Advances in Materials Manufacturing VI - Existing and Emerging Materials

KEYNOTE
COM22145: Additive Manufacturing of CX Stainless Steel: A Comparison Between Small-Scale and Large-Scale Fabrication Methods

Ali Nasiri, Mahya Ghaffari, and Alireza Vahedi Nemani, Dalhousie University

Abstract: With more than 50 Mt of annual production, stainless steels have witnessed the highest production and consumption growth rate per year within the last 30 years among all other metallic materials. This demanding market needs to be supported through implementing efficient and cost-effective manufacturing techniques. In recent years, the emerging additive manufacturing technology has opened up new fabrication opportunities with customized designs, reduced production time, and improved materials consumption, fostering sustainability in manufacturing systems. Focusing on this topic, in this talk, additive manufacturing of recently developed 13-8 Mo precipitation hardening martensitic stainless steel, also known as CX stainless steel, with applications in plastic molding tools, extrusion dies, and marine will be discussed. Particular attention will be given to both small-scale and large-scale fabrication methods of the alloy employing laser powder bed fusion and wire arc additive manufacturing processes, respectively. The pros and cons of both processes are discussed along with detailed comparisons between their as-printed microstructural features, mechanical properties, and corrosion performance.

KEYNOTE
COM22012: Al Alloys and Casting Processes for Applications in Electric Vehicles

Henry Hu, University of Windsor

Abstract: With the rapid expansion of battery-powered electric vehicles (BEV) in the automotive industry, research interest in lightweight Al alloys and their casting processes and applications has increased considerably. The substitution of castable aluminum alloys with superior strengths and electrical conductivity for copper reduces the weight and size of electric induction motors, and improves the energy efficiency and driving range of the BEVs. The present article was intended to give a general introduction into the common cast Al aluminum alloys and their relevant processes, and to motivate the development of high strength and conductive Al alloys for practical realization of Al applications in the motors of the BEVs. A number of cast alloy systems containing Cu, Si, Ni, Mg, Fe and Ti were evaluated, in comparison to nanostructured wrought Al alloys. The conventional casting processes suitable for Al alloys, high pressure die casting, squeeze casting and sand casting, were described. Strengthening mechanisms including solid solution strengthening, precipitation strengthening, dislocation accumulation strengthening and grain boundary strengthening were presented. The phenomenon of electrical conduction for Al alloys was outlined. The mechanical properties and electrical properties of the recently developed Al alloys for casting and deformation processes were comprehensively listed and critically reviewed in association with microstructural characteristics.

KEYNOTE

COM22170: High-Speed Nanoindentation Mapping of Additive Manufactured Titanium Alloys for Aerospace Application

Yu Zou, University of Toronto

Abstract: Titanium alloys and γ-TiAl intermetallics are widely used in additive manufacturing of aerospace engine components, but their complex microstructures and related micromechanical properties have not been fully explored. In this project, we employ high-speed nanoindentation mapping, electron probe microanalysis, and electron backscatter diffraction to characterize as-deposited and heat-treated Ti-6Al-2Zr-Mo-V and alloys. Our results show the correlations between mechanical contrasts (hardness and elastic modulus) and phase contrasts (α and β). The hardness and elastic modulus of the α and β phases are increased due to the element redistribution after annealing (Al diffuses from β to α; Mo and V diffuse from α to β). We also use a K-means clustering algorithm to analyze nanoindentation dataset and distinguish between α and β phases. In addition, we used the AM technique to fabricate a γ-TiAl/Ti_2AlNb graded material by depositing γ-TiAl powder on a Ti_2AlNb alloy substrate. High-resolution scanning electron microscopy and high-speed nanoindentation are employed to characterize the microstructure and mechanical properties of the transition zone from the Ti_2AlNb substrate (disk) to the γ-TiAl alloy (blade). Our study provides a new methodology to give a better understanding of the microstructure-mechanical property relationship of additive manufactured multiphase alloys across length scales.

KEYNOTE

COM22175: Hybrid Manufacturing of IN718

Sila Atabay, Priti Wanjara, and Javad Gholipour Baradari, National Research Council Canada; Josh Soost, Matsuura Machinery, USA, Inc.; Mathieu Brochu, McGill University

Abstract: Laser powder bed fusion (LPBF) is a popular additive manufacturing (AM) technique due to its ability to produce complex geometries with minimum material waste. These advantages have motivated research in LPBF processing of advanced alloy systems, including nickel-based superalloys, to create high-performing, long-lasting parts in the aerospace industry. Amongst the Ni-based superalloys, AM of Inconel® alloy 718 (IN718) has been widely studied, not only due to its outstanding high-temperature properties but also because of its good weldability. However, LPBF still has certain drawbacks that require further investigations for specific part geometries. A key concern is the poor surface quality of the LPBF fabricated parts that require post-process machining, which can obliterate the cost benefits of AM. Hence, it would be of interest to use hybrid additive and subtractive manufacturing in a single setup to produce parts with high-quality surface finishes and tight dimensional tolerances. Thus, this study investigated the application of a hybrid additive-subtractive method (Matsuura LUMEX-Avance-25) to fabricate IN718 benchmarking coupons. The coupons were then examined for surface finish both with and without high-speed machining. The microstructure of the hybrid manufactured IN718 was investigated thoroughly in the as-fabricated condition and following post-process heat treatment. Finally, hardness, tensile properties, and fracture behaviors were studied in both conditions.

