrix Composite

Abstract: The addition of aluminosilicates like mullite as reinforcement to Ti-6Al-4V alloy, which possesses improved thermal shock and thermal stress resistance can mitigate against poor thermal and wear resistance, while in service as energy efficient brake rotors. However, the high cost of metal powders like mullite, will prohibit the use of mullite as reinforcement to Ti-6Al-4V alloy for manufacture of energy efficient brake rotors. Hence, harnessing mullite from a secondary copper resource can be a cost effective approach to inhibit this setback. This paper therefore aims at presenting the comparative study conducted on two separation techniques (i.e. physical separation (PS) and chemical separation (CS)) to concentrate mullite into tailings of a copper smelter dust (CSD). This aim was achieved by processing the CSD with the density concentrator (physical) and froth flotation concentrator (chemical) for changes in grade of mullite in respective tailings. Results showed that the mullite grade in tailings obtained from using PS (initial grade = 17.05 wt% and final grade = 35.02 wt%) as concentrator is higher than that obtained from using CS (initial grade 19.11 and final grade = 21.67 wt%) as concentrator. It was therefore concluded that the mullite obtained with the use of PS method is not only better in grade, but also better in approach, in terms of economy and environment (since the separating medium is water alone). It was therefore recommended that the PS method be used to harness the mullite from this waste material (CSD) and used as a cost effective reinforcement to Ti-6Al-4V alloy for manufacture of energy efficient brake rotors.

Pretty Linda, Daniel Okanigbe, Abimbola Popoola, and Olawale Popoola, Tshwane University of Technology

COM0046: Industrial Tests of Cyanide Gold Recovery from Tailings of Uchalinsky Concentrating Plant

Abstract: Uchalinsky Concentrating Plant (Uchalinsky GOK) being a part of JSC «UMMC» is the largest producer of copper and zinc concentrate in Russia. Through flotation enrichment of sulfide copper-zinc ore into concentrates the major elements - copper and zinc - are extracted, and minor elements—precious metals gold and silver—go partially into commercial products. In order to reduce the precious metals losses in tailings of the concentrating plant the leading experts of the research institute JSC «Irgiredmet» carried out a comprehensive research targeted at finding an appropriate financially viable process in the course of 2017 to 2020. Having performed research for gravity and flotation enrichment as well as by combined pyro-hydrometallurgical methods of tailings treatment, the hydrometallurgical process based on

selective leaching of gold by the method of sorption cyanidation was developed. This process was field-tested in large-scale and then recommended for industrial testing at JSC «RPC «Bashkirskaya Gold Mining Company» (JSC RPC BGMC) being a part of JSC «UMMC» in order to trial the proposed conditions of cyanidation and to prepare an aggregated technical and economic estimate for making a decision on feasibility of designing and construction of tailings treatment department at JSC «Uchalinsky GOK». For the purpose of industrial tests, a sample of actual concentrator's tailings from the site of copper-zinc ore treatment from Uzelginsky and Novo-Uchalinsky deposits has been prepared. The chemical composition of the assay is as follows: 0.14-0.18% Cu, 0.22-0.30% Zn, 1.0-1.2 g/t Au, 14.0-15.2 g/t Ag. Under production conditions of JSC RPC BGMC the following key operations have been tested: - desintegration and lime-air treatment of tailings; - tails cyanidation; - cake filtration. 1. At the production site of JSC RPC BGMC pilot tests for cyanidation of the tailings received from Uchalinsky GOK were carried out according to the technology developed by JSC "Irgiredmet", 225 tons of tailings were processed, the following indicators were achieved: - dry lime consumption (100 %) – 8.2 kg/t, - NaCN consumption (100 %) – 200-600 g/t, - cyanidation time– 6 h, - extraction of gold into solution, or specified per sorbing agent – 19.6-26.6 % or 0.23-0.3 g/t. 2. Pilot test results are consistent with the data of works performed earlier by JSC "Irgiredmet". A slight decrease in gold recovery rates from 28-30% according to JSC "Irgiredmet" to 19.6-26.5% is associated with: - a lower gold content in test tailings - 1.13-1.19 g/t, instead of 1.35 g/t in pilot tests of JSC "Irgiredmet"; - the complex salt composition of the circulating leaching solution (increased content of copper, zinc, thiocyanates, etc.) and process equipment of JSC RPC BGMC. 3. The aggregated estimation based on the pilot test results received at JSC RPC BGMC showed that, taking into account the lower initial gold grades in tailings - 1.0-1.2 g/t and its recovery rate at the level of 23-25%, the technology developed by JSC "Irgiredmet" remains profitable. 4. Based on the results achieved, it was decided to implement front-end engineering design of the tailings processing area at JSC "Uchalinsky GOK".

Evgeny Vasilyev, Andrey Panshin, Sergei Iakornov, and Alexey Pushkin, JSC Ural Mining & Metallurgical Company

COM0067: Functionalized Biopolymer for Non-sulfide Gangue Suppression in Froth Flotation Cleaner Stage

Abstract: Cleaner flotation concentrates often consist of fine clay-size to colloidal particles, due to common regrinding of rougher concentrate material to liberate the target minerals. Fine particles are more difficult to float, and finer particles producing low concentrate grade may require more cleaner stages to reduce entrainment and achieve the final desired grade. In addition to these difficulties, complex ore geologies can cause further slime coating and agglomeration of gangue, when recovering final-grade concentrate. Due to these challenges, there remains a clear need to improve froth flotation separation processes by developing solutions that out compete the interaction between the gangue and the metals. This paper highlights patent-pending, biopolymer technology that controls non-sulphide gangue- by encapsulating or coating charged particles of water-reactive, charged and/or high surface area minerals. Encapsulated gangue is therefore unable to interact with the desired metal minerals, yielding higher ore grade more quickly in the cleaner circuit. The charge-optimized substituents engineered on our biopolymer backbone specifically interact with fine water-reactive particles. Reproducible trends in representative

flotation tests have been conducted, and we have provided a consistent increase in metal (copper, gold, and silver) grade, at equivalent metal recoveries.

Laura Benavides and William Gibbs, Integrity Mining and Industrial LLC; Charlie Landis, Integrity Bio-Chemicals LLC

COM0087: Optimization of an Environmentally Benign Eluent for Scandium with Significantly Improved Elution Efficiency

Abstract: Utilization of secondary sources for the extraction of rare earth elements and critical metals such as Sc has attracted significant attentions over the last decade. These elements are crucial for sustainable developments in clean and strategic applications. The tailings and waste materials of mining activities often contain notable amount of REEs along with low concentrations of Sc. Scandium is an expensive metal with unique applications in aerospace however, full utilization of Sc has not established due to its high price and lack of reliable supply. We previously introduced two ion exchange resins with exceptionally high selectivity and capacity for adsorption of Sc from coal fly ash pregnant leach solutions. In this comprehensive study, which builds on the previous work, an environmentally friendly eluent was investigated for efficient elution of Sc. While almost no Sc could be eluted with H_2SO_4 (2 and 5 M) under shake flask conditions, the preliminary results indicated that this green eluent was able to significantly improve the elution efficiency of Sc to about 50% at room temperature. Other elution parameters were also optimized to obtain high elution yields for Sc.

Mehdi Mostajeran and Rory Cameron, CanmetMINING, Natural Resources Canada

COM00137: Synergistic Effect of *Acidithiobacillus ferrooxidans, Leptospirillum ferrooxidans* and *Acidithiobacillus thiooxidans* on Oxidation of Refractory Gold Ore

Abstract: Over time, by increasing gold mine exploitation and fast depletion of high-grade gold ores, low-grade and refractory gold ores are considered as the main resources for gold production. Bio-oxidation is a viable and preferred eco-friendly technology for processing of low grade and difficult ores to treat for gold extraction. In this study, a mixture of *Acidithiobacillus ferrooxidans, Leptospirillum ferrooxidans* and *Acidithiobacillus thiooxidans* was used for bio-oxidation of refractory gold ores. During bio-oxidation, ferric iron, as an active agent is regenerated by iron-oxidizing bacteria (*A. ferrooxidans* and *L. ferrooxidans*) and the sulfide component of the mineral is converted to sulfuric acid using sulfur-oxidizing microorganisms (*A. ferrooxidans* and *A. thiooxidans*). This paper investigates sulfur-oxidation of each bacteria in the mixture of acidophiles in the system. At 15% pulp density during 30 days of the experiment at 30°C and 150 rpm, 59.63% sulfur has been oxidized by the mixture of bacteria. The results show that *A. ferrooxidans* was the main bacteria during the first three weeks of biooxidation which was responsible for sulfur oxidation and ferric generation. While *L. ferrooxidans* was the main species after a few weeks for ferric generation and compared to *A. ferrooxidans,* had a higher tolerance to ferric iron inhibition. Furthermore, *A. thiooxidans* population was approximately constant throughout sulfur-oxidation.

Atefeh Azizi, Harshit Mahandra, Juliana Ramsay, and Ahmad Ghahreman, Queen's University

COM00149: Evaluation of Different Techniques for Cyanide Measurement from Biological Samples in Gold Bio-cyanidation

Abstract: Cyanide is the most common lixiviant applied in the extraction of gold and silver. However, due to a decrease in the grade of gold in the deposits and increase in the regulations against the use of cyanide, researchers have been looking for some viable alternatives. One of the most promising options is to biologically produced cyanide (bio-CN) which is green and capable of delivering satisfactory gold recovery with minimum footprint. This will reduce the need for shipping of cyanide. Although the reagent is very promising, there are still many aspects of the process that requires further development. Cyanide characterization from biological samples is one of the areas that has been less discussed by the researchers. There are some other biological products in the bio-cyanidation systems that can potentially interfere with cyanide in its measurement; thus, a reproducible technique for cyanide measurement in biological samples is necessary. Accordingly, in this research, different cyanide measurement techniques, including titration against silver nitrate with rhodanine and iodine indicators, end-point determination based on potentiometry, and UV-vis identification with $NiCl_2$ have been compared. Among the techniques, end-point potentiometry against silver nitrate was considered as the most feasible technique for cyanide determination.

Fariborz Faraji, Harshit Mahandra, and Ahmad Ghahreman, Queen's University

COM00153: Comparison of Energy Cost between Freeze Crystallization and Conventional Evaporative Technologies

Abstract: Industrial water recovery can be categorized into thermal or membrane technologies. Although membrane technologies are energy efficient, they often require sophisticated pre-treatments, and are not suitable for high salinity effluents. Evaporative thermal technologies are widely adopted for this regard, but their intensive energy consumption calls for alternative solutions. At the other end of the thermal spectrum, freeze crystallization (FC) can instead be used for high salinity effluents for water recovery. Because the enthalpy of freezing for water is around 7 times less than that of evaporation, freeze crystallization is thermodynamically advantageous compared to evaporative thermal technologies. We have performed energy cost calculations using OLI Studio and explored various cases under which FC can be more favourable than evaporation technology. FC can benefit as a climate-driven process in northern and arctic regions and has a smaller CO_2 footprint as it only consumes electricity which can be produced from renewable sources reliably in the near future. As industry strives to achieve low energy operations and carbon neutrality, FC can be a potential replacement for the current evaporative water recovery technologies.

Runlin Yuan and Vladimiros Papangelakis, University of Toronto

COM00180: The Effects of Pilot-Scale Microwave Pretreatment on the Cyanidation of a Canadian Gold Ore

Abstract: In 2018, the Government of Canada launched the Crush It! challenge, with the objective being for a company to develop a new innovative process which improves the efficiency of comminution. Team CanMicro is currently researching the application of high-power microwaves for assisted comminution and ore sorting. A high-power 150 kW microwave system was used to carry out batch and continuous treatments on a Canadian gold ore. Complementary batch bench-scale tests were also conducted to serve as a comparison. Both untreated and microwave treated samples were subjected to leaching tests followed by BET surface area analysis. In comparison to the untreated sample, the continuously treated pilot-scale sample welcomed a 14% improvement in gold recovery after a leaching time of only 6 hours. Batch testing on the pilot and bench scales obtained bulk sample temperatures of 198°C and 205°C, respectively. In spite of the similar temperatures, the pilot sample achieved an improved recovery of around 3.3 times greater than the bench sample and an increase in specific surface area of roughly 1.4 times. While higher energy dosages were found to yield a greater increase in the specific surface area, lower, and thus more economical energy dosages such as 2 kWh/tonne can still increase the amount of available surface reaction sites, thus improving the gold recovery in downstream unit operations.

Adam Olmsted, Queen's University; John Forster, University of Toronto; Xinyi Tian, Met-Solve; Darryel Boucher and Erin Bobicki, University of Toronto; Chris Pickles, Queen's University

COM00185: Analysis of Interactions between Anionic Dispersants and Mature Oil Sands Tailings by Zeta Potential Distributions

Abstract: The effect of a polymeric dispersant, sodium lignosulfonate (LS), on distribution of zeta potential values of all tracked particles of mature fine tailings (MFT) was studied. Three different types of lignosulfonates were investigated to determine the importance of molecular weight and level of anionicity of LS on the distribution of zeta potential values. Changes in the zeta potential distributions enhanced understanding of the mechanism of adsorption of LS on tailing particles. It was realized that the width of the zeta potential distribution gradually increased with polymer adsorption. At high concentrations, the entire zeta potential distribution shifted towards more negative values which indicated that LS was adsorbed on all particles of MFT above a critical dosage. The results indicated that the molecular weight of the polymers was a more defining factor in comparison with the level of anionicity polymers in determining the surface charge characteristics of the tailing particles.

Hamid Alizadeh and Marek Pawlik, The University of British Columbia

COM0036: Role of MIBC in the Kinetics of Carbonaceous Matter Flotation from Gold Ores

Abstract: The presence of carbonaceous matter (C-matter) in double refractory gold ores leads to poor gold recoveries (<60%) when the ore is treated by alkaline pressure oxidation followed by thiosulfate leaching. To improve the gold recovery, flotation was considered for the separation of carbonaceous matter (C-matter) prior to pressure oxidation. In this study, the effect of MIBC dosage on flotation performance and kinetics was investigated, using kerosene as a collector. The results showed that C-matter recovery and selectivity increased with increasing

MIBC dosage. Changes in flotation selectivity were attributed to reduced entrainment resulting from decreased bubble size at low MIBC dosages, and increased foam height and retention time at high MIBC dosages. Through kinetics modelling, the flotation rate constant was found to increase with increasing MIBC dosage. The increase in flotation rate constant resulted from decreasing bubble size until CCC. Above the CCC, interaction between collector and frother resulted in faster induction time, sustaining the increase in flotation rate constant. As flotation time increased, grade and recovery converged, independent of MIBC dosage. However, when flotation time was short, high dosages of MIBC resulted in reduced gangue entrainment, faster kinetics, and improved selectivity. Future work will focus on using this information to optimize flotation conditions and tests for bubble and induction time changes during flotation.

Sugyeong Lee, Charlotte Gibson, and Ahmad Ghahreman, Queen's University

COM0040: Parameterizing the Kinetics of Wet Low-intensity Drum Magnetic Separation Using Particle Properties and Operating Conditions

Abstract: Wet low-intensity magnetic separation is a technique widely used in the mining industry, especially for the beneficiation of magnetite ores. Its principle relies on the separation of magnetite-rich particles from the nonvaluable ones in a suspension interacting with a nonhomogeneous magnetic field. The separation is achieved via the particles distinctive response to the forces acting on them in the separator (magnetic, gravitational and hydrodynamic). These forces are exerted differently depending on both particle properties and operating conditions. Their influence on the separation performance has been rarely explored from a fundamental point of view. This work describes the development of a two-step approach that integrates ore characterization and process modeling to deconstruct the separation kinetics as a combination of effects associated to particle properties and operating conditions. The model relies on assimilating a laboratory-scale separator as a perfectly mixed tank reactor. It expresses the kinetic rate as a function of the particle size and composition, magnetic susceptibility, feed rate, magnetic field intensity and solids fraction. Preliminary results suggest that the approach satisfactorily describes the ore separation amenability. Considering physical principles underlying the separation allows distinguishing the particle intrinsic effects from process related factors. The model can directly apply for equipment design and improving the process efficiency of existing operations.

Juan Sebastian Guiral-Vega, Université Laval / COREM; Jocelyn Bouchard and Éric Poulin, Université Laval; Clémence Du-Breuil, COREM; Laura Pérez-Barnuevo, Université Laval

CHALLENGES OF INDUSTRY 4.0: SENSORS, CONTROL, AUTOMATION, AND THE USE OF DIGITAL INFORMATION

COM00145: How Industry 4.0 Can Leverage Pyrometallurgy and What It Cannot Replace

Abstract: The Industry 4.0 revolution is moving fast. Whoever wants to efficiently transform metallurgical assets operation and maintenance need to catch the train in time. A couple of new

(and not so new) technologies and methods are available for metallurgists and Control Engineers. They can go beyond some of the traditional approaches optimizing safety, production, quality and communication when reducing losses, costs, emissions and damage. Modern platforms, skills and knowledge allow a new generation of online advisory systems which are Expert Systems enriched with AI and advanced control of the plants. Systems are smarter, faster, more efficient, more integrated and more accessible than ever allowing success stories in record timeframes. XPS has conducted multiple digital transformation projects with success over the years including use of AI for Furnace integrity at the start of the new millennium. However, thanks to new tools, more projects focusing on pyrometallurgical assets were developed in the last few months. All of these projects have required a strong partnership between Metallurgists Engineers, Control Process Engineers and Data Scientists Engineers. New platforms, tools and skills have opened the door to a new chapter, namely predictive and prescriptive metallurgy: Digital Twin models comparing online parameters with advanced metallurgical models like Thermodynamic ones and computing optimum operating parameters. Advanced analytics tools to be more predictive on chemistry changes or to alert sooner on equipment failures or instrumentation issues. Automatic online FMEAs and root cause analysis able to alert sooner on drifts and allowing automatic or fast manual response before a major disturbance happens (Equipment or process related) Energy and utilities consumption optimization Solutions are available for extractive and chemical metallurgy to address new challenges including environmental and safety standards, changes in the ore body or development of new metallurgical products. Is Industry 4.0, Artificial Intelligence and Machine Learning the only viable solution to all the issues? Is it an easier transition than the previous ones? The answer is NO. If previous technology transitions are still not completed the gap to be Industry 4.0 “compliant” may be important. Industry 4.0 and its cybersecurity requirement are demanding better network topologies, and digital communication with instruments, machines and control systems. Advanced Analytics rely on data, instrumentation and knowledge of the process. Intelligent instruments are not adding value if the measurement principle is wrong or if instruments are not installed in compliance with the state-of-the-art. Finally, some machine learning exercises are still inadequate. There are essentially three main root causes: A lack of good information and data for a model to succeed or be repeatable. A lack of knowledge of the process or a lack of discussion with individuals sharing the knowledge. Sometime a wrong desire to replace proven methods and algorithms by new AI ones that are not competitive in a specific domain. The presentation will cover industry 4.0 tools, methods and skills that are successfully improving pyrometallurgy but will also address limitations and some false definitions of the digital transformation.

Nicolas Lazare, XPS a Glencore Company

COM00146: Digital Transformation in Mining and Metallurgical Complexes

Abstract: Ores are becoming extremely variable with mineralogy, hardness disturbing the grinding, and flotation circuits. The current grinding and flotation sensors provide large amounts of data for process optimization. Adding the right context and operational events enables to augment to operational knowledge for proactive actions for improving the performance of the Crushing, Grinding, Flotation and Thickening/Filtration circuits. A data-driven strategy is needed to enable operations, maintenance, and business personnel to quickly and easily take corrective action when abnormal conditions occur. A Digital Plant Template transforms data into operational insights in real-time. It uncovers the hidden, idle and downtime losses using a Unit canonical strategy to model the plant. By measuring, managing these unproductive times, people find new ways of avoiding them improving the profitability of the plant. The inFORMAtion created by the real time analytics enables to calculate Recovery in real time and to develop predictive analytics models to find the best operating condition based on the type of ore currently mined. The creation of new workflows and collaboration between mining and concentrator plant and the enterprise including services providers are enabled. These days of remote operations having the capability to integrate mining operations from the drilling to the product delivery is a blessing. People can work from the houses supporting the operations and staying safe and healthy with the families. Mines are in remote difficult to get places. SMEs today can increase the productivity by developing predictive models to classify the operating conditions due to large variations in their ores and catch the hidden production, energy and water losses by equipment, type of ore, support and unmeasured disturbances. People are calling this strategy Follow the Money strategy to be able to survive and to adapt to these unforeseen forcing factors affecting the communities and support. We will expand the strategy to Extractive Metallurgy and show a few examples.

Osvaldo Bascur, OSB Digital, LLC

COM00147: Data Mining Tools in the Mining Industry: Copper Electrolytic Refinery Study Case

Abstract: Data mining has driven the discovery of new interactions between process variables. One of the areas little studied in this regard is the copper electrolytic refinery. The Chuquicamata Copper refinery has an annual production of 480,000 Tons of copper cathode (A grade). The electrochemical process has a duration of 10 days with a current density of 300 A/m^2. In this global context, exist a lot of process variables to take control, like impurities, electrolyte rate, additive addition, short circuits and current efficiency. In the present work, classification and regression models are used for having a global process control. The classification models like SVM, Decision Trees and Logistic regression show an easy way to see the different effect of the process variables over a quality variable of final product (Cathodic Rejection). The regression models show the future behavior in different scenarios and how this result have a huge impact in the cost of the electrochemical process. In other line, the classification models are easy tool for the operation team. They can see the effect of process variables day by day in the electrochemical cell. The fusion of both models has a strong impact in the global process control for take future decision and minimizing the process cost.

Luis Perez, INNOVAXXION SPA

COM00156: Online Condition Monitoring: Extending the Value beyond Maintenance

Abstract: Online condition monitoring systems have been used by the Mining industry for many years. As online condition monitoring systems adopt emerging technologies and are becoming less expensive, more mines are installing these systems with a specific view to improve asset

reliability and reduce maintenance costs. At the same time, mining companies are investing (or looking to invest) in other technologies associated with digital transformation, such as advanced process control, energy management information systems, and digital twins. This paper will discuss how the information provided by online condition monitoring systems can be leveraged in these other technologies associated with digital transformation. By taking a more holistic view to leverage all available data sources where possible, the value of digital transformation technologies can be greatly increased.

Carl Sheehan, Spartan Controls

COM0097: Discrete Event Simulation in Support of New Sensor Applications at Copper and Nickel-copper Smelters

Abstract: Discrete event simulation (DES) is an important tool to assist in debottlenecking a range of metallurgical, manufacturing and other types of plants, and is also currently used in a number of industrial, commercial and service-oriented sectors. Concepts of DES are adapted within the present paper to address the challenges at conventional copper and nickel-copper smelters, including the restructuring of Peirce-Smith converter cycles. In particular, one approach to justify the installation of a novel suite of sensors involves the simulation of a smelter over a large number of operating days, without and with the proposed new sensors. A critical comparison between the simulated to-be and as-is systems is valuable to reliably estimate the payback period of the sensors, which may be coupled with additional equipment upgrades.

Alessandro Navarra, McGill University; Roberto Parra, University of Concepción; Phillip Mackey, P.J. Mackey Technology Inc.

COM0098: Framework for Developing Successful Partnerships between Operating Facilities and Machine Learning Experts

Abstract: With the power of machine learning (ML) demonstrated successfully in various industrial applications, metallurgical operations are now open to augmenting their push for implementation of classical process control methods with novel ML-based AI applications. However, successful implementations of ML in extractive metallurgy are still not commonplace. NTWIST and Sherritt have collaborated on AI implementation at Sherritt's operations and developed a robust collaborative framework. Sherritt Technologies experts initially identified a number of potential applications, and using criteria developed by NTWIST, determined the most promising application for AI was in a circuit whose performance was subject to operational upsets. After the initial objectives were formulated, one year of historical data was analyzed to identify the potential value of AI implementation. NTWIST established the operational baseline, quantified the opportunities for improvement, assessed the data quality, established a risk register and refined the objectives based on the new findings. A quantified definition of the opportunity to improve the circuit product solution quality was established, which may result in cost savings and a circuit throughput increase. Opportunities for improvement of target conformance of the circuit key performance indicators were also identified. This paper will share learnings on evaluating applications of ML to the control of hydrometallurgical circuits.

Ilya Perederiy, Grayson Ingram, and Chowdary Meenavilli, NTWIST; Milan Djumic, Robert Lopetinsky, and Eddy Miao, Sherritt International Company

COM0099: Mine-to-smelter Integration Framework for Regional Development of Porphyry Copper Deposit

Abstract: Trends toward the widespread use of electric vehicles and renewable energy sources all point to continued growth in copper demand. This demand will be met mainly by new primary copper production, with recycling expected to contribute significantly to copper supply. Significant quantities of copper ore are presently mined from porphyry deposits in which typically, near-surface copper oxides are recovered hydrometallurgically by leaching, solvent extraction and electrowinning, whereas the deeper copper sulfides are only amenable to milling followed by pyrometallurgical processing including smelting and converting, leading to electrolytic refining. The Chilean copper porphyries together are the largest group of operating copper mines and are likely to remain so into the future. However, several of these deposits are forecast to show increasing levels of arsenic-bearing minerals, such as enargite, thus posing issues in processing. As mature copper mining districts exhaust the near-surface oxides and higher-grade sulfides, individual mines will need to adjust their operations accordingly. However, it is considered that due to such changes, re-engineering efforts might be more economically coordinated across several mines, to collectively handle the evolving ore feeds. The present paper adapts a digital twin approach to support mine-to-smelter integration within porphyry copper districts. This quantitative framework is initially intended for the re-engineering of individual mines and concentrators, and utilizes discrete event simulation, mass balancing and geostatistics. Sample computations are presented that are loosely based on the Chilean context.

Ryan Wilson and Alessandro Navarra, McGill University; Kevin Perez, University of Antofagasta; Norman Toro, Universidad Católica del Norte; Roberto Parra, University of Concepción; Phillip Mackey, P.J. Mackey Technology Inc.

CHLORIDE METALLURGY

COM00102: Chloride Chemistry, Its Advantages for Modern Metals Extraction Processes

Abstract: It has long been appreciated that chloride chemistry has a number of advantages over the more traditional sulfate route for both extracting and separating metals. Modern materials of construction, coupled with the development of a more cost-effective and efficient hydrochloric acid regeneration technology mean that chloride-based processes offer both lower capital and operating cost advantages. Chloride-based processing routes are able to recover much more of the contained metal values in a feed, including iron in a benign and marketable form, and particularly the so-called rare and rare-earth elements which are increasing in demand in our electronic age. These factors, therefore, add appreciably both to the overall economics of a project, but also offer a much more sustainable approach to our dwindling natural resources. Additionally, chloride-based flowsheets are much more environmentally-friendly, offering practical alternatives to two of the biggest headaches faced by the industry, namely residue volume and toxicity. The paper presents a brief theoretical background review, focusing on the

laterst developments of the low-temperature, selective hydrovhloric acid regeneration process, which is the key unit operation for any chloride flowsheet, and discusses in general the advantages of the chloride approach.

Bryn Harris, Consultant

COM00103: Treatment of Electric Arc Furnace Dust via a Chloride-Processing Route

Abstract: Electric Arc Furnace Dust (EAFD) has an estimated global production of 8 million tonnes annually, of which 1 million tonnes is generated in North America, with a contained annual metal value of the order of US$6 billion. Despite many attempts over the years, with pyrometallurgical, hydrometallurgical or hybrid processes, currently the only commercially viable method of treating EAFD is smelting in a Waelz Kiln (or a Rotary Hearth Furnace), which essentially recovers only the zinc, in an impure oxide form, and generates a secondary slag waste, which is mostly still toxic and requires disposal. This paper describes the development of a chloride-based treatment process. In particular, the key unit operation of acid regeneration is discussed, and a techno-economic evaluation of the process versus the standard Waelz Kiln is presented, showing the advantages of the chloride route.

Bryn Harris, Consultant; Carl White, NMR360; Thomas Hofbauer, Andritz Metals; Mike Dry, Arithmetek Inc.

COM00136: Cerium Removal from a Mixed Rare Earth Chloride Solution by Oxidation with Hydrogen Peroxide

Abstract: Rare earth elements (REE) are found together in most ores due to their similar atomic radii and ability to substitute each other in mineral structures. Cerium is the largest constituent of these ores, up to 50%; as such, Ce is overproduced by the industry in an effort to meet demand for less abundant REE that are required for the manufacturing of high-tech products. Ce removal is the first required step in REE purification, because the large fraction of Ce in the concentrate lowers the throughput of the subsequent steps and negatively impacts the manufacturing costs. Most Ce separation methods are developed based on the very low precipitation pH and solubility of $Ce(OH)_4$ compared to the other lanthanides. The present work focused on operational aspects of cerium removal by oxidation with hydrogen peroxide (H_2O_2) from a synthetic mixed REE chloride solution. H_2O_2 was selected as the oxidant of choice due to its good oxidation power and cleanness as a reagent. Batch tests to determine the Ce removal kinetics and extent via oxidation-precipitation with H_2O_2 were performed under ambient conditions, for pH values in the acidic range and various H_2O_2 doses. It was demonstrated that the reaction proceeds via an intermediate metastable form of ceric peroxide, $Ce(OOH)(OH)_3$, which in time decomposes and converts to ceric hydroxide, $Ce(OH)_4$. Ce removal kinetics were fast (under 15 min) and Ce removal levels were between 80 and 95%, depending on the pH and H_2O_2 dosage.