KEYNOTE
COM22174: Picosecond Laser Surface/Deep Patterning of Alumina Ceramics

Hamidreza Yazdani Sarvestani, Warren Amsellem, Zachary Katz, I. Esmail, C. Beausoleil, Javad Gholipour Baradari, and Behnam Ashrafi, National Research Council Canada

Abstract: Traditional machining techniques pose significant drawbacks when applied to ceramics due to the material's inherent brittleness. Specialized laser machining has been known to solve these issues through higher precision and micrometer-scale feature control. In this study, a picosecond fiber laser has been used as a material removal system for different engineering applications of industrial grade alumina ceramics with a variety of thicknesses and feature dimensions. This work explored picosecond laser process parameters such as focal position, linear speed, and wobble amplitude in order to control cut depth and optimize cut quality in terms of kerf width, kerf taper, surface cleanness, while avoiding crack formation. The surface roughness was assessed to determine the quality of the cuts. The optimal process parameters between the surface finish and material removal rate were introduced. Using a circular wobble laser pattern, it was determined that a greater cut depth can be achieved at lower linear speeds and wobble frequencies due to the higher linear energy density. It has also been found that the kerf taper is dependent on the cut depth and wobble amplitude, where the measured cuts follow the geometric relation between these parameters accurately.

COM22113: Direct Laser Writing of Copper / Copper Oxide Patterns for Emerging Roles in Advanced Electronics

Joshua Jones, University of Waterloo

Abstract: There has been increase in interest in flexible electronics for roles in applications such as wearable electronics, and solar technology. Current technologies for fabricating flexible electronics tend to rely on costly nanomaterials as raw materials. This paper presents an alternative processing method that circumvents the need for pre-fabricated nanomaterials, while still achieving comparable electrical properties. Direct Laser Writing (DLW) is a new manufacturing technique where an aqueous copper ion film is applied to a flexible substrate and then selectively irradiated with focused laser energy to produce a resulting structure of interconnected copper nanoparticles in a single step. During DLW laser energy simultaneously reduces the copper ions present in the solution to form nanoparticles, and subsequently sinters the nanoparticles into a continuous structure. In addition to being low cost DLW also benefits from being suitable at room temperature and not requiring or producing any environmentally harmful materials. Through controlling laser parameters the chemical composition of the copper can be controlled, resulting in a high degree of control over the electrical properties of the resulting patterns. We demonstrate in this paper the ability to achieve flexible patterns with conductive and semi-conductive electrical properties. Finally, we intend to demonstrate the unique capabilities of DLW by showcasing some of the flexible electronic devices we have been able to fabricate using DLW, namely a memresistive copper / copper oxide junction.

COM22019: Fabrication of Thin Rotary Tools Through a Combination of Cross-Rolling and Austempering-Tempering

Hamidreza Mirzakouchakshirazi, Université Laval; Rémi Georges, FPInnovations; Bruna Ugulino, FPInnovations; Roger Hernandez and Carl Blais, Université Laval

Abstract: Production of thin rotary cutting tools involves several challenges related to the maximization of uniform tensile and bending properties and levelness. This research project investigates the feasibility of manufacturing these tools through cross-rolling and austempering-tempering of a high carbon low alloy steel. In this regard, the combination of the new deformation process and austempering-tempering was compared to a commercial circular saw blade made by conventional hot rolling followed by quenching and tempering. The results reveal that the cross-rolled austempered materials show higher resistance to tempering. They also show that the combination of cross-rolling and austempering-tempering results in higher hardness (9%), yield stress (19%), UTS (19%), and bending strength (22%) while maintaining similar ductility when compared to the quenched and tempered material. The reason for such an improvement is related to the presence of homogeneous α and ε fiber textures in combination with a microstructure made of lower bainite. Tempering of bainite close to the bainitic transformation temperature range permitted to adjust strength/ductility and maximize the levelness of the final product. The novel manufacturing approach proposed enables the production of thinner rotary tools that minimize waste during the cutting operation.

COM22038: Heat Treatment of Multi-Material Additively Manufactured Maraging Steel and Stellite Alloy

Jubert Pasco and Clodualdo Aranas, University of New Brunswick; Kanwal Chadha, Planetary and Space Science Centre, Univeristy of New Brunswick; Yuan Tian, voetalpine Additive Manufacturing Centre Ltd.