Georgiana Moldoveanu and Vladimiros Papangelakis, University of Toronto

COM0019: Metso:Outotec Copper Chloride Leaching Process for Copper Concentrate

Abstract: Metso:Outotec have been working to optimise Metso:Outotec Copper Chloride Leaching Process for sulfidic copper concentrates. Process will produce LME grade A copper cathode along with by-products such as zinc, gold and silver, hydrometallurgically from the copper concentrate. Metso:Outotec Copper Chloride Leaching process has been tested with batch tests and with fully integrated continuous pilot runs with good results. The test work has been done using different type of copper concentrates. This paper presents pilot run test results for copper concentrate that contains copper mainly as chalcopyrite with notable silver and gold contents. Techno-economical evaluation for a plant with 100 000 tpa copper cathode production were done based on the test work and Metso:Outotec's internal databases. The Capex (capital expenditure) & Opex (operating expenditure) of Metso:Outotec Copper Chloride Leaching Process were found to be very attractive. First, the concentrate is leached in agitated reactors at atmospheric pressure in copper chloride solution. Copper is subsequently removed from the pregnant leach solution by solvent extraction and finally recovered in electrowinning. Silver is leached together with copper and it can be recovered from the solution after copper solvent extraction. The copper leaching residue is re-leached in more concentrated chloride media in order to leach gold. Gold is recovered from the solution by activated carbon. The plant is flexible with respect to raw materials and is designed to achieve minimal environmental impact.

Marko Lampi and Kaarlo Haavanlammi, Metso:Outotec

COM0035: Metso Outotec Coated Titanium Anode Technology for Chlorine and Oxygen Evolution in Electrowinning Processes

Abstract: Electrowinning of nickel and cobalt is conducted in aqueous chloride-based, sulfate-based or their mixed solutions. Selection of anode material/coating based on an electrolyte and other operation conditions is one of the most significant factors to reduce the operation cost and increase productivity. This paper presents performance and durability of Metso Outotec Coated Ti Anodes with various mixed metal oxide coatings which are suitable for chlorine, oxygen and their mixed evolution reactions respectively. This technology realizes environmentally friendly and efficient metal electrowinning processes with low cell voltage and high stability.

Tian Zhang, Heikki Aaltonen, and Timothy Robinson, Metso Outotec Finland Oy

COM0037: Miller High Temperature Chlorination for Fine Gold Refining

Abstract: All refining circuits used to process gold mine doré and to produce fine gold bullion rely entirely on chloride metallurgy. Miller high temperature chlorination remains a staple for the larger refineries due to its reliability and speed of processing on almost any composition of high-grade impure gold, offering a one-step process to achieve a purity up to 99.5%. The cast gold can be further purified through electro-refining to achieve 99.99% commercial purity. There has been a push by industry to find alternative approaches in recent years due to chlorine storage and handling hazards. Proven alternative processes are based on chloride hydrometallurgy routes. One new high temperature vacuum furnace process presents some exciting separation opportunities for doré yet cannot, on its own, replace Miller chlorination. Rather than focusing on alternative and 'greener' techniques, the aim of this paper is to review Miller process fundamentals. This includes the unique chemical affinity for chlorine gas to selectively and efficiently convert all impurity metals into chloride salts, their behaviour at high temperatures and the downstream deportment of other precious metal values namely, silver and the platinum group metals. The process has experienced only minor changes since its inception in the 19th century. Current plant practice is described with a section on the processing of the salt slag and recovery of by-products.

Vicken Aprahamian and Stephanie Hultgren, Royal Canadian Mint; Bryn Harris, Consultant

COM0039: Use of Commercial Sodium Hypochlorite to Replace Chlorine for Cobalt Separation at Port Colborne Refinery

Abstract: Vale's Port Colborne Refinery (PCR) produces close to 2000 mt of electrowon Co metal through treatment of nickel/cobalt carbonate feed from the operations in Sudbury. In the Refinery process, the cobalt is separated from nickel in solution using sodium hypochlorite (NaOCl) prepared by mixing chlorine and soda ash. The required chlorine is brought to the Refinery site as liquid chlorine in rail cars. In June 2020, Vale Base Metals took the decision to pursue lower safety risk alternatives to liquid chlorine. Consequently, a test program was conducted over the following two months at the Vale Technology Centre in Mississauga to investigate the feasibility of using commercial sodium hypochlorite to replace chlorine for cobalt/nickel separation at PCR. The results from bench scale testing confirmed that commercial sodium hypochlorite, together with soda ash, can be used to effectively separate cobalt from nickel in solution. Plant trials with commercial sodium hypochlorite were then conducted at PCR in October 2020, confirming the bench scale results. Following this success, the delivery of liquid chlorine in rail cars ended in October and the Refinery initiated permanent transition to commercial sodium hypochlorite. This paper presents the results and challenges addressed through the steps of process development and plant implementation.

Tao Xue, Ramanpal Saini, I. Mihaylov, Naomi Sourour, J. Capobianco, P. Cook, and G. Bangarth, Vale

COM0065: Gold Extraction Using CLEVR Process™ on High-grade Arsenopyrite Concentrate

Abstract: A gold bearing concentrate containing 105 g/T of gold, 23.8% iron, 12.8% arsenic and 18% sulphide was processed at the laboratory scale to evaluate the gold extraction yield using the CLEVR Process™ while providing a permanent stabilization solution for the arsenic. The concentrate was first oxidized using a thermal approach. Optimization work was done on the calcination step with temperature ranging from 650 to 750ºC and contact time from 45 to 120 minutes in air. Under optimized conditions, 95.1% of the arsenic was removed, thus producing a calcine containing 0.85% arsenic The calcine was then submitted to DST's CLEVR Process™ for gold extraction using CLEVR standard approach consisting of 25wt% solid, 2wt% [NaOCl], 70 g/L [NaCl], 10 g/L [NaBr], pH 950 mV, room temperature and 1 h contact time. Under optimized conditions, a gold extraction yield of 95.2% was obtained while cyanidation yielded

70.1%. A flowsheet was proposed where the volatilised arsenic from the calcination step is recondensed as arsenic trioxide and then vitrified using DST's GlassLock Process™.

David Lemieux, Jean-Philippe Mai, and André Drouin, Dundee Sustainable Technologies

COM0066: Column Leaching of Chalcopyrite Ore in Ferric Sulfate Media in the Presence of Iodide/Iodine under Controlled Solution Potential and pH

Abstract: Chalcopyrite leaching takes place slowly in acidic ferric sulfate media at ambient temperature. The addition of iodide has been found to significantly accelerate the leaching kinetics. A complete dissolution of chalcopyrite concentrate was achieved in reactor leaching with the addition of 150 mg/L of iodide at room temperature. The formation of elemental sulfur as the leaching product and jarosite precipitation did not appear to hinder the leaching process. No effect of particle size was observed in reactor leaching in the size range studied. However, the column leaching tests using a primary copper sulfide ore showed a significantly lower performance, which was attributed to a lower degree of mineral liberation in the ore. To investigate the effect of mineral liberation on the leaching behavior of chalcopyrite ore in the presence of iodide, a series of saturated column tests were carried out with ore particles of three different size fractions to reflect different degrees of liberation. Saturated column testing was used to ensure that all particles were in contact with the leaching solution and that there were no major gradients of solution potential, pH, and temperature within the column. The solution potential and pH were fully controlled by diverting the solution coming out of the leaching column to separate reactors for potential and pH adjustments before being recirculated to the column. The experimental results showed that the particle size had a negative effect on the copper extraction, which decreased with increasing particle size or decreasing degree of mineral liberation. A mathematical model incorporating the effect of particle size was developed to describe the kinetics of iodide-assisted leaching of chalcopyrite.

Ronny Winarko, Wenying Liu, and David Dreisinger, The University of British Columbia; Akira Miura and Yuken Fukano, JX Nippon Mining and Metals Corporation

COM0076: DASH, a Novel Process for the Recovery of Iron and Hydrochloric Acid from Chloride Solution Part II: Engineering Evaluation

Abstract: Regeneration of hydrochloric acid (HCl) from ferric chloride solution is a key aspect of any chloride-based process for leaching iron rich material. The current commercial technology for recovering chloride units is pyro-hydrolysis; however, its application is generally limited to relatively smaller scale, stainless steel pickling operations, due to equipment size limitations. A concept, referred to as the DASH process, has been developed by Sherritt Technologies in which concentrated HCl and hematite can be recovered from a ferric chloride solution. The concept involves crystallization of an iron-ammonium chloride double salt followed by thermal treatment of the salt under a steam atmosphere to decompose the salt and hydrolyze the iron to HCl and hematite. A similar concept can also be applied to magnesium chloride solutions to regenerate HCl and produce magnesium oxide. In the formation of a double salt, the DASH process is expected to be more energy-efficient and scalable than conventional HCl regeneration technologies for application within chloride-based leaching processes, such as leaching of laterite

ore. However, the design of the proposed DASH process on a large scale introduced significant engineering challenges related to its high gas handling requirement and severe operating conditions. While the DASH process concept has been demonstrated at a laboratory scale, its application on a commerical scale presents a challenge due to its high capital inensity and complex engineering design.

Cory Kosinski, Jay Mahal, John Marsh, and Jan Smit, Sherritt International Corporation

COM0077: DASH, a Novel Process for the Recovery of Iron and Hydrochloric Acid from Chloride Solution Part I: Crystallization and Thermal Decomposition

Abstract: Hydrolysis of iron chloride solution to produce hematite (Fe_2O_3) and regenerate hydrochloric acid (HCl) is a key step in several proposed chloride-based laterite leach processes. Hematite can be sold as a by-product instead of occupying space in a tailings facility and HCl can be recycled back to the laterite leach, minimizing reagent costs. Drawbacks of the concept include the high capital cost and the high energy consumption related to the hydrolysis step. Sherritt Technologies has developed and tested a process conceived to minimize energy consumption in hydrolysis, referred to as the DASH process. In this process, iron chloride is first removed from solution by forming a double salt of ferric chloride ($FeCl_3$) with ammonium chloride (NH_4Cl), and then reacting the double salt with steam to produce hematite, HCl, and NH_4Cl for recycle to crystallization. In the test work, double salt crystals were produced in the form of $2NH_4Cl \cdot FeCl_3 \cdot H_2O$ (kremersite) by partial evaporation of a solution containing a 2:1 molar ratio of NH_4Cl to $FeCl_3$ in a bench-scale rotary evaporator. The double salt was then reacted with steam in a bench-scale fluidized bed reactor containing hematite seed, at 400°C, to hydrolyze the $FeCl_3$ to Fe_2O_3 and HCl. The NH_4Cl that was released during hydrolysis was deposited from the gas stream by maintaining the downstream temperature higher than the boiling point of HCl, but lower than the decomposition temperature of NH_4Cl. The hematite product contained up to 70.5% Fe, along with < 0.1 wt% NH_4 and 0.05 wt% chloride.

Baseer Abdul, Teresa Bisson, Michael Collins, Jan Smit, Kent Smith, and Eric Tao, Sherritt International Corporation

COM0080: Gold Leaching in Ferric Chloride Media: A Practical Approach

Abstract: Several countries have banned the use of cyanide for gold extraction due to environmental concerns. The depletion of oxides and the necessity to treat low-grade refractory ores for which cyanidation may not be economically feasible have motivated the investigation of alternative lixiviants. As sulfide oxidation in the pretreatment occurs in acidic conditions, ferric chloride is considered to be a prospective lixiviant for gold extraction at acidic pH, thus avoiding the additional costs of neutralization and toxic by-products handling. This study assessed the feasibility of using acidic ferric chloride media for gold extraction by conducting a series of batch leaching tests at 35°C with mineral samples of increasing complexity. Firstly, we investigated the effect of solution potential, a key process variable on gold dissolution, by using a pure gold wire. Gold extraction was measured by the mass loss method over the course of leaching. Subsequently, we conducted ferric chloride leaching of a free milling oxide ore under the optimal conditions identified in the tests with the pure gold wire. Gold concentration in solution was determined by the standardization method with an ICP-OES. The analytical procedure developed in this study could serve as a baseline for measuring gold concentration in other similar studies. The results of the leaching tests show that 0.798 V was the potential threshold for pure gold dissolution in the presence of 3 M chloride. A marked increase in the gold extraction was observed by increasing the potential to 0.880 V. The batch leaching tests with the oxide ore were performed at 0.3 M ferric, 3 M chloride and a solution potential of 0.880 V. The results showed that it was feasible to leach gold from the oxide sample, with the soluble gold concentration reaching between 0.35 and 0.54 ppm within 2 to 7.25 hours of leaching. Pretreatment of the oxide sample with sulfuric acid prior to ferric chloride leaching did not improve gold dissolution, which was attributed to the gold head grade being lowered by losses of fine particles. The decrease in the solution potential during leaching, which was associated with pyrite oxidation, was thought to be responsible for gold extraction plateauing at low values. Increasing the temperature of the leaching solution to 45 °C improved the kinetics but not the overall extraction.

Kresimir Ljubetic and Wenying Liu, The University of British Columbia

COM0082: Hydrochloric and Hydrofluoric Acid Recovery: New Options and How to Make Your Flow Sheet Waste-water Free

Abstract: Acid recovery is an important process step in pickling and leaching processes. Pyrohydrolysis in spray roasters and fluidized bed reactors is well established to recover hydrochloric, hydrofluoric, and nitric acid. Besides the well known applications to recover pure process streams from steel pickling or ilmenite leaching, the focus turned more to the processing of mixed oxides and to closed loop operations by changing from calcium hydroxide neutralization to magnesium hydroxide, where the metal chloride and the hydrochloric acid can be recovered. In pilot and demo-plant installations several new process options have been tested. A pilot unit for up to 75 L/h of metal chloride solution was installed, as well as a demo-unit for 200 L/h. Mixtures for the Li-battery production—nickel-cobalt-manganese-chloride—were extensively tested and showed a huge potential to save production costs of the cathode material. Furthermore, the pilot plant unit was used to test the conversion of metal fluorides into oxides. Niobium and Titanium fluoride solutions were successfully tested and can be processed in commercial size spray roasters to produce high purity metal oxides.

Frank Baerhold, Thomas Hofbauer, Stefan Mitterecker, and Martin Brazda, Andritz Metals

COM0025: Kinetic Study on Selective Chlorination of Iron from Ilmenite Ore

Abstract: Crude titanium dioxide was produced by the selective chlorination of ilmenite with coke and chlorine gas. Selective chlorination rate of iron in ilmenite was investigated by shrinking core model. Iron in ilmenite was removed as ferric chloride gas, and porous titanium oxide remains in the system. The effects of pore characteristics, such as porosity and tortuosity of titanium oxide product layer on the diffusion rate of chlorine gas were considered and the calculated reaction rate fitted on the experimental results. The calculated reaction rate curves had a good agreement with the experimental results, and the rate controlling step of the selective chlorination of ilmenite was changed from chemical reaction controls to diffusion controls through the product layer. Reaction temperature affected both the pore size distribution and pore structure of the particles which determine the diffusion rate of reactant gas through the pores. In other words, when the reaction temperature increased, the pore size and tortuosity increased. Also, the reaction rate constant values also presented high as the reaction temperature increased. On the other hand, as the reaction progressed, the chemical reaction resistance and product layer diffusion resistance are showed competitive relationship. The overall reaction rate at lower reaction temperature was controlled by the product layer diffusion, but the chemical reaction resistance was increased as the reaction temperature increased.

So-Yeong Lee, Sung-Hun Park, and Ho-Sang Sohn, Kyungpook National University

COM0029: Mechanistic Model for Solvent Extraction by Basic Extractants: Closing the Gap between Theory and Experiments

Abstract: The mechanism of solvent extractions of metal ions by basic extractants is mainly described as an anion exchange process. Typically, chloride anions are supplied as the ligands. However, the anion exchange model fails to explain some experimental observations and, therefore, is incomplete. Extractions are often studied by building a net metal transfer reaction. We employ a more fundamental approach to understand how to reach the equilibrium state. Herein, we study the speciation and hydration of metal complexes and salting-out agents. Metal ion stabilization in the aqueous and organic phase determines the extraction. In the aqueous phase, the stabilization is determined by hydration. Reducing the charge density of a metal ion by complexation with anions lowers its hydration. On the other hand, salting-out agents increase the extraction primarily by decreasing the concentration of free water molecules, dehydrating the metal complex in the aqueous phase. Experimental data to support the novel model include extractions of Cu(II), Co(II) and Zn(II) by methyltrioctylammonium diluted in toluene. Understanding the chemistry behind solvent extractions is of great importance to efficiently design new separation flowsheets or improve existing ones, without the need for extensive trail-and-error-based research. The proposed model enables to qualitatively predict the optimum conditions for metal extractions and separations by adjusting the aqueous phase for a given organic phase.

Rayco Lommelen and Koen Binnemans, KU Leuven

CORROSION AND ENVIRONMENTAL DEGRADATION OF MATERIALS

COM00104: Practical Examples to Move Operations towards UN Sustainable Development Goals (SDGS) by Managing Corrosion Risk

Abstract: Proactive management of corrosion in critical physical assets is known to bring economic, social and governance benefits to mining operations. We have mapped out specific corrosion impacts versus the UN Sustainable Development Goals (SDGs) and can show that the intersection is surprisingly widespread. This paper will describe practical case studies from the perspective of this framework, showing real-life examples of the impact of asset corrosion on

sustainability efforts. Each case study describes the practical actions carried out in each case to control corrosion using best practice corrosion management, data-driven predictive modelling, monitoring and technology adopted from other sectors.

Zoe Coull, Brycklin Wilson, and Muan Wei, ICE Dragon Corrosion Inc.

COM0011: Fabrication and Characterization of FeCoNiCrCu-xAl High-entropy Alloy Coatings on 00Cr12 Alloy

Abstract: High-entropy alloys (HEA) in simple solid solution phase are considered as promising candidates of coating materials applied on high temperature alloys due to their high strength and good resistances to oxidation and corrosion. In this study, high-throughput (HTP) approaches were adopted in both fabrication and characterization of the FeCoNiCrCu-xAl (x=10-40 at. %) HEA coatings on 00Cr12 alloy. It was believed that HTP approaches could facilitate rapid screening for a FeCoNiCrCu-xAl HEA coating with excellent high temperature oxidation properties. The dependence between Al content and microstructure of the FeCoNiCrCu-xAl HEA coatings was determined. It was found that the grain size of the prepared coating increased from 15.6 nm to 24.8 nm with Al increasing from 10.3 at. % to 19.8 at. %; no significant change in grain size was observed with further increase in Al content. The microstructure of the FeCoNiCrCu-xAl coatings altered gradually from FCC to FCC+BCC, and then BCC as Al increased from (10.3-11.8, 14.2-19.8 and 23.2-40.6 at. %), respectively. The mechanism of phase transformation in the FeCoNiCrCu-xAl coating with respected to the influence of Al content was discussed in detail.

Meifeng Li and Jing Liu, University of Alberta; Chungen Zhou, Beihang University

COM00128: Effect of Resin Impregnation on Corrosion Behaviour of Alumix 321 Powder Metallurgy Alloys

Abstract: Abstract: Aluminum and its alloys is an important engineering group of materials due to its distinguished properties such as high strength to weight ratio, good thermal and electrical conductivity, and good corrosion resistance. This group of materials is a good choice for designers in many fields such as the automotive, structural, and aerospace industries. Driven by the need to expand aluminum alloys applications, composite, cermet, powder metallurgy and additive manufacturing approaches have been recently successful in different applications. However, these new systems require in-depth corrosion characterization in order to be fully adopted by industry. In this research, corrosion properties of an Al-Mg-Si powder metallurgy alloy known as Alumix 321 was investigated. Electrochemical corrosion techniques were used to characterize its corrosion performance in a simulated seawater solution (3.5 wt% NaCl). The alloys were compacted, sintered, and then resin impregnated. The results show that the corrosion rate of the alloys after resin impregnation is lower than as-sintered alloys. Keywords: corrosion, powder metallurgy, aluminum, pitting, electrochemistry, resin impregnation

Abdulwahab Ibrahim, College of the North Atlantic-Qatar; Paul Bishop, Dalhousie University; G.J. Kipouros, Independent Metallurgical/Materials Engineering Researcher

COM00163: The Roles of Mo and Cr during the Breakdown and Repassivation of Oxide Films Formed on Ni-based Alloys in Acidic Media

Abstract: The elemental content of corrosion products released from the surfaces of Hastelloy BC-1, C-22, and G-35 specimens exposed to naturally aerated 1 M hydrochloric acid solutions was quantified by operando application of atomic emission spectroelectrochemistry (AESEC), to explore the compositional contribution to each alloy's response to surface activation, spontaneous repassivation, and electrochemically promoted passivation, including the kinetics. After the surface oxides were intentionally damaged to initiate the corrosion process, spontaneous repassivation proceeded primarily by processes resulting in deposition and accumulation of Mo-containing species, though accumulation of Cr-rich oxides was also an important factor. An alloy's ability to recover from oxide film damage was found to improve with increased Mo content. For the alloy with the lowest Mo content considered here, approximately 8 wt.% Mo, repassivation was unsuccessful and active dissolution was observed. For alloys with higher Mo contents, BC-1 (22.10 wt.% Mo) and C-22 (12.97 wt.% Mo), repassivation occurred quickly and dissolution rates stabilized at values comparable to those of the original passive surface; however, alloy C-22 required a slightly longer time and exhibited momentary breakdown events. The surface species responsible for successful repassivation were found by ex-situ X-ray photoelectron spectroscopy to be predominantly Mo(IV) oxides. During electrochemically promoted passivation processes, previously accumulated Mo species were found to be partially removed, while accumulation of Cr species dominated the film formation; however, Mo still played a significant part during the re-formation of the Cr-rich passive oxide film. The concept of Mo species accumulation and subsequent dissolution is consistent with our previous studies of film breakdown and repair. These findings suggest the dual role of alloy Mo in stabilizing and repairing the oxide film.

Jeffrey Henderson, Fraser Filice, Dmitrij Zagidulin, Mark Biesinger, Brad Kobe, David Shoesmith, James Noel, and Xuejie Li, The University of Western Ontario; Kevin Ogle, Chimie ParisTech

COM00170: Detection of Temper Embrittlement in HY80 Steel Using the Statistical Dispersion of Micro-hardness Data

Abstract: There is no reliable portable non-destructive (ND) method to predict both the decrease in function/performance of a steel structure as it undergoes temper embrittlement over the embrittlement range from 400 to 575°C. The goal of this research is to develop a magnetic-based ND system to detect the early onset of embrittlement, or toughness degradation in high strength HY80 steels. The first stage of the research focuses on quantification of changes in microstructure and material properties of HY80 steel subjected to thermal treatments that foster embrittlement. HY80 steel specimens are heat-treated in air at 8 temperatures from 400 to 650°C for 1, 2, 7 or 10 days. Results show that average micro-hardness values increase with increase in treatment temperature. The breadth of micro-hardness values is larger for specimens that are heated at 475 and 550°C for 10 days. X-ray diffraction is used to map residual stress (crystallographic elastic strain) and plastic deformation (diffraction peak-broadening) in each specimen. Results are consistent across each specimen but there are noticeable differences between specimens subjected to different thermal treatment. Future study includes Charpy

impact testing to measure toughness; and measuring electro-magnetic properties with magnetic-based ND systems such as magnetic Barkhausen noise analysis (MBNA). Results will be employed to establish empirical relationship between material property changes and electromagnetic signal response.

Shannon Farrell, Defence Research and Development Canada

COM0020: Effectiveness of Pulse Waterjet Coating Removal

Abstract: Coating removal is generally performed to remove worn or damaged exterior coatings in order to carry out periodic recoating. Conventional methods of coating removal include chemical stripping, mechanical abrasion and abrasive media blasting, which are not applicable to hard and soft coatings and are time-consuming and harmful to both the environment and user. Therefore, the coating removal industry has identified the need for alternative methods that address the environmental and safety concerns without compromising substrate safety. Paint removal via pulse waterjet provides a possible alternative solution to satisfy the current demands of industry, since no solid media or chemicals are used in the process. The technology can also be automated by implementing robotic systems to decrease worker exposure, plus water can be recycled and reused to decrease hazardous waste. National Research Council Canada has examined the effect of the de-coating process for non-skid coated panels, as well as hard coatings (HVOF) by assessing the effectiveness and impact on substrate materials. The characterization involved a microscopic and surface roughness investigation of painted and non-painted plates, including residual stress measurements and metallographic analyses.

Ali Merati and Mackenzie Bauer, Aerospace - National Research Council Canada; Andrew Tieu, VLN Technology Inc.

COM0031: Degradation of Dented Fusion-bonded Epoxy Coating in Various Aggressive Environments

Abstract: As a direct barrier layer separating the underlying pipeline steel from the corrosive external environment, pipeline coatings are expected to maintain their protectiveness in various aggressive environments and over a long exposure period. The presence of defects, however, compromises the barrier integrity of the coating. Here we create a dent (~ 1.2 mm in depth) defect in fusion-bonded epoxy (FBE) coated steel panels and investigate its impact on the anti-corrosion properties of FBE after immersion in solutions with varied pH and temperatures for a period of four weeks. Fourier-transform infrared spectroscopy (FTIR) of the coating surface revealed that an increase of O-H band peak intensity, as well as shifts of several bands' peak positions, correlate with increased water uptake and, thus, coating degradation. From electrochemical impedance spectroscopy, dented FBE coatings show a significantly lower (i.e., 3 to 6 orders of magnitude) coating impedance than that measured for intact coatings. Degradation of these dented coatings was found the most severe in alkaline solutions (pH around 12) at different testing temperatures, followed by that in acidic solutions (pH around 2), and was least severe in neutral solutions (pH around 7). At 65°C, a thin layer was formed on top of these dented coatings. This layer, when formed in neutral solutions, helped to maintain a relatively high coating impedance in the range of 106 to 108 ohm-cm^2. However, the layers formed in both

alkaline and acidic solutions did not provide this benefit. Further compositional studies on this layer would provide more insight.

Min (Mina) Xu, Hongxing Liang, and Edouard Asselin, The University of British Columbia

COM0042: The Impact of Micro-galvanic Coupling versus Macro-galvanic Coupling on the Corrosion Response of Laser Powder Bed Fused AlSi10Mg-Cast AA2618 Dissimilar Metal Combination

Abstract: This study aims to investigate and determine the controlling factor in the electrochemical response of laser powder bed fusion (L-PBF) fabricated AlSi10Mg-cast AA2618 dissimilar metal combination for plastic injection molding applications. Due to the compositional variations between these alloys, the fabricated bimetal structure can be prone to macro-galvanic corrosion. Furthermore, the heavily precipitated microstructure of AA2618 cast alloy combined with microstructural inhomogeneities in L-PBF AlSi10Mg alloy can be susceptible to micro-galvanic corrosion attack. However, the scale of contribution from each of these two corrosion mechanisms to the overall electrochemical response of the fabricated structure are not known. Focusing on this gap, in this study, detailed corrosion performance analysis of the L-PBF AlSi10Mg-AA2618 bimetal structure as compared to the individual base materials is conducted through anodic polarization testing and Mott-Schottky analysis to determine the dominant corrosion mechanism in the fabricated structure. Correlations have been made between the obtained corrosion properties and heavily precipitated microstructure of AA2618 alloy containing anodic Al_2CuMg and various cathodic Fe-containing intermetallic compounds (IMCs) versus the Al-matrix as well as more uniform microstructure of L-PBF AlSi10Mg comprised of sub-micron sized eutectic Al-Si network in primary Al-matrix.

Parisa Fathi and Mohsen Mohammadi, University of New Brunswick; Mehran Rafieazad, Memorial University of Newfoundland; Ali Nasiri, Dalhousie University

COM0047: Local Damage of Elbow under a CO_2-saturated 3.5% NaCl Solution System

Abstract: The elbow is a weak part in the pipeline system. Accidents caused by elbow damage are very common, causing inestimable economic losses. When the fluid medium flows through the elbow, the velocity of the fluid medium is forced to change because of the sudden change of the flow channel. The change of fluid velocity at the elbow will cause the uneven distribution of pressure load at the elbow. The stress in different regions of the elbow is quite different, and the distribution of the force field at the elbow is complex. There are also differences in electrochemical corrosion in different regions of the elbow. The local corrosion behavior of the elbow was studied through weight loss method, electrochemical tests and the finite element simulation. A corrosion damage model of the elbow was proposed to analyze the local damage mechanism of the elbow under the coupling action of the flow field, force field and electrochemical field. Results showed that the corrosion damage at the elbow was closely related to the velocity distribution and stress distribution at the elbow. In the regions with high flow velocity and high stress, the corrosion rate was fast. The regions with high stress, such as the middle upper part of inner part, acted as anode. The corrosion rate of the inner wall of the elbow

was higher than that of the outer wall of the elbow, and the maximum corrosion rate appeared at the middle upper part of inner part of elbow.

JianGuo Liu, GuangYing He, Long Wang, Gan Cui, Xiao Xing, and Zili Li, College of Pipeline and Civil Engineering, China University of Petroleum (East China)

COM0050: High-temperature Molten Salt Corrosion of Stainless Steels under Oxy-fuel Co-combustion of Coal/biomass Feedstocks

Abstract: Oxy-fuel co-combustion of biomass and coal is a promising technology to achieve negative CO_2 emission with a relatively low cost. However, the material technology gaps, especially the selection of boiler tube materials to resist fireside corrosion by flue gas + deposit ashes, must be addressed to ensure the commercial deployment of this technology. In this study, the high temperature corrosion behavior of stainless steels as candidate boiler tube materials was studied at 650°C in simulated flue gas + salt mixture environments of oxy-fuel coal and biomass co-combustion system. The corrosion products were analyzed by SEM/EDS and XRD while the corrosion degree was characterized by direct mass change, mass loss measurements and thickness change. Due to the synergistic effects of oxidation, sulfidation and chlorination, the tested steels developed porous corrosion products with cracks. Besides, intergranular corrosion becomes pronounced with time, indicating the severe corrosion environment of this system.