Abstract: The ability to simplify the fabrication of a multi-material component with complex architecture to a single part with sectional variation of properties has attracted research interest in multi-material Additive Manufacturing. Accordingly, the present work employed a dual-metal Laser Powder Bed Fusion technique to manufacture a multi-material product, consisting of Stellite alloy (MP1) and maraging steel (MS1) in a single printing process. A single heat treatment strategy that improves the mechanical properties of both alloys was also applied. The resulting heat treatment effects on the microstructure, microhardness, and mechanical properties were investigated. Diffusion and thermodynamic simulations from EDS analysis results show consistent amounts of intermetallic precipitation on regions of both base metals close to the interface. Electron Backscatter Diffraction (EBSD) analysis of the dual-metal samples revealed consistent dominant fiber textures after printing and after heat treatment, which is the || building direction (BD) fiber texture for the MP1 region and the || BD and || BD fiber textures for the MS1 region. Analysis of the microstructure also revealed martensitic growth along the building direction close to the interface after heat treatment. Furthermore, nanoindentation tests revealed a steep hardness transition in the interface, which became more evident with an increase in MS1 hardness and a slight decrease in MP1 hardness after heat treatment. Finally, tensile tests show a slight increase in elongation while retaining the as-printed strength. Future work will verify if any precipitates formed in the MS1-MP1 interface.

COM22028: Influence of Microstructure and Alloy Composition on the Machinability of Alpha/Beta Titanium Alloys

Mostafa Shehata and Shimaa El-Hadad, Central Metallurgical Research and Development Institute CMRDI; Helmi Attia, McGill University; Mahmoud Sherif, Khaled Ibrahim, and Ahmed Farahat, CMRDI

Abstract: Due to their unique properties, titanium alloys are used in major industries, including the biomedical, aeronautic, and automotive industries. Compared to aluminum alloys which are also used in several industries, titanium alloys have remarkable mechanical properties, such as superior strength to weight ratio and exceptional corrosion resistance at elevated temperatures. Titanium alloys are known as expensive materials when compared to other metals. The main reasons arise from the extraction process and difficulties encountered in melting and fabrication processes. Despite recent developments and extensive usage of titanium alloys, machining of titanium alloys still remains a major industrial concern since they are classified as difficult-to-cut materials. In the current work, the machinability of the recently developed titanium alloy Ti6Al7Nb (Ti67) was investigated and compared to the commercial Ti6Al4V (Ti64) alloy. Both of cast and forged specimens were used to investigate the influence of microstructure on the machinability process. A wire electric discharge machine was used for this purpose and different parameters were applied. Ti67 alloy showed more fine microstructures in both of cast and forged conditions compared to Ti64. Significant differences in the machined surfaces were obtained and referred to the differences in the microstructures and alloy composition.

COM22054: Influence of Layer Thickness Upon the Dimensional Accuracy and Surface Roughness of AISI D2 Tool Steel Manufactured Using Directed Energy Deposition

Samer Omar and Kevin Plucknett, Dalhousie University

Abstract: This research focuses upon the influences on the dimensional accuracy and surface roughness of directed energy deposition (DED) processed AISI D2 tool steel through alteration of the layer thickness, while keeping the remaining system operating parameters at constant values. The DED process involved laser deposition of AISI D2 tool steel powder on annealed AISI D2 substrate, in order to build multi-layered rectangular specimens. After deposition, the DED manufactured specimens were assessed without any further machining processes. The dimensional accuracy (i.e., actual height of the deposited specimen in comparison to the designed height) was evaluated using both a manual approach, using calipers, and computational method, using confocal laser scanning microscopy (CLSM). It was observed that the increase in the layer thickness decreases the degree of overbuilding. Moreover, CLSM was used to examine the top and side surfaces roughness of the DED processed specimens. It was found that the use of lower layer thickness improves the top surface roughness. However, there was not a monotonic effect for layer thickness upon the side surface roughness of the DED processed samples.

COM22108: Laser Ablation of Thin Films for Flexible Sensor Manufacturing

Ningyue Mao, Pablo Enrique, Norman Zhou, and Peng Peng, University of Waterloo

Abstract: Today, with the development of the Internet of Things (IoT), the demand for specialized sensors that can measure physical properties is greatly increased. Conventional electronics manufacturing techniques such as photolithography are typically used for large-scale production of sensors, however this process can require expensive cleanroom facilities and hazardous chemicals. In addition, it offers little flexibility in terms of customized designs for small production volumes, due to high fixed costs and long lead times. A mask-free and inkless method using nanosecond pulsed UV laser ablation for sensor

manufacturing is investigated. This method greatly simplifies the patterning process into a single step and allows for a short turnaround time for custom designs. In general, the quality of the fabricated sensor depends on laser power, scanning speed, pulse frequency, and scanning strategy. In this study, the influence of these laser parameters on the ablation depth and edge quality of NiCr thin films are investigated. The laser ablation process is optimized to obtain high quality thin film sensors that have the potential to offer custom sensor production at low cost and with short lead times.

COM22013: Laser Powder Bed Fusion of M789 Steel on Wrought N709 Steel Substrate

Kudakwashe Nyamuchiwa, University of New Brunswick; Yuan Tian, voetalpine Additive Manufacturing Centre Ltd; Kanwal Chadha, Planetary and Space Science Centre, University of New Brunswick; Clodualdo Aranas, University of New Brunswick

Abstract: A newly developed maraging steel, M789, was additively manufactured on top of a wrought precipitation hardening steel, N709, using laser powder bed fusion (LPBF). A fully dense M789 was achieved. The EBSD confirmed a completely martensitic structure with less than 1% retained austenite. The results show that the M789 steel had a lower hardness of 550 HV compared to 680 HV for N709. Moreover, no significant diffusion of alloying elements from the M789 to the N709 material was detected. Based on the initial assessment, a post-processing heat treatment is necessary to achieve homogenous mechanical properties between the dissimilar alloys.