Kaiyang Li and Yimin Zeng, CanmetMATERIALS, Natural Resources Canada

COM0057: Characterization of an Aluminum-stainless Steel Bi-metallic Composite Fabricated Using a Hybrid Additive Manufacturing Process

Abstract: Bi-metallic systems are attractive components for oil and gas applications, where properties of high strength and high driving force for corrosion are required. In the present study, diamond lattice structures were built from 316L stainless steel powder using a selective laser melting (SLM) technique. Diamond lattice design was selected because it was predicted to exhibit higher mechanical properties than other lattice structures with the same density. Their cavities were filled with an aluminum alloy using vacuum-assisted melt infiltration to yield a bi-metallic composite. For comparison purposes, monolithic aluminum alloy was also cast under the same casting conditions. The yield stress and compressive strength of the SLM fabricated 316L stainless steel lattices were enhanced when their relative density increased. Scanning electron microscopy (SEM) revealed no bonding between 316L stainless steel/aluminum alloy interfaces. As a result, there appeared to be no load transfer between the stainless steel lattice and the aluminum alloy under tension. The fracture mode in tension was determined to be brittle for the monolithic aluminum alloy and ductile for both the stainless steel lattice and bi-metallic composite. A comparison with compressively loaded bi-metallic sample will be presented. Corrosion potential of the fabricated bi-metallic composites was found to be more stable than that of the monolithic aluminum in KCL aqueous solutions with a similar temperature and concentration.

Morteza Ghasri Khouzani, X. Li, Abdoul-Aziz Bogno, Z. Chen, Jing Liu, Hani Henein, and Ahmed Qureshi, University of Alberta

COM0071: Corrosion Performance of UNS K91560 Steel under Bitumen Partial Upgrading Process

Abstract: Thermal cracking technique is seen as a cost-effective pathway to partially upgrade oilsands bitumen to facilitate the economic transportation of bitumen through pipelines. However, very limited work has been performed in terms of materials corrosion under partially thermal cracking of bitumen. In this study, a low-alloy steel, UNS K91560, was exposed to simulated partial thermal cracking of bitumen at 440°C in a bench top reactor to investigate the liquid phase corrosion. After three cyclic tests with a total exposure time of 6 hours, the corrosion of the steel was evaluated via direct mass change, and the corrosion products were characterized using X-ray diffraction and scanning electron microscope/energy dispersive X-ray spectrometry. The samples likely experienced naphthenic acid corrosion and sulfidic corrosion. $Fe_{1-x}S$ and $FeCr_2S_4$ enriched in the outer layers of the scale, whereas metal oxides accumulated in the inner layers. No pitting corrosion occurred based on the cross-section examination.

Xue Han and Yimin Zeng, CanmetMATERIALS, Natural Resources Canada

COM0095: Salt-covered and Salt-free Steady-state Dissolution of Zn

Abstract: Localized corrosion attack on metals and alloys that propagates on an occluded area is a major concern in many engineering applications. The chemistry of the solution within the occluded area considerably differs from the bulk solution. A high concentration of dissolving metal cations and aggressive species (mostly Cl^- ion) and a low pH are characteristics of the local pit solution. Because of the restricted geometry of the occluded area, the mass transfer of the dissolution products is limited, which results in accumulation of dissolving metal cations, supersaturation of the local solution, and eventually precipitation of a metal salt film on the corroding surface. It is known that precipitation of a metal salt during steady-state dissolution has an important impact on metal dissolution kinetics, however, to what extent the presence of the salt film is necessary for stable pitting is not fully explored. While the effect of this metal salt film on the dissolution behavior of stainless steel has been extensively studied, the dissolution of pure metals in the presence of a salt film has received less attention. In the present study, the dissolution kinetics of pure Zn was studied in 1.0 M NaCl solution in salt covered and salt-free dissolution states using the lead-in pencil electrode technique. Salt-free dissolution of Zn showed similar characteristics as salt-covered dissolution. However, in the salt-free state, the current density was found to be potential dependent, suggesting a migration effect on the total ionic current density. Moreover, on the contrary to stainless steel, it was found that the presence of a metal salt film is not a necessary step for stable pit growth on pure Zn, as pits sustain stable growth at potentials well below the salt film stability potential. The findings presented herein provide a better understanding of the pitting corrosion of metals and alloys.

Davood Nakhaie and Edouard Asselin, The University of British Columbia

COM0010: Implications of Contact-free Insulation on Mitigating Corrosion under Insulation

Abstract: Corrosion under insulation (CUI) refers to the external corrosion of piping and process equipment when they are encapsulated in thermal insulation. CUI is influenced by numerous parameters including type of insulation, condition of metal, aeration levels, thermal and moisture cycles, etc. It is believed that although the presence of drain-holes may result in a higher uniform corrosion rate by accelerating oxygen diffusion into the insulation, applying drain-holes to facilitate the water dry-out is a feasible means to inhibit CUI. In order to mitigate CUI, a contact-free system was proposed by adopting commercial drain plugs and spacers between the steel and thermal insulation. The present work aimed to investigate the implication of contact-free insulation on the CUI performance under isothermal wet and cyclic wet conditions in 100 ppm NaCl solutions using both mass loss measurements and microscopic characterization. Carbon steel (CS) pipes with and without epoxy coatings were selected as the substrate materials. The results showed that CS pipes suffered from localized corrosion in the closed-contact system. Localized disbanding/damage of the coatings was also observed. The proposed contact-free system substantially facilitated the moisture dry-out and oxygen diffusion into the pipe/insulation interface. As a result, the average corrosion rates and local defects on both coated and uncoated coupons were greatly reduced compared with coupons from the closed-contact system. Therefore, the proposed contact-free design seems to be a promising method to mitigate CUI.

Mingzhang Yang, University of Alberta; Ahmad Raza Khan Rana, Integrity Products & Supplies Inc.; Omar AlChaar, Dalhousie University; Jing Liu, University of Alberta

COM00100: Microstructural Evolution and Electrochemical Performance of the Interfacial Region between a Wrought and a Wire Arc Additive Manufactured 420 Martensitic Stainless Steel

Abstract: In this study, the interfacial microstructure and electrochemical performance between a wire arc additive manufactured 420 stainless steel and a wrought AISI420 substrate was investigated. The microstructural characteristics and crystallographic orientation of the interfacial region were characterized using scanning electron microscopy (SEM), X-ray diffraction (XRD), and electron backscatter diffraction (EBSD) analysis and subsequently were compared to the as-printed and the base plate conditions. The characterization of the interfacial region revealed the formation of five distinct microstructural regions, including (i) base metal, (ii) far heat-affected zone (HAZ), (iii) close HAZ, (iv) partially melted zone (PMZ), and (v) fusion zone. To characterize the corrosion response of the interfacial region, open circuit potential (OCP), potentiodynamic polarization (PDP), and electrochemical impedance spectroscopy (EIS) tests were performed in aerated 3.5 wt.% NaCl electrolyte at room temperature. In the as-printed sample, the formation of chromium depleted regions adjacent to the delta ferrite phase led to the occurrence of localized corrosion attacks and significantly diminished the corrosion resistance. The corrosion performance of the interfacial region revealed severe deterioration adjacent to the as-printed side, possibly attributed to the formation of high fraction of primary austenite grain boundaries (PAGBs) in the fusion zone as susceptible sites to localized corrosion. Compared to the as-printed and interface samples, the sample from the substrate exhibited superior electrochemical performance with improved passive film stability ascribed to the absence of delta ferrite phase and lower fraction of PAGBs in the substrate.

Salar Salahi, Memorial University of Newfoundland; Mahya Ghaffari, Alireza Vahedi Nemani, and Ali Nasiri, Dalhousie University

COM00105: Improved Erosion-Corrosion Resistance of Electroless Ni-P Coating by the Incorporation of Superelastic NiTi Nanoparticles

Abstract: Low carbon steel pipelines have been extensively used in oil and gas industry to transport crude oil due to their low cost and wide availability. However, the erosion-corrosion resistance of low carbon steel pipelines is insufficient to withstand aggressive environments due to their low hardness and corrosion resistance. Electroless Ni-P is a potential coating to protect steel pipelines from erosion-corrosion due to its high hardness and good corrosion resistance. Nonetheless, electroless Ni-P coating has low toughness, which tends to crack during impact. One way to toughen electroless Ni-P coating is by the addition of superelastic NiTi nanoparticles. The price of NiTi nano-powder, however, is 5-10 times higher than that of Ti nano-powder. Therefore, in present study, Ni-P-NiTi nanocomposite coatings were prepared on AISI 1018 steel substrates by electroless co-deposition of Ni-P and Ti nano-particles followed by annealing. Erosion-corrosion resistance of the coatings was investigated by slurry pot erosion-corrosion tests. Erosion-corrosion test results revealed that the presence of superelastic NiTi nanoparticles within the Ni-P matrix significantly improved the erosion-corrosion resistance of Ni-P coating.

Zhi Li, Rielle Jensen, Zoheir Farhat, and George Jarjoura, Dalhousie University; Md. Aminul Islam, National Research Council Canada

COM00107: Investigating Internal Oxidation of Ag-xIn Alloys in a Time-resolved Study

Abstract: Internal and intergranular oxidation are known to lead to embrittlement of materials, particularly in high temperature applications. In the nuclear industry, internal/intergranular oxidation is proposed as a possible mechanism for stress corrosion cracking (SCC) in Ni based alloys at relatively low homologous temperature and in reducing aqueous environments. Generally, Ni-based alloys containing Al, Cr, and Si are a major focus in studies investigating internal oxidation because of their wide industry application. However, Ag-In alloys provide a simple model system to study these oxidation phenomena since silver is noble in air atmosphere (T>148°C) and In forms stable indium oxide. This system has been used by researchers to study the science governing internal oxidation and subsequent embrittlement. In this study, internal oxidation of Ag-xIn alloys (x =10, 13, 16 at.%) was investigated in an air atmosphere at 180 and 240°C, where lattice diffusion is negligible, to better understand the science behind this oxidation phenomenon at low homologous temperatures. After exposure for between 7 and 42 days, Ag nodules were observed on the surfaces of all alloys, confirming stress relief due to internal oxidation, and the presence of short circuit diffusion pathways. Nodule size and surface coverage in alloys with different indium concentrations were compared. The effects of crystallographic orientation and grain boundary misorientation were investigated using electron backscatter diffraction (EBSD) and found to influence nodule expulsion, and internal or external oxidation tendency. Analytical transmission electron microscopy (TEM) was used to study the nanoscale morphology and chemistry of nodules and the internally oxidized region. Additionally,

a time-resolved analysis using scanning electron microscopy (SEM) was used to study nodule formation and nodule coalescence mechanisms.

Yasaman Ghaffari and K. Daub, Queen's University; R.C. Newman, University of Toronto; S.Y. Persauda, Queen's University

COM00161: Biodegradation of Diethylenetriamine (DETA) and Metal-DETA Chelates

Abstract: Diethylenetriamine (DETA) can be used to selectively depress pyrrhotite during the flotation of nickel sulphide ores. DETA can significantly improve nickel recovery and concentrate grades; however, it is challenging to manage in the tailings and effluent. DETA forms complexes with Ni^{2+} and Cu^{2+} which are stable at high pH and cannot be removed from effluent with conventional wastewater treatment techniques. As a result, the use of DETA in flotation can lead to concentrations of Ni^{2+} and Cu^{2+} in final effluent that exceed the federally and provincially regulated values. The objective of this study is to investigate biodegradation as a mitigation strategy for DETA-metal chelates. Biodegradation is a process which uses bacteria to breakdown polymers with biodegradable linkages; the biodegradation of DETA would release the chelated metal ions for recovery. Literature on the biodegradation of pure DETA is mixed and inconclusive, while the literature on the biodegradation of DETA-metal complexes is non-existent. Preliminary results have shown that a mixed bacteria culture is capable of degrading unchelated DETA and Ni-chelated DETA in the presence of an added carbon and energy source. Cu-chelated DETA showed no signs of biodegradation and this is either due to the strong chelation bond between copper and DETA or due to the anti-bacterial effect of copper. It is hypothesized that the mixed culture is using the DETA as a partial nitrogen source.

Erin Furnell and Erin Bobicki, University of Toronto

COM0022: Electrochemical Study of Aluminum Filiform Corrosion

Abstract: Filiform corrosion (FFC, also known as under-film corrosion) is commonly observed on surfaces of coated aluminum and aluminum alloys (AA), especially in environments combining marine and industrial atmosphere. The chemical composition of the substrate is believed to play an important role in FFC resistance of AA. This work aims to investigate the influence of alloying elements, Cu and Mn, on the FFC behaviour of Al alloys at room temperature. To do so, commercially pure aluminum (AA1100) and alloys such as AA2024 (Mn) and AA3003(Cu) were selected as candidate materials. The FFC behaviour of Al and Al alloys was investigated using electrochemical methods. To simulate the underfilm electrolyte environment, polarisation measurements were carried in an anolyte (5% NaCl + 0.1M $AlCl_3$, pH=2) and a catholyte (Phosphate buffer solution, pH=7), respectively. Results show that the resistance to FFC initiation (ΔE_{PR}, V), the driving force for propagation (ΔE_{corr}, V), and the FFC current density (i_{FFC}, mA/cm^2) follows the same trend as 2024 (Cu) > 3003 (Mn) >1100. In summary, adding alloying elements, Cu and Mn, can effectively reduce the possibility of FFC initiation; however, once the FFC being initiated, Cu and Mn can accelerate the propagation and growth of the filaments.

Daniela Arango Vasquez and Jing Liu, University of Alberta

COM0023: The Thermal Stability and Corrosivity of Bio-oil with Methanol Addition

Abstract: The stability and corrosivity of bio-oil remain uncertain and have initiated extensive research activities targeting potential problems for bio-oil upgrading applications. Studies have shown that blending a small portion of methanol into bio-oil led to promising results in reducing the aging rate of bio-oil. However, little effort has been made to investigate the effect of methanol addition on the corrosivity of bio-oil and the influence of lixiviated metal ions on the aging rate of mixed oils. Herein, the main task of this work is to evaluate how methanol addition (5–20 wt%) affects the thermal stability and corrosivity of bio-oil by performing a series of aging and parallel immersion experiments for 168 hours at temperatures up to 80°C. Various characteristics of bio-oil such as viscosity, total acid number, and water content are tracked vs. time. Low-carbon steel (A36), stainless steel (SS304), and nickel-based alloy (Hastelloy X) are chosen for immersion experiments. Weight and dimension changes of these metal strips are recorded for corrosion rates. Optical microscopy (OM) and scanning electron microscopy (SEM) with energy-dispersive X-ray spectroscopy (EDS) are applied to characterize the surface morphology and corrosion products. EDS maps confirmed the roles of Cr and Ni for slowing the corrosion kinetics of SS304 and Hastelloy X alloys in bio-oil.

Haoxiang Wang and Jing Liu, University of Alberta

COM0024: Thermodynamics of Hydrogen Atom Generation and Entrance into Steel Surface

Abstract: Hydrogen degradation has caused lots of concern in pipeline industry, especially for high strength steel under stressing condition. Hydrogen atoms could enter steel easily and accumulate at susceptible microstructure. Theoretically, hydrogen gas pipeline might suffer severest HE risk as a result of dissociation of hydrogen molecular, but there were few failure cases reported caused by HE. Thus, thermodynamic calculation was conducted to determine the possibility of H-atom generation inside the pipeline under service condition. Hydrogen atoms could be generated by two methods: spontaneous dissociation of interior moleculars and dissociative adsorption on steel surface. Gibbs free energy change criterion was introduced to include motional contribution for both methods rather than only considering total density functional theory (DFT) energy. Microscopical motional contribution to free energy was related to macroscopical state function by partition function. Transition state and energy change were studied by Cambridge Sequential Total Energy Package (CASTEP). Influence of stress was introduced by DFT calculation. Results of calculation showed that H-atom spontaneously dissociated from interior moleculars under service condition could be neglected. However, dissociative adsorption is a feasible method to introduce H-atom on steel surface. External stress would influence adsorption energy and free energy change by altering total DFT energy of reactant state and product state simultaneously. Path of diffusion into subsurface, transition state and energy barrier of it could also be investigated by ab initio calculation.

Yinghao Sun and Frank Cheng, University of Calgary

COM0028: Corrosion Performance of Reactor Candidate Alloys during Hydrothermal Liquefaction (HTL) of Cellulose and Lignin in a Batch Reactor

Abstract: Hydrothermal liquefaction (HTL) is a promising thermochemical approach for the conversion of wet and waste biomass feedstocks into crude bio-oils and other valuable chemicals. A technical issue that needs to be carefully addressed for the scale-up of HTL technology is potential corrosion occurring on the process core equipment, especially the reactors. A range of oxygenated, aggressive sulfur and/or chlorinated compounds, as well as organic acids, can be generated during the biomass conversion at the HTL operating temperatures ranging from 200 to 400°C, consequently creating a harsh environment to the reactor inside surface. In this study, the corrosion performance of candidate alloys (e.g., austenitic stainless steels and Ni-based alloys) are investigated in a batch reactor containing hot pressurized water and one of the typical model compounds in lignocellulosic biomass (cellulose, hemicellulose, or alkali lignin). The obtained results from the HTL of the model compounds are used to establish the correlation of alloy corrosion rates with initial biomass fiber compositions. The validation of the developed correlation is further done by comparing with the results obtained from the HTL of raw lignocellulosic biomass, i.e., agricultural/forestry residues. This paper is to summarize our results obtained most recently.

Haoyu Wang, Haoyang Li, and Charles Xu, Western University; Yimin Zeng, Xue Han, and Kaiyang Li, CanmetMATERIALS, Natural Resources Canada; Minkang Liu, University of Alberta

COM0032: Modification of Steel Corrosion Resistance in Seawater with Deep Cryogenic Treatment

Abstract: Corrosion resistance in natural environments is an important parameter that influences the lifetime and usability of materials in various applications. Corrosion preventive measures such as coatings and paints have been proven to be effective methods. However, when the surface of the material is damaged or worn off, the protective effects diminish and result in corrosion-induced failure of the material. To counteract such events, the materials corrosion resistance should be improved throughout the entire volume of the material. For martensitic steels, a novel procedure is the implementation of deep cryogenic treatment (DCT) during the material fabrication. During DCT the material is subjected to temperatures of liquid nitrogen (-196°C). DCT inherently changes the properties and mechanisms of transformation of austenite into martensite and encourages additional development of carbides. It has been reported, that DCT changes properties of steel such as hardness, toughness and wear resistance, as well as reducing density of defects in crystal structure etc. Within this study the effect of DCT on corrosion resistance of various steels with predominant martensitic structure is investigated by temporal analysis in natural seawater. The results indicate a decreased formation of corrosion products, reduced pitting corrosion and stress corrosion cracking for DCT treated steels. The corrosion resistance improvement is correlated to the modified microstructure and increased formation of carbides.

Patricia Jovicevic-Klug, Tjaša Kranjec, Matic Jovicevic-Klug, and Bojan Podgornik, Institute of Metals and Technology

COM0048: The Effects of Tempering Time on the Microstructure and Corrosion Behavior of Wire Arc Additively Manufactured 420 Martensitic Stainless Steel

Abstract: In this study, the effects of tempering time on the microstructure and corrosion behavior of a 420 martensitic stainless steel fabricated using wire arc additive manufacturing were investigated. The microstructure of the as-printed part consisted of retained austenite and detrimental delta ferrite embedded in a martensitic matrix. The undesirable delta ferrite phase was eliminated through austenitizing, followed by air-quenching of the as-printed samples, before tempering at 400°C. A wide range of tempering time from 1 h to 8 h was investigated. The tempered microstructure was found to contain a martensitic matrix along with both inter- and intragranular nano-sized carbide precipitates, formed within and along primary austenite grains and their boundaries. Electrochemical studies revealed a decrease in pitting potential and passive layer resistance of the fabricated alloy as tempering time increased, indicating the deterioration of corrosion resistance. The corrosion morphology assessment of the tempered samples revealed that primary austenite grain boundaries were the preferential sites for localized corrosion attacks in all samples, ascribed to the formation of intergranular chromium carbide precipitates, causing the alloy's susceptibility to intergranular corrosion.

Jonas Lunde and Salar Salahi, Memorial University of Newfoundland; Ali Nasiri, Dalhousie University

COM0053: Investigation on Corrosion of Candidate Steel for the Construction of Supercritical Water Gasification (SCWG) Reactor under Batch-mode Conversion of Lignocellulosic Biomass Model Compounds

Abstract: Supercritical Water Gasification (SCWG) is a recently developed promising technology in which wet raw biomass materials, crude bio-oils, or other bio-wastes are converted into syngas (a mixture of CO and H_2) using a supercritical water medium. Although considerable research activities have been employed on the technology development, the optimum operation conditions of SCWG processes are not yet well defined due to the complexity of raw feedstocks and conversion environmental chemistry. From corrosion perspective, it is also unclear which alloys are the best candidates for the construction of SCWG reactor to avoid catastrophic disaster as the reactors are operated in high-temperature and high-pressure harsh SCW environment containing organic vapors and reducing gases. In addition, the generated conversion products were collected and analyzed. In the work, the corrosion performance of Cr-bearing steel (SS310) under the SCWG conversion of three typical lignocellulosic biomass model compounds (cellulose, hemicellulose, lignin) is investigated to explore the influence of biomass feedstocks on corrosion and advance the mechanistic understanding of how high Cr steels corrode in SCWG environments. The produced gases and organic matters are collected and analyzed to reveal the chemistry of SCWG processes. The corrosion rate of the steel is assessed using the weight loss measurement method and the formed corrosion products are characterized with advanced microscopy techniques.

Haoyang Li, Haoyu Wang, and Charles Xu, Western University; Yimin Zeng, Xue Han, and Kaiyang Li, CanmetMATERIALS, Natural Resources Canada; Minkang Liu, University of Alberta

COM0063: Effect of Surface Modification on Corrosion Control of Type 409 Stainless Steel in a Hydrothermal Aqueous Solution

Abstract: Surface coating modification is proven to significantly improve the corrosion resistance of Fe-based alloys in subcritical and supercritical water environments. Surface coatings are currently considered to improve the corrosion control of candidate structural alloys in hydrothermal liquefaction (HTL) biomass conversion processes. Current candidate alloys for this application require suitable resistance to both general corrosion and stress corrosion cracking modes to withstand the HTL process conditions (250-374°C and 4-22 MPa). The objective of this study is to determine the relative extent to which chromium-based coatings can improve general corrosion control. The Cr-based coatings considered include electroplated Cr and chromized; application of these coatings are considered to improve the corrosion control of substrate Type 409 stainless steel (Fe-11Cr) relative to a mechanically-ground surface baseline condition. Samples are immersed in a simulated aqueous biomass conversion product mixture (KCl (aq) + K_2CO_3 (aq)) at 310°C and 10 MPa at three different exposure times (10, 15, and 20 days) using a static autoclave test system. Evaluation of corrosion extent will be conducted through analysis of pre- and post-exposure samples using various surface characterization techniques. The Cr coatings substantially reduced weight change after exposure and showed little evidence of corrosion compared to the mechanically ground baseline. This presentation presents the results acquired to date.

Elliott Asare, McMaster University; Yimin Zeng, CanmetMATERIALS, Natural Resources Canada; Joey Kish, McMaster University

COM009: Elements on Hot Corrosion of Boiler Tube Alloys and Potential Application of Ceramic Yttria Stabilization Zirconia

Abstract: Boiler tube alloys suffer from significant corrosion induced by metal chlorides and sulfates under high temperatures. This work aims to explore the corrosion behavior of three typical tube alloys (including 310S, Inconel 625, and alloy 800) and a ceramic Yttria stabilization Zirconia (YSZ) under mixture salts at 500°C. The chemistry of used mixture salts was determined according to the common deposits from waste-to-energy (WTE) plants. Normalized mass loss data suggest that the corrosion resistance follows a sequence of Inconel 625 (~60 wt% Ni) >Alloy 800 (~31 wt% Ni)>310S (~20 wt% Ni), and the corrosion rates after 500 h exposure were determined as, YSZ (0 mm/yr) In addition, corrosion products on cross sections were characterized by scanning electron microscopy (SEM) with energy-dispersive X-ray spectroscopy (EDS). After 500 h exposure, a thin Cr-rich layer was formed on Inconel 625 to resist the corrosion from mixture salts; while a dense Ni-rich layer was formed in Fe-based alloys (Alloy 800 and 310S) to protect the substrates. In the meantime, YSZ presented no oxidation layer nor mass loss at 500°C after 500 h exposure in simulated WTE salts. Overall, this work provides a better understanding of the effects of Ni and Cr on corrosion properties of boiler tube alloys, and reveals the potential application of YSZ as the coating material for boiler tube.

Haofei Sun and Jing Liu, University of Alberta; Luchao Sun, Tiefeng Du, and Jingyang Wang, Chinese Academy of Sciences

LIGHT METALS FOR HARSH ENVIRONMENTS

COM0017: Advanced Titanium Alloys with Tailored Properties for Application in Medical Engineering

Abstract: In general, Titanium alloys combine outstanding mechanical properties and biocompatibility with corrosion resistance and are, therefore, used in many challenging applications and are exposed to harsh environments including, for instance, blood and other body fluids at surfaces of medical implants. Nevertheless, for special products, well-tailored properties are needed which might not be achievable by a specific part design so that new or modified Titanium alloys are needed. In this overview-paper, alloy development strategies and thermo-mechanical treatments performed in the Titanium Research Group at the Institute for Materials Science of the Technische Universität Braunschweig are discussed at different examples, including (1) medium-strength alloys based on CP-Titanium containing, amongst others, oxygen and iron as major alloying elements for application in implants and ostesynthesis, (2) low-modulus, high-strength, nano-structured Ti 13Nb 13Zr for dental implant systems and (3) modified alloys based on Ti 6Al 4V for 3D-printed (e.g. selective laser melting) implant applications. In terms of the latter, the focus is set to influence the crystallisation behaviour and the phase-transformation to achieve more homogeneous material properties. In this paper, a special focus is set on the alloy development techniques, the design of thermo-mechanical treatments and the analyses carried out to achieve well-balanced properties of advanced Titanium alloys.

Carsten Siemers, Fabian Haase, Lina Klinge, and Florian Brunke, Institute for Materials Science, Technische Universität Braunschweig

COM0018: Mo- and In-containing Titanium Alloys for Medical Applications

Abstract: Due to their high specific strength, biocompatibility, and corrosion resistance, titanium alloys are often used in the field of medical applications. Alloys used include, amongst others, various grades of CP-Titanium or, if a higher strength is required, Ti 6Al 4V (ELI) and Ti 6Al 7Nb. However, Al and V are known to be toxic elements. Moreover, Al is suspected to cause breast cancer and Alzheimer's disease. For this reason, Al- and V-free titanium alloys on the basis of CP-Ti Grade 4+ (Ti 0.40O 0.08C 0.5Fe) with the composition Ti (0.40-0.44)O 0.08C 0.5Fe (3.0-6.0)Mo and Ti 0.44O 0.08C 0.5Fe (0.5-2.5)In have been developed and studied, which contain Mo or In as additional alloying elements. Small specimens of the alloys have been produced in laboratory scale and deformed in compression tests with subsequent recrystallization annealing. Microstructure and phase analyses have been performed by optical and scanning electron microscopy, EDS analysis, and X-ray diffraction. Additionally, phase diagram and solidification simulations have been carried out for the Mo-containing alloys. The resulting mechanical properties of the alloys have been evaluated by hardness measurements. The Mo-containing alloys exhibit hardness values between approx. 360 HV10 and 500 HV10 in the recrystallized state and, therefore, should exhibit a similar or higher strength than Ti 6Al 4V (ELI). Hence, some of the studied alloys might be a possible alternative for Ti 6Al 4V (ELI) in medical applications.

Fabian Haase, Carsten Siemers, Christian Temmen, Jonas Veer, and Joachim Rösler, Institute for Materials Science, Technische Universität Braunschweig

COM00188: Predicted Back-meniscus Stability for the Horizontal Single Belt Casting (HSBC) Process

Abstract: Horizontal Single Belt Casting is an emerging Near-Net-Shape-Casting (NNSC) Process for producing thin strips directly from liquid metal. It boasts highly competitive economic and environmental advantages over conventional casting methods. However, many conditions must be correctly managed to obtain a high-quality product. The behaviour of the "back meniscus" is one of them. For any melt, meniscus behaviour depends critically on the belt velocity, the incoming velocity of the melt stream, and the backwall gap. These all influence the meniscus, and its transient motions. The present research considers the casting AA2024 alloy, modelling two representative metal delivery systems, vertical, and 45° slope entry designs, considering two air gaps, and three belt speeds, when delivering the melt onto the cooling, moving belt. All other important conditions (σ, θ, ρ, Ra, etc.) remained constant. This modelling was performed using Fluent-Ansys 19.1. Results were validated by pilot scale experiments.

Daniel Morales, Carlos Riviere, Mihaiela Isac, and Roderick Guthrie, McGill University

COM00189: Modelling the Use of Sized Microbubbles to Advantage for In-line Degassing and Refining of Aluminum Melts

Abstract: In-line hydrogen degassing and melt refining units for molten aluminum, typically inject argon and fine magnesium chloride particles subsurface under the first impellor, and argon under all six in-line impellors, so as to degas the melt of dissolved hydrogen, and remove dissolved Ga, Ca, K, Na, by reaction with the $MgCl_2$ particles. This results in forming microbubbles of all sizes, some of which remain in the melt, and are transferred to the final product, compromising the melt quality, visible by LiMCA reading. Managing the generation of the right sizes of microbubbles, will help the process of cleaning the melts. Using the equivalent APS III system for measuring bubble sizes, an improved inert gas injection system aimed at forming bubble in the 600–1000 µm size range was studied, eliminating the problem of 50–200 µm microbubbles, and effectively aiding in transfer of reacted MgCl2 particles to the surface, prior to casting. These experiments are simulated in a water analog system.