COM22040: Microstructural Characterization of Pack Borided H13 Tool Steel Processed Using Directed Energy Deposition

Owen Craig, Kevin Plucknett, and Riley Roache, Dalhousie University

Abstract: H13 tool steel samples were prepared using directed energy deposition and were then pack-borided at temperatures of 800°C, 850°C, 900°C, or 950°C, with a hold time of 4 hours for each temperature. As a baseline, wrought H13 tool steel samples were also pack-borided under identical conditions. The microstructures and crystalline phases for the borided samples were characterized using X-ray diffraction, scanning electron microscopy, energy-dispersive X-ray spectroscopy, wavelength-dispersive X-ray spectroscopy, hardness, and confocal laser scanning microscopy. After applying the thermochemical heat-treatment to the tool steel samples, a characteristic 'saw-tooth' appearance of the boride layer is observed in the cross-section of all samples, which is slightly flattened due to the high alloying in the tool steel. This boride layer consists of a FeB layer (tensile) on the outer surface, with a Fe_2B layer (compressive) below. With increasing boriding temperature, the borided layer increased in thickness. WDS confirmed that the elements Si, C, and Cr were redistributed due to the formation of the boride layer. It was observed that the boriding process significantly improved the hardness of the samples. There was no clear trend in terms of the surface roughness after boriding at the various temperatures, with samples processed at 900°C having the highest surface roughness. The surface of as-borided samples shows a porous appearance with cracking due to the residual tensile stresses of the FeB layer.

COM22016: Monotonic and Cyclic Deformation Behavior of a Silafont®-36 Cast Aluminum Alloy in an Overaged Condition

Soumya Sobhan Dash, Ryerson University; Dejiang Li, Xiaoqin Zeng, and Dongyang Li, University of Alberta; Daolun Chen, Ryerson University

Abstract: Lightweight Silafont®-36 alloy containing minor iron has been developed for automotive applications due to its high tensile strength, long fatigue life, and superior ductility in the as-cast condition. The mechanical properties of this alloy are expected to vary with its temper conditions. T7 heat-treatment involving a long aging time after solution heat treatment (also known as over-aging) is one of the commonly used temper conditions to achieve stabilized aluminum alloys. This treatment helps decrease the susceptibility to stress corrosion cracking and increase the exfoliation resistance and thermal conductivity of some Al-Si-Cu alloys, despite accompanied moderate strength. The load-bearing structural application of such alloys inevitably involves strain-controlled cyclic deformation behavior. Although the information on some tensile properties of the alloy under study experienced T7 treatment has been reported, no studies on its low-cycle fatigue behavior can be found in the open literature. The objective of this study was to evaluate the cyclic deformation behavior of a high-pressure die-cast (HPDC) Silafont®-36 alloy in the T7 state in relation to its microstructures (including potential gas porosities and surface blisters generated during the HPDC and solution treatment) and clarify underlying deformation mechanism. Details on this study will be presented at the conference.

COM22132: Open Pore Effect on Structural Adhesive Joining of AA6061-T6 Al Alloy Using an Epoxy Adhesive

Mani Mohan Tiwari, Saleema Noormohammed, X. -Grant Chen, and Dilip Sarkar Université du Québec à Chicoutimi

Abstract: Adhesive joining offers significant weight reduction by minimizing use of rivets/bolts used traditionally in aluminum assembling. Obtaining strong joints even with strongest adhesives is still a challenge due to inadequate surface treatment resulting in poor adhesive/surface interfacial bonds. Al surfaces are generally treated with acid anodization or by mechanical abrasion. Considering the ecological challenges a salt instead of acids in anodizing AA6061-T6 Al alloy surfaces was used to improve adhesive bond strengths. The surfaces anodized in an optimized electrolyte of disodium hydrogen phosphate (Na_2HPO_4) salt at a controlled temperature of ~5°C with different current densities provided a higher rms surface roughness of ~1.53 µm as compared to ~0.63 µm on the as-received surface. Scanning electron microscopy images revealed the effective growth of porous oxide layers with wide pores (~0.60 µm). Mechanical testing performed on single lap shear specimens prepared by bonding the Al surfaces using a 2-C epoxy adhesive showed an increased joint shear strength of ~28.5 MPa on salt anodized Al as compared to only ~12.3 MPa on the as-received counterpart. The cohesive rupture modes and their correlation to the pore size and surface roughness in terms of mechanical interlocking of adhesive were elaborated.

COM22112: Synthesis of Fast-Weathering Nutrient-Doped Silicate Minerals, and Their Prospect as a Negative Emissions Technology

Asif Ali, Rafael Santos, and Yi Wai Chiang, University of Guelph

Abstract: Enhanced weathering of silicate minerals is a negative emissions technology that captures atmospheric CO_2 via the formation of carbonates. When certain silicate rocks are mixed with agricultural soils, improved agricultural yields are witnessed, implying that the benefits are two-fold. Natural silicates, such as basalt and olivine, weather too slowly in basic soils and regions with low rainfall rates and cold temperatures, opening the opportunity for faster-weathering synthetic silicates to be produced via carbon-neutral pathways. The minerals we are synthesizing for this purpose include calcium silicates (larnite (β-C_2S), calcio-olivine (γ-C_2S), cuspidine, and pseudowollastonite), and calcium-magnesium silicates (åkermanite, bredigite, and merwinite). To boost their soil fertilizing ability, thus increasing their agronomic value, we are investigating the doping of these silicate minerals with nutrients such as K, P, and Se. The manufacturing process of these minerals is being studied to achieve even higher weathering rates by creating dislocations and preferential reaction sites through milling process, and by controlling the cooling time for regulating polymorphicity and crystallinity. The successful synthesis of these silicate minerals at laboratory scale and their performance for capturing atmospheric carbon at higher rate will pave further ways for industrial production and large-scale implementation.

COM22109: Transient Softening at the Fusion Boundary of Spot Welds in Advanced High-Strength Steels: Dark Horse of the Heat Affected Zone

Oleksii Sherepenko, Dileep Ramachandran, Alireza Mohamadizadeh, and Elliot Biro, University of Waterloo

Abstract: The use of Advanced High-Strength Steels (AHSS) in body-in-white (BiW) components provide significant potential for weight reduction of a car body. Presence of metallic surface coatings, used for corrosion protection, such as Zn and Al-Si, combined with a high strength of AHSS cause a decrease in joinability, thus creating a challenge to produce resistance spot welds meeting commercial quality requirements. Welding with longer welding times is recommended for joining AHSS in several standards and is sometimes used to improve spot weld joinability during manufacturing. Welding with longer times, however, has been connected to a localized softening at the fusion boundary of spot welds, referred to as halo ring. Present work gives an overvirew of halo appearances in the literature and sums-up the research effort of the recent years to study the mechanisms reslponsible for the halo formation in spot welds of AHSS. It has been shown that the halo is caused by local decarburization at the fusion boundary if nugget growth saturates early in the welding process and the fusion boundary remains stationary, allowing for enough time for carbon diffusion to occure. Welds with severe softening at the fusion boundary tend to fracture along the softened region, sometimes leading to reduced of energy absorption in the fracture process. Promoting nugget growth at the end of the welding process has been shown to mitigate decarburisatio and reduce softening, giving a pathway to halo elimination.

COM22147: Tribological Performance of 13–8Mo Maraging Stainless Steel Fabricated Via Wire Arc Additive Manufacturing in As-Printed and Heat-Treated Condition

Elham Afshari, Mahya Ghaffari, Alireza Vahedi Nemani, and Ali Nasiri, Dalhousie University

Abstract: Wire arc additive manufacturing (WAAM) is a metal additive manufacturing technology with high material deposition rate. In this study, tribological properties of precipitation hardened (PH) 13–8Mo martensitic stainless-steel parts produced by WAAM have been investigated. The influence of anisotropic microstructures created during WAAM process on the wear behavior of the fabricated part was investigated by performing scratch testing. In addition, to assess the effect of post-printing heat treatment on wear performance, the as-printed samples were subjected to solution treatment followed by aging, after which the wear properties in different directions were evaluated. It was found that in the as-printed condition, there is a considerable difference in scratch resistance between different directions with the highest scratch resistance along the deposition direction on the plane aligned with the building direction, while the building direction on the same plane revealed the least resistance. Applying the aging heat treatment was found to improve the homogeneity of the microstructure and resulted in a more uniform scratch resistance throughout the WAAM fabricated part. Besides, the wear performance of heat-treated samples was superior to that of the as-printed ones, and samples that were aged at 600 ºC showed the highest scratch resistance. The role of the microstructural features on the wear mechanism of the samples are thoroughly elucidated in this article.

COM22167: Wear and Corrosion Behavior of High Entropy Alloy Coatings Fabricated Using Flame Spraying and Cold Spraying

Rakesh Bhaskaran Nair and Andre McDonald, University of Alberta

Abstract: Recent progress in advanced metallic materials has enabled the development of high entropy alloys (HEAs) for tribological-related applications. HEAs are comprised of at least five components fabricated in equimolar or close to equimolar concentrations that exhibit favourable microstructural characteristics and exceptional properties. However, assessments and analysis of wear and corrosion performance, and behavior of thermal-sprayed HEA coatings have not been fully explored. The present work aims to reveal the influence of microstructure on abrasive wear and corrosion behavior of equimolar AlCoCrFeMo HEA coatings deposited by cold spraying (CS) and flame spraying (FS). X-ray diffraction, scanning electron microscopy equipped with energy dispersive spectroscopy, and micro-hardness testing were utilized to understand the microstructural and mechanical properties of the coatings. Performance evaluation based on abrasion damage and electrochemical corrosion was investigated according to ASTM standards. The microstructure revealed body-centered cubic (BCC) structures and mixed oxides for FS HEA coatings, whereas CS HEA coatings lacked oxides with BCC phases. Evolution of oxides and BCC phases resulted in FS HEA coatings with high hardness and wear resistance compared to CS HEA coatings. However, the presence of oxides and high porosity deteriorated the corrosion performance of FS HEA coatings, such that it was two times lower than that of CS HEA coatings. The evolution of multiple oxide phases and underlying microstructural features of FS HEA coatings resulted in improved resistance to damage due to wear loading, but undermined resistance to electrochemical corrosion. These results suggest that FS HEA coatings can be potential candidates for extreme environments while simultaneously opening avenues for designing new materials with improved microstructures and mechanical properties.