Ajay Panicker, Giacomo Daniel Di Silvestro, Mihaiela Isac, and Roderick Guthrie, McGill University

COM0033: Nanocrystalline Ti 13Nb 13Zr Alloy for Dental Implant Applications

Abstract: For dental implant applications, titanium is the first choice because of its low elastic modulus, high strength, biocompatibility as well as excellent corrosion resistance. Typical alloys used in dental implants are Ti 6Al 4V (ELI) and commercially pure (CP) Titanium Grade 4. Compared to that of the jawbone (105 GPa) is still too high so that stress shielding leading to bone degradation and implant loss might occur. Furthermore, Ti 6Al 4V contains Aluminium and Vanadium which are known to cause severe health issues. Consequently, new Titanium

alloys like Ti 13Nb 13Zr are intended to be used in dental implants in the future. In the present study, nanocrystalline Ti 13Nb 13Zr (Nano-TNZ) is investigated which was produced by severe plastic deformation. In the as-deformed state, the alloy combines moderate stiffness and high strength with low ductility. Especially, the elongation at fracture is too low to fulfill the requirements of ASTM F1713. Therefore, a recrystallization and ageing procedure is developed. Here, a well-balanced ratio of the three possible phases (α- and β-phase as well as α"-martensite) needs to be achieved to reach high-strength, a Young's modulus between 50 GPa and 90 GPa, sufficient ductility and a grain size smaller than 1 µm to allow bone cells to adhere and grow but avoid bacteria colonisation. After recrystallization the properties can be further adjusted by precipitation hardening (α_S) and/or martensite decomposition.

Lina Klinge, Carsten Siemers, Björn Sobotta, Hendrik Krempin, Lukas Kluy, and P. Groche, Technische Universität Darmstadt

COM0043: Review of Thermal and Wear Characteristics of Spark Plasma Sintered Titanium Alloy Reinforced with Mullite-rich Tailings for Production of Energy Efficient Vehicle Brake Rotors: South African Case Study

Abstract: The low thermal conductivity and poor wear resistance of titanium alloy (Ti6Al4V) limits its use as material to design brake rotors, despite its high strength, low density, high fracture toughness, and excellent corrosion resistance. The addition of aluminosilicates like mullite as reinforcement to Ti6Al4V alloy, which possesses improved thermal shock and thermal stress resistance owing to low thermal expansion, good strength and interlocking grain structure properties, can mitigate against poor thermal and wear resistance, while in service as brake rotors. Additionally, harnessing mullite from secondary resources of copper like the Copper Smelter Dust (CSD), will not only aid in the sustainability of the earth, but controls and minimize environmental pollution posed through non-biodegradable solid wastes in form of metallic solid wastes and powdery materials amongst others. Furthermore, the drawback of poor ductility arising from high affinity of Ti6Al4V composites for nitrogen and oxygen during processing can be mitigated with the use of Spark Plasma Sintering (SPS) to fabricate the titanium alloy reinforced with mullite rich tailings for the production of an energy efficient motor vehicle brake rotor. Hence, this paper presented the review of publications in the open literatures relating to the following: problem definition and formulation, thermal conductivity and mechanical properties of Ti6Al4V+ $3Al_2O_3{\cdot}2SiO_2$ composite for production of brake rotors, thermal conductivity and mechanical properties of Ti6Al4V alloy for production of brake rotors, process for manufacturing engineering components from Ti6Al4V alloy and Ti6Al4V based composites. It was concluded that a gap of knowledge exist in the area of developing a metal matrix composite using Ti6Al4V reinforced with mullite rich tailings from a secondary copper resource as a structural material for the production of brake rotors. It was therefore recommended that there should be a research focused on investigating the thermal and mechanical characteristics of SSPS titanium alloy Reinforced with CSD for the production of energy efficient brake rotors.

Daniel Okanigbe, Pretty Linda, Abimbola Popoola, and Olawale Popoola, Tshwane University of Technology

COM0072: Microstructure Formation in AA6XXX during Nano-second Pulsed Laser Processing

Abstract: The properties of AA6XXX alloys such as high strength-to-weight ratio, good shape forming along with their good corrosion resistance allows for versatile applications such as rocket, cars and marine structures. In this work, the microstructure obtained using ultra-fast nano-second pulsed laser processing in analyzed using SEM, EBSD, TKD and HRTEM. It is shown that the alloys melts and solidifies along thin capillaries, in which grains with size less than a micron are obtained while the initial grain size is 40 µm. The melting and solidification stage are analyzed to determine the frontiers of the melt pool and deepened crystallographic analysis allows to propose a scenario for the grain microstructure observed. Finally, High-resolution imaging with TEM shows that due to the ultra-fast melting and solidification, the liquid phase was not homogeneous and that such atomic scale heterogeneities possibly play a role in microstructure formation using nano-second pulse laser processing.

Daria Zhemchuzhnikova and Julien Zollinger, Institut Jean Lamour - Université de Lorraine

COM00124: Effect of Cu Content on Microstructure Evolution and Semisolid Behavior of AA6111 Alloy

Abstract: AA6111 Al alloys usually suffer from high hot tearing susceptibility mainly due to a large solidification interval as well as the presence of rod-like intermetallic particles. To investigate the impact of Cu concentration on hot tearing susceptibility, two AA6111 alloys containing 0.15 (A) and 0.5 wt.% Cu (B) were prepared by DC Casting. The cast ingots were defected due to severe cracking, initiated from the cast butt, and propagated to the steady-state region. The fracture surfaces were examined by optical and electron microscopes to investigate the role of intermetallics on cracking. Fracture analysis of alloy B showed intergranular cracking, driven mainly by the decohesion of Fe-bearing intermetallic from Al matrix. Computational thermodynamic modeling was also employed to predict the phase evolution and liquid fraction during solidification. Furthermore, the mechanical behavior of the alloys near solidus temperature was characterized using partial remelting tensile tests. Alloy B exhibited higher strength relative to alloy A in the near-solidus region; but by increasing temperature, the strength of alloy B was gradually reduced, and both alloys presented similar strength at 552°C. Microstructure characterization revealed that, by increasing the test temperature, Al_2Cu intermetallics located on the periphery of Fe-bearing intermetallics experienced incipient melting

Mohamed Qassem, University of Quebec at Chicoutimi; Daniel Larouche, Laval University; Mousa Javidani, University of Quebec at Chicoutimi; Josee Colbert, Arvida Research and Development Centre, Rio Tinto Aluminum; X. -Grant Chen, University of Quebec at Chicoutimi

COM00125: Effect of Two-Step Homogenization on the Evolution of Al3Zr Dispersoids in Al-0.3Mg-0.4Si-0.2Zr Alloy

Abstract: Al3Zr nano-particles can be introduced in Al-Mg-Si 6xxx alloys to improve their elevated-temperature behavior and recrystallization resistance. The effect of a two-step homogenization on the evolution of Al_3Zr dispersoids and flow stress in Al-0.3Mg-0.4Si-0.2Zr

alloy was investigated. The two-step homogenization included a first step at 400°C for 48 h followed by a second step at 500°C for 2 and 5 h. This was compared with single-step treatments conducted at 400°C for 48 h and 500°C for 2 and 5 h. The evolution of the Al_3Zr dispersoid distribution was studied using scanning and transmission electron microscopy together with microhardness and electrical conductivity measurements. The flow stress was measured by high-temperature compression tests using a Gleeble 3800 thermomechanical simulator. The results showed that homogenizing at 400°C for 48 h produced a high number density of Al_3Zr dispersoids and high flow stress. In contrast, homogenization conducted at 500°C, which is closer to industrial homogenization practice for Al-Mg-Si alloys, reduced the dispersoid amount and flow stress. The two-step homogenization treatment appears to be an acceptable compromise between the low and high temperature single-step homogenization treatments, providing a satisfactory number density of Al_3Zr dispersoids and moderate flow stress.

Ali Elashery and Emad Elgallad, University of Quebec at Chicoutimi; Nick Parson, Arvida Research and Development Centre, Rio Tinto; X. -Grant Chen, University of Quebec at Chicoutimi

WALSIM IX: WATER, AIR, AND LAND SUSTAINABILITY ISSUES IN MINING AND METAL EXTRACTION

COM00110: Gas Handling Aspects of Radioactive Metal Melting for Nuclear Waste Management

Abstract: Nuclear power is currently the only candidate for generating reliable "carbon free" baseload electricity during its operation. Therefore, nuclear power will continue to play an integral role as the world transitions into a low carbon economy. The need for technologies to remove, consolidate, and reduce nuclear waste will only increase throughout the entire nuclear material lifecycle. Radioactive metal melting holds significant promise and opportunity for providing these needs. The primary goal of radioactive metal melting is to reduce the volume of nuclear metallic waste going to repositories and the secondary goal is to recycle / release the metal if practical. The selection of off-gas technologies is critical to the success of a metal melting process, as it serves to capture the airborne radioactive contaminants generated. In this paper, a comprehensive review of various off-gas technologies that could be employed is presented. These technologies were assessed against a set of criteria including technology effectiveness, operational complexity, maintenance intensity and exposure risks. The purpose of the paper is to outline a framework that can be used to select suitable off-gas technologies to capture radioactive contaminants from nuclear metal melting processes and summarize key design considerations.

Roki Fukuzawa, Tom Szwedowski, Brandon Yates, and S. Gagner, Hatch Ltd.

COM00114: Improving the Performance of a Mineral Battery: Use of a $CuFeS_2$/Activated Carbon Anode Material

Abstract: The use of renewable energy sources at remote mine sites could significantly reduce greenhouse gas emissions. But for the continuous supply of energy from these renewables, the development of new energy storage systems may be needed. One approach could be to use naturally abundant minerals as electrode materials. This work describes the use of $CuFeS_2$ as a negative electrode material in a mineral flow battery. The reversible ferrous/ferric couple occurring on a positive graphite felt electrode is used to support the charge/discharge process. The cell design, optimization of the operating conditions and performance of the mineral battery are discussed. For instance, the addition of activated carbon in $CuFeS_2$ and Cu^{2+} in the catholyte improved the charge storage capacity of the mineral battery. The partial reversibility of the charge transfer processes on the surface of $CuFeS_2$ facilitated energy storage (~ 4 $Wh\text{-}kg^{-1}$) during 100 charge/discharge cycles. This system has a coulombic efficiency of ~50 % and an energy efficiency of ~16%. The values, which are on the low end as compared to commercial battery systems, are the result of irreversible faradaic processes, i.e. Cu and Fe dissolution from the $CuFeS_2$, which are desirable in the context of mining. This hybrid mineral battery, then, has the dual functionality of energy storage and Cu extraction from the $CuFeS_2$. The extraction of valuable Cu and partial storage of the supplied energy could reduce fossil fuel consumption and CO_2 emissions at or near mine sites.

Kashif Mairaj Deen and Edouard Asselin, The University of British Columbia

COM00148: Potential of Ionic Liquids in Solvent Extraction for the Recovery of Cobalt and Nickel from Waste Matrices: A Review

Abstract: The demand for cobalt and nickel is projected to increase significantly in the next few decades as they are heavily used in current technologies, which has led to cobalt and nickel being considered critical metals. Consequently, the recycling of cobalt and nickel is essential to ensure the continuity of their expected supply and demand. Solvent extraction has been extensively used to separate and recover cobalt and nickel from primary and secondary resources. The environmental hazards concerning the utilization of conventional solvent extraction have encouraged the use of greener alternatives. Recently ionic liquids have been considered a new environmentally friendly approach to common organic solvents as they are much less flammable and non-volatile options. This work presents a detailed study of ionic liquids as a new alternative to separate and recover cobalt and nickel from secondary resources. The principles of ionic liquids, literature review of the last decade, and research gaps of their implementation have been considered in this work.

Guillermo Alvial-Hein, Harshit Mahandra, and Ahmad Ghahreman, Queen's University

COM00160: Behavior of Magnesia-, Silicon Carbide- or Alumina-based Refractories in Contact with Molten Copper Matte and Slag at Teniente Converter

Abstract: Currently, about 80% of the primary metallic copper in the world is produced from low-grade sulfide ores, which are usually concentrated by froth flotation and later treated by pyrometallurgical processes. Bath smelting represent about 30% of the global technological participation, in this alternative, concentrate and oxygen-enriched air are fed through tuyeres or

lances into the furnace's molten matte layer, while flux and reducing agents are usually incorporated by the furnace roof. Among these technologies, the Chilean Teniente Converter (CT), has recurring maintenance campaigns around the blowing zone due to; mechanical stress of tuyeres caused by “punching" in order to keep them open, high thermal gradient affected by the blast blowing, and the wearing of refractory brick mainly because of erosion and corrosion by intense fluid dynamics and contact with molten phases, respectively. The latter has the highest impact on the maintenance, in this scenario, any modification that enhanced the service life of the refractory material will positively impact the productivity, the Opex and the performance of smelting reactor. Regarding the refractory masonry, Magnesia–chromite bricks are typically used to line the entire smelting reactor, but it results not to be the most suitable material and strategy, because there are specific requirements during the operation which mainly depends on the zone in the reactor and the contact of the brick with gas, slag or copper matte. In order to clarify technically and economically the most suitable refractory masonry for the melting of copper sulphide concentrate at Teniente Converter considering Fayalite slag, the behaviour of three kind of bricks of: Magnesia (MgO)-, Silicon carbide (SiC)- and Alumina (Al_2O_3)-based, with molten copper matte and slag were investigated by experimental laboratory tests under controlled oxygen partial pressure atmosphere (pO_2) and temperature. A cylindrical specimen of refractory was immersed into molten, matte (70 wt% of copper) or Fayalite slag, contained into a high purity magnesia crucible, the specimen was connected to a rheometer in order to assure a controlled rotation and simulate the movement of the condensed phases into the furnace under controlled pO_2 and temperature. This experimental array allowed to clarify the phenomena of corrosion and penetration of the molten phases in the interaction zone. After five hours the crucible was quenched, copper matte, slag and cylindrical refractory were cut and analysed by using SEM-EDS technique. MgO-C- refractories showed a high reaction and penetration in contact with copper matte, while MgO-Cr based ones lower levels, but for these exist differences depending on the porosity and the presence of alumina content as minor component. SiC-base refractories had a low reaction in contact with copper matte but the highest with slag. Finally, Al_2O_3-based refractories showed low reaction with both phases but they are the most expensive in the market. According to the results, the latter refractory should be used in the blowing zone of Teniente converter, while that of MgO-Cr in the rest of the reactor to optimize Opex and reduce the maintenance frequency of the furnace

Julio Ossandon, Camila Pizarro, and Leandro Voisin, University of Chile

COM00187: Neutralization of Acid Mine Drainage Using Limestone and Waste Concrete Sludge

Abstract: Reducing the cost of neutralization process is the main challenge for the continuous treatment of acid mine drainage (AMD) which contains harmful heavy metals such as Cu, Pb, Cd, and Zn. Passive treatment is a method for removing these harmful metals from AMD without a daily management and power. Since the cost of a passive treatment is less than that of active treatment method, various studies are being conducted for its large-scale implementation. In this study, a series of batch tests and reaction tests with small-scale channel were conducted with two kind of neutralizers (limestone and concrete waste sludge) and the actual AMD to clarify their reaction characteristics and neutralization potentials. Limestone is commonly used in passive treatment system, and concrete waste sludge is a highly alkaline waste material which

consists mainly of $Ca(OH)_2$, quartz, and calcite, and is expected to have a high neutralization potential. In the experiments with limestone, the solution pH increased from 4 to 6-7 in both batch and channel tests. Although the concentration of Cu and Pb successfully met the Uniform National Effluent Standards in Japan (Cu: 3 mg/L, Pb: 0.1 mg/L), that of Zn and Cd did not decrease to the standards (Zn: 2 mg/L, Cd: 0.03 mg/L). On the other hand, in the cases with concrete waste sludge, the solution pH easily exceeded over 10, and the harmful metals were sufficiently removed from AMD. However, it is found that it is necessary to adjust the flow rate or the filling ratio of neutralizer in order to suppress the pH increase. Analyses of the precipitates showed that Zn and Cu were effectively removed from the AMD as silicate minerals in addition to carbonate minerals in the case with concrete waste sludge. Finally, we developed the geochemical simulation model for the acid neutralization treatment in the channel type wetland using a geochemical modeling software (The Geochemist's Workbench 2020) based on the results of reaction tests. We confirmed the changes of the neutralization potential and the removal efficiency of harmful metals in response to changes in the filling ratio of the neutralizer and the AMD flow rate. In our presentation, we will show the optimum channel size, kind and/or combination of neutralizer, and the amount of neutralizer for the various types of AMD (flow rate, water chemistry) based on the abovementioned geochemical simulation.