Deep Decarbonization Pathways for Pyrometallurgical Processes: Opportunities & Challenges

KEYNOTE
COM22071: Decarbonization in Ferroalloys and Si-Production Opportunities and Challenges

Eli Ringdalen, SINTEF

Abstract: Various methods and technologies for decarbonization of ferroalloy production are available; each with their own challenges and opportunities. Their potential and the most promising method vary between the different ferroalloys as well as with location, energy mix and time frame. Ferroalloys are industrially produced mainly in submerged arc furnaces (SAF) where electric energy is used for reduction and are supplied by electrodes to the reduction zone The main raw materials are oxides that are reduced to alloy by solid carbon. Possible pathways for decarbonization can be changes of existing processes, use of new or alternative raw materials, pre-processing of raw materials, post processing of off-gases or completely new processes, or a combination of some theese. Some examples are given in the paper. Greenhouse gas emissions from ferroalloy industry has decreased the last decades by changes in existing production as furnace design and improved process control. Both carbon and energy consumption has been reduced. The potential for further reduction is limited by the amount of carbon required to remove oxygen in the ore. Alternative technologies are thus sought. Use of a non-fossil reductant as biocarbon will reduce fossile emissions and do not require any main changes in existing process. It is already in use and is often seen as the easiest solution. The main challenges are availability and to have qualities that do not reduce furnace performance or increase specific energy and carbon consumption. Pretreatment and prereduction of ores are especially relevant for Mn- and Cr- alloy production. Although this will reduce CO_2 emissions, carbon is still needed for final reduction and other methods must be used in addition. Use of CO-rich off-gas as raw material for other products or carbon capture and storage of the gas, will reduce the CO_2 emissions from the actual plant, but in most cases over time result in same global CO_2 emissions. Recirculation of gases back to the process is a way to decrease this drawback. New, alternative methods can be gaseous reduction, mainly with hydrogen, electrolysis and metallothermi. The possibility for use of each of theese for a specific alloy depend on the reduction potential that can be obtained in the actual case. For all the ferroalloys there are technical challenges that must be overcome before such new technologies can be used. Different alternative approaches as use of plasma or new electrolytes have been proposed. A combination of different technologies is in some cases the best choice. To be sustainable and contribute to decarbonization, carbon consumption and CO_2 emissions from the total value chain must be reduced. In evaluation of potentials and challenges it must thus be ensured that pre-processing, postprocessing, raw material and energy use and steps in new process does not increase total consumption of fossile carbon. Examples of pathways for decarbonization of ferroalloy production, with focus on Mn, FeSi and Si production will be presented and discussed.

KEYNOTE
COM22085: Deep Decarbonization and Pathways to Net Zero Emissions – A Steel Industry Perspective

Ian Cameron, Hatch Ltd.

Abstract: The steel industry and its related supply chain emit more greenhouse gases (GHGs) than any other metal produced. Accounting for 7-9% of global GHG emissions, steel production is deemed a 'hard-to-abate' industry due its reliance on carbon to reduce iron ore to iron. Steel demand will grow significantly due to population growth, demands to build renewable energy systems, and a need for more resilient infrastructure The steel industry challenge is to reduce GHG emissions while increasing output by as much as a 30% over the next 30 years. A credible path to net zero GHG emissions is essential for access to the capital needed to convert current facilities to new green steel plants. The iron ore and steel industries are exploring many technologies to develop pathways to net zero including advanced iron ore upgrading, steel scrap usage; process electrification; hydrogen and biomass reduction of iron ore; and carbon capture, utilization, and storage Starting from current steel industry GHG emission profiles, technology routes that enable deep GHG reductions will be described, including an update on technology readiness levels and commercialization timeframes. Pathways to net zero by 2050 are possible; likely routes and key enabling technologies for the incumbent blast furnace-basic oxygen furnace (BF-BOF) route; the direct reduction ironmaking - electric arc furnace (DRI-EAF) route; and the scrap melting EAF steel producers will be presented.

KEYNOTE

COM22017: Transitioning Toward a Low-Carbon and Circular Economy: The Role of Life Cycle Assessment in the Metallurgy Sector

Annie Levasseur, École de Technologie Supérieure

Abstract: It is now widely recognized that human activities exert an unbearable pressure on natural resources and environment, and the metallurgy sector is no exception. Major changes at all stages of products life cycles are required in order to decrease greenhouse gas emissions that are responsible for climate change, as well as other pollutants, and to optimize the use and recirculation of resources in our current highly linear pattern of production and consumption. A wide range of solutions are possible, going from less energy intensive extraction and refining activities to the development of recycling processes. Life cycle assessment (LCA) is the preferred tool to assess potential environmental impacts of products, processes and services, while taking into account their entire life cycle. As a diagnosis tool, LCA is widely used to identify the processes that contribute the most to environmental impacts in order to prioritize efforts and make sure that the solutions proposed do not lead to higher environmental impacts elsewhere in the life cycle. In this talk, the general LCA framework will be presented, focusing on challenges and opportunities for the metallurgy sector. Case studies will also be presented to show how LCA could be used to quantify potential environmental benefits associated with different low-carbon and circular initiatives to be implemented.

KEYNOTE

COM22161: Using Hydrogen as a Reductant in Fire Refining at Aurubis Hamburg's "Down-Town" Smelter

Torben Edens and Johann Steindor, Aurubis AG

Abstract: The deoxidation of copper or "poling" is the final step in the pyrometallurgical process of primary and secondary copper extraction. The deoxidation generates CO_2 since gaseous and liquid hydrocarbons (natural gas) are the common choice for reducing agents. Previous energy and cost saving measures increased the efficiency of the process, but the inherent production of CO_2 cannot be avoided. The use of hydrogen as a reductant may decarbonise a core process of copper production, which is a desirable target for the metal industry in general and Aurubis in particular. The primary smelter in Hamburg runs two anode furnaces with a capacity of 270 t per batch each. From September to December

2021, the anode furnaces were provisionally supplied with hydrogen and 14 batches were poled using hydrogen. These experiments were designed to determine in full scale operational tests the properties of the poling with hydrogen in terms of efficiency and process control. The average efficiency of poling with hydrogen was higher than poling with natural gas. The adjustment of the volume flows and the temperature control of the process was always controllable. The end point of the poling with hydrogen could be determined similarly to the poling with natural gas based on the temperature curve. The tests showed the importance of nitrogen addition for stable jetting conditions where clogging of the tuyeres was a phenomenon observed when pure hydrogen was used. An important observation from the tests was that the efficiency of the reduction was not affected by the addition of nitrogen. This paper will discuss in detail and share the learnings of full-scale polling tests in the Hamburg anode furnace and discuss requirements for its introduction into the daily production.

COM22018: Circored Fine Ore Reduction and DRI Smelting: A Way to Decarbonize Steel Making

Max Koepf and Sebastian Lang, Metso Outotec GmbH & Co KG

Abstract: At the UN Climate Change Conference COP26 at the end of 2021, participating countries agreed that by the end of next year they would set more ambitious 2030 emissions reductions goals. The shift towards "green steel " production is therefore the key theme for the steel industry also in 2022, as countries and steelmakers compete and cooperate in the race to transform an industry that currently accounts for some 8% of global CO_2 emissions. The hydrogen-based direct reduction of iron ore combined with EAF smelting is being widely discussed as a possible replacement for the commonly used BF/BOF route in steelmaking. One alternative to shaft furnaces is Metso Outotec’s Circored process, which uses fine ore as feed for fluidized bed reactors, eliminating the cost and energy-intensive pelletizing step. As a direct reduction process using 100% hydrogen as the reductant, Circored has already proven its functionality in an industrial-scale demonstration plant. However, most of the DRI/HBI production processes rely on DR-grade pellets, while this quality is globally only accounting for some 20% of the global iron ore production. This will create challenges for many DRI-based projects, since there are so far no ready-made solutions for smelting of BF-grade DRI. Metso:Outotec approach to this is the combination of Circored with a DRI smelting furnace. This solution is targeting to replace a small/medium sized blast furnace, producing hot metal with desired carbon content that can be utilized in the existing steel plants with BOF-converters. Because of the big volume in the furnace, this combination is capable in smelting low grade feed with high gangue content and therefore enables using BF-grade feed for DRI production.

COM22067: Electrical Resistivity of Charge Materials in the Si-Process and Its Effect on Energy and CO_2 Emissions

Haley Hoover and Merete Tangstad, Norwegian University of Science and Technology (NTNU); Gudrun Sævarsdottir, NTNU/RU; Meggi Glowaki, NTNU

Abstract: Understanding the resistivity of the charge mix in the silicon furnace is an essential part of the effort to reduce carbon emissions and decrease power consumption. If the charge mix high in the furnace is too conductive, current paths will not penetrate deeply, lowering the Si yield and increasing energy and carbon consumption. The need to maintain a highly resistive charge demands an understanding of how the conductivity of the charge changes as the charge itself is transformed. The bulk resistivity of mixtures of char, quartz, and woodchips is investigated as they are heated to 1600°C. The results are compared to measurements of material found deeper in the furnace such as SiC and Si, as well as with other carbon materials. Factors such as density, composition, and microstructure are discussed. The char had the lowest resistivity of 17 mΩm at 1550°C and was approximately the same as the char and woodchips mixture, which was 19 mΩm at 1600°C. The char and quartz mixture had the highest resistivity of 95 mΩm at 1600°C. Finally, the mixture of char, quartz, and woodchips had a resistivity of 47 mΩm at 1600°C, but the results had a higher standard deviation. Compared to previous studies on partially transformed SiC (6–36 mΩm), the resistivity is higher at 1600°C for the mixtures containing quartz. Finally, carbon emissions are calculated and compared for different Si-yields to qualitatively show the significance of optimal current paths.

COM22006: Electrically Heated Fluid Bed as a Low-Carbon Option for Pyrometallurgical Processes

Kamal Adham, Hatch Ltd.