Yutaro Takaya, University of Tokyo; Shigeshi Fuchida and Chiharu Tokoro, Waseda University; Takaya Hamai, Yusei Masaki, and Kengo Horiuchi, Japan Oil, Gas and Metals National Corporation

COM0026: Modelling the Solvent Extraction Separation of Neodymium from Praseodymium Using a First Principles Thermodynamic Model

Abstract: In this work, we demonstrate the value of a first principles thermodynamic model for the solvent extraction separation of neodymium from praseodymium. The experimental and pilot plant work of Lyon et al. (2017) was utilized to generate a thermodynamic model of a solvent extraction, scrubbing, and stripping process. Solvent extraction isotherms taken from Lyon et al. were used to successfully fit equilibrium constant values for the organic-aqueous interface cation exchange reactions ($R^2 > 97\%$). The fitted thermodynamic model was used seamlessly within a SysCAD process simulation model of the pilot plant design proposed within the same paper. The resulting SysCAD model predictions of organic and aqueous stream compositions and properties within the circuit closely matched steady state pilot plant data reported by Lyon et al. Having a comprehensive model of the rare earth SX process enables efficient multivariate optimization. Thus, process optimization studies using the SysCAD process model were conducted and demonstrated a trade off between product stream purity, praseodymium rejection, and neodymium recovery. The effect of additional scrubbing stages was also investigated and was found to be very important. The SysCAD process simulation model can also incorporate non-ideal operational effects, such as incomplete phase separation within the settlers and heat loss.

K.L. Lyon, V.P. Utgikar, M.R. Greenhalgh, "Dynamic Modeling for the Separation of Rare Earth Elements Using Solvent Extraction: Predicting Separation Performance Using Laboratory Equilibrium Data", Ind. Eng. Chem. Res. 2017, 56, 4, 1048–1056.

Kevin Heppner, SysCAD

COM0045: Campaign Life Extension of Upgraded Horizontal Converters during the Process of Intensive Smelting and Converting with Oxygen-Enriched Blowing

Abstract: The design of the upgraded horizontal converter (Victory Smelting Process Unit (VSP)) for autogenous smelting of copper sulfide polymetallic concentrate using oxygen is described. It is shown that the on-blast operation of the converter enriched up to 24.0–27.4% vol. leads to an increase in the heat load on refractory materials to 62.8–85.0 kW/m^2 and a decrease in the VSP campaign to 107 days. The developed system of refractory elements water cooling under vacuum (vacuum water cooling system) has facilitated to extend the overhaul period up to 205 days and increase the charging efficiency by 19%. Further modernization routes of the combined conversion smelting unit (VSP) are determined. Vacuum water cooling system implementation in upgraded VSP enhanced the unit lifetime from 107 to 205 days. Heat flow rates are calculated in the most heat-stressed structural VSP components. Performance indicators of the unit fitted with forced cooling system are evaluated. Further VSP upgrades are defined.

Konstantin Bulatov, JSC Uralmekhanobr

COM0061: Assessment of the Net Emissions Reduction Potential of Iron Ore Beneficiation for Blast Furnace Ironmaking

Abstract: Decarbonization of the iron and steel industry is a significant technical challenge. As the industry pursues the long-term goal of sustainable steelmaking, efficient operation of existing ironmaking infrastructure will be critical to achieving the emissions reductions targets set by national and international policy initiatives. Operational experience has demonstrated that increasing the iron content of the ferrous raw materials used in the blast furnace, the dominant ironmaking technology, is an effective strategy for reducing specific fuel consumption. Although most iron ores undergo beneficiation prior to their use in the blast furnace, further upgrading of these ores represents an opportunity to partially offset fossil fuel consumption at the blast furnace. This paper analyzes the emissions trade-off across these two linked processes and assesses the optimal strategy for achieving a net reduction in the carbon footprint of the iron and steel industry value chain.

Britt MacKinnon, Richard Elliott, Ian Cameron, and Manuel Huerta, Hatch

COM00106: Recycling Ferronickel Concentrates as an Iron Source to Extract Nickel from Nickel Sulphide Concentrates

Abstract: The conventional nickel extraction from sulphide nickel ore consists of smelting and refining, producing high purity metallic nickel products. The limit of the traditional extraction process is the significant cost of SO_2 abatement, disposal of by-products (e.g., slags), and complex refining treatment. With the interest of reducing SO_2 emissions and simplifying the extraction process, the authors investigated a solid-state (800°C) thermal treatment of nickel sulphide concentrates in the presence of metallic iron under a neutral atmosphere. The results showed that approximately 97% of Ni was extracted into ferronickel (FeNi) particles with d_{80} = 45 µm. Recycling these FeNi particles as an iron source yielded new FeNi precipitations in the sulphide matrix with d_{80} = 20 µm. The Ni concentration in the resulting sulphide phase was in the range of 1–3 wt%. Optimization is required to use the recycled FeNi particles as seeds to increase the size of newly precipitated alloy particles.

Fanmao Wang, Sam Marcuson, and Mansoor Barati, University of Toronto; Leili Tafaghodi, McMaster University

COM00109: Leaching of Selenium, Tellurium and Silver from Copper Anode Slime by Sulfuric Acid in the Presence of Manganese(IV) Oxide and Graphite

Abstract: The leaching of constituent metals from copper anode slime (CAS) (22.23% Se, 1.53% Te, 9.66% Ag) by sulfuric acid in the presence of manganese(IV) oxide and graphite has been investigated, varying the conditions such as stirring speed (200–600 rpm), H_2SO_4 concentration (0.5–3.0 M), MnO_2:graphite:CAS mass ratio (0–1) and temperature (25–90°C). The metal leaching was facilitated by the galvanic interaction with MnO_2, while graphite played the role of a catalyst. Under the most suitable conditions (500 rpm, 2.0 M H_2SO_4, 0.8/0.8/1 MnO_2/graphite/CAS mass ratio and 90°C temperature), the extent of leaching of Se, Te and Ag from the CAS, together with Mn from MnO_2 after 6 h was recorded as 90.8%, 81.9%, 80.7% and 84.1%, respectively, as compared to 76.8% Te, 69.4% Se, 67.2% Ag and 55.9% Mn after the leaching of CAS with MnO_2 without graphite under the same conditions; the leaching efficiency was still lower in the absence of MnO_2 (32.6% Te and negligible Se and Ag). The leaching kinetics of tellurium and silver at temperature 25–50°C in the presence of MnO_2 and graphite fitted well to the mixed and surface chemical reaction models, respectively, and changed to follow the diffusion and mixed control models in the temperature range 60–90°C with the respective apparent activation energies of 17.8 and 12.2 kJ/mol. That of selenium was controlled by the surface chemical reaction with the estimated activation energy of 27.6 kJ/mol in the temperature range 25–90°C. The manganese leaching followed the mixed-control model (activation energy of 56.7 kJ/mol) at the all tested temperature.

Kurniawan Kurniawan, Korea University of Science and Technology; Jae-chun Lee, Korea Institute of Geoscience and Mineral Resources; Jonghyun Kim, Korea University of Science and Technology; Rina Kim and Sookyung Kim, Korea Institute of Geoscience and Mineral Resources

COM00111: Bioengineered Microorganisms for Nickel Removal

Abstract: Liquid mine effluents may contain dissolved metals at concentrations too low to be economically extracted by existing technologies, yet too high for environmental discharge. Treating this wastewater often requires chemical precipitation of the dissolved metals using limestone and subsequent disposal of the sludge in tailing impoundments. While this is a cost-effective solution to meet regulatory standards, it represents a lost opportunity. The research presented will demonstrate the use of synthetic biology to engineer microorganisms to remove dissolved nickel from simulated liquid mine effluents at ppb-ppm concentrations. Specifically, Escherichia coli is artificially equipped with a class of highly-specific transporter protein systems

evolved over millions of years to capture nickel from metal-scarce environments. Preliminary results at bench scale reveal the engineered strain removes 97% of dissolved nickel from a 10 mg/L (ppm) solution in 3 h, which translates to a bioaccumulative perfromance of 2 $mg_{Ni}/g_{cell}/h$ that is larger than the literature's best reported strain by two-fold. Immobilization of the engineered strain to enable easier aqueous separation and strategies to recover the bioaccumulated nickel for downstream processing are discussed.

Patrick Diep, Heping Shen, Alexander Yakunin, Vladimiros Papangelakis, and Krishna Mahadevan, University of Toronto

COM00113: Green Engineering for Simultaneous Carbon Capture and Lithium Purification through Carbonation

Abstract: To address the power and energy demands of electric cars and high-energy storage devices, Li-ion-based technology demands a progressively higher volume of lithium raw material. As extraction and purification of lithium by different hydrometallurgical techniques is tedious and relatively cost-inefficient, the lithium carbonate precipitation recovery process being employed for the commercial recovery of lithium. As carbocation plays a vital role, in our current investigation purification of lithium carbonate through carbonation using carbon dioxide has been investigated. Lithium carbonate precipitation from lithium sulfate and hydroxide solutions through carbocation using carbon dioxide has been investigated. The effect of various factors that affect the carbocation of lithium from sulfate and NaOH solutions like temperature, time, flowrate, and equilibrium pH has been investigated. Followed by carbocation, precipitated carbonate was analyzed by XRD. Quantitative recovery (up to 99% efficiency) of pure lithium carbonate (3N pure) recovery as a function of temperature has been observed. The obtained result indicated through engineering innovation carbon capture and lithium recovery can be addressed simultaneously.

Cris Arellano and J.Y. Lee, University of Science and Technology; Y.J. Song, Kangown National University; B. Swain, Materials Science and Chemical Engineering Center, Institute for Advanced Engineering

COM00130: Effect of Calcium Ions on Oxidation and Surface Secondary Mineral Accumulation Formation on Pyrite in Alkaline Conditions

Abstract: Pyrite is often regarded as a gangue mineral that should be depressed strongly in blended sulfides flotation system, and lime is generally used as an economic depressant and a pH regulator. With the introduction of calcium ions into flotation system, the hydrophilicity of oxidized pyrite surface will be enhanced via the surface accumulation of hydrophilic secondary minerals, where the pyrite oxidative dissolution and reprecipitation of calcium and iron containing species both play a vital role during this process. In this work, the influence of Ca ions on the pyrite oxidation rates was initially investigated, and the promoting effect of surface calcium-containing minerals accumulation to the reprecipitation of iron oxides/hydroxides from solution was observed according to the surface analysis test. The influence of Ca ions on pyrite oxidative dissolution at pH 9, 10.5 and 12 was investigated via solution analysis. The result shown an obvious accumulation of total dissolved sulfur at pH 12 in both Ca addition and non-

Ca addition systems, while the Ca ions performed a slight depression to the surface sulfur dissolution of pyrite in each corresponding pH condition. Subsequently, the distribution of secondary minerals on pyrite surface was observed by thermal field emission type scanning electron microscopy (FE-SEM), which showed a high affinity between Ca-species such as $CaSO_4$, $Ca(OH)_2$, $CaCO_3$ and dotted iron oxides/hydroxides from energy dispersive spectrometer (EDS). The related bonding forms for aforementioned minerals were further verified by the Fourier transform infrared spectroscopy (FTIR). This research reflected the positive influence of Ca ions on the reprecipitation of dissolved iron-species on pyrite surface as iron oxides/hydroxides. The stronger affinity of Ca species on iron oxides surface facilitates the aggregation of negative-charged iron-species such as $Fe(OH)_4^-$ from the solution and subsequently accompany with its transformation into secondary iron oxides/hydroxides in alkaline condition. Hence, this phenomennon will deepen our understanding of the continuous enhancement of the surface hydrophilicity of pyrite in alkaline condition.

Jifeng Xue, Sana Ishida, Shigeshi Fuchida, and Chiharu Tokoro, Waseda University; Takuya Kaseyama, Yuji Aoki, and Yoshinobu Kishimoto, Sumitomo Metal Mining, Company Limited

COM00162: Separation of Lanthanum, Europium, and Ytterbium via Selective Adsorption onto Algal Biomass and Recovery via Desorption

Abstract: Separation of rare earth elements (REEs) has often proven difficult as they possess similar physicochemical properties and are found at dilute concentrations. The conventional method for REE separation via organic solvent extraction which is energy intensive and produces environmentally hazardous waste. A more environmentally benign alternative for separation and recovery of REEs is to use microbial biomass, like microalgae, through biosorption, where metal ions bind to specific highly concentrated ligands within the cell wall. This process has previously been shown to effectively concentrate REEs at bulk concentrations below 50 mg/L to 150 mg/g dry biomass and shows potential in the recovery of REEs from dilute streams such as mining effluents. It has also been shown the heavy REEs adsorb preferentially over light REEs allowing for the selective separation of REEs. We have also resolved issues surrounding implementation of biosorption into an engineered system by growing microalgae in a self-immobilizing and highly concentrated form known as a biofilm. To better understand the adsorption selectivity for biofilm biosorption we measured the extents of adsorption for three REEs for algal biofilms and suspended algal biomass. The effects of pH and other metals like iron and aluminum on biosorption have also been investigated.

Mitchell Zak, Nicolas Carunungan, Vladimiros Papangelakis, and D. Grant Allen, University of Toronto