Abstract: Using a "green electricity" heating source, produced from renewable resources such as wind/solar/hydro, pyrometallurgical processes can lower their carbon-footprint significantly. Fluid beds are commonly used for drying ores, calcining concentrates and decomposing metallic salts, normally with energy input from fossil fuel combustion. Electrically heated fluid beds can be used instead of the fuel-burning units, as a low-carbon option for pyrometallurgical processes. Heating can be provided in a number of ways, including fluidizing air-heating, in-bed indirect heating and in-bed direct heating. These methods and their applicability to different metallurgical processes are described in this paper.

COM22090: Evolving Project Lifecycle Processes for Decarbonization of Pyrometallurgical Facilities

Guillaume Pregliasco, Sameet Dalvi, Gino De Villa, Lucy Rodd, and Alisha Giglio, Hatch Ltd.

Abstract: Numerous companies in the mining and metals industry have committed to ambitious decarbonization targets with milestones in 2030–2050. Select projects have also experienced difficulty securing funding due to a lack of greenhouse gas (GHG) abatement consideration as part of the project planning. Consequently, the industry is being forced to change its current approach to decarbonization, both for brownfield and greenfield projects. Industry leaders have taken steps to organize themselves around carbon emissions considerations, including changing their project lifecycle processes to ensure that projects align with the organization's GHG emission reduction targets while satisfying investors' requirements. There are both technological and financial challenges that need to be overcome, oftentimes requiring new approaches to ensure these decarbonization initiatives can get the traction that they need and can be implemented in an appropriate timeline. Historically, projects have been focused on operating costs and energy efficiency as key factors behind a project's economics, without separate consideration for GHG emissions. However, energy efficiency and GHG emissions intensity do not always correlate with each other, and therefore separate accounting of GHG emissions is required. This paper will discuss how GHG emissions, intensity, and cost of abatement can be treated in a similar way to conventional project metrics and incorporated into a project's techno-economic assessment. Furthermore, this paper discusses the role of decarbonization strategies in mitigating project risk, meeting project approval requirements, and allowing access to capital, all of which must be aligned with the organization's overall decarbonization targets. These changes to project lifecycle processes also present a significant opportunity in the shape of new flowsheets and integration of new decarbonization technologies that are now more easily incentivized within a framework that includes decarbonization mandates.

COM22070: Fossil-Free Carburization of Hydrogen-Based DRI

Sandeep Kumar, LKAB; Hesham Ahmed, Bo Björkman, and Johanna Alatalo, Lulea University of Technology

Abstract: Iron and steel industries are major contributors to the greenhouse gas emissions. The majority of these emissions are linked to the use of fossil-based reductant, and replacing them by green H_2 enables the transition toward fossil-free iron and steel making. However, the produced carbon-free direct reduction iron (DRI) will present the refining and steelmaking operations to have the starting point far from today's operational practices. Therefore, in hydrogen-based iron making process, a way to introduce carbon in a controlled manner is essential. Hence, carburization of hydrogen-reduced DRI was studied at the single pellet scale using gases simulating bio-based syngas. The factors affecting the carburization process, such as gas composition, temperature and duration as well as the simulated bio-syngas were investigated thoroughly in the temperature range of 600 to 800°C. Further, the carbon introduced into the hydrogen reduced DRI can either be in the form of cementite, graphite (free-carbon) or mixture of both. Therefore, the effect of carbon content and the form in hydrogen-based DRI for their respective melting characteristics have also been investigated, and presented here.

COM22123: Green Hydrogen for Steel Production - A Case Study

Gareth Richardson and Peter Appleby, Atkins; Maria De Campos and Sina Mostaghel, SNC-Lavalin

Abstract: Decarbonisation of steel sector is currently receiving a significant attention in many countries, mostly focusing on direct reduction of iron using hydrogen. However, unless green hydrogen from renewable energy sources becomes available in sufficient quantities and at an economical cost, the overall decarbonization of steelmaking remains a challenge. The current paper covers the learnings from a recent feasibility study completed for the conversions of a direct reduction iron (DRI) and associated electric arc furnace (EAF) plant to a green steel plant. The feasibility study centred around the transition from hydrogen, produced by natural gas combustion, to a green hydrogen supply system, based on electrolysis with a power supply mix of renewables and nuclear energy. Four areas of interest are laid out in the paper: a) Electricity source and its impact on the levelized cost of hydrogen, b) Electrolyser plant types and suitability for integration, c) Value stacking through electrical load management and benefits for plants with electric arc furnaces, d) Impact of high purity hydrogen on the DRI plant and the necessary adjustments to be made. The identified benefits include producing minimized carbon dioxide during production of the steel, possible increased DRI capacity, mitigation of EAF impact on grids and tuneable carbon content of the DRI.

COM22060: Have Lunatic Ideas for Hydrogen Use from the 80s and 90s Become Keys Towards a Decarbonized Future in Copper and Nickel Pyrometallurgy?

Joël Kapusta, BBA

Abstract: As a budding professional in nonferrous pyrometallurgy back in the 90s, I enthusiastically accompanied my mentor at Air Liquide and visited smelters and research centres in North America and Europe. Our purpose was to present our ideas for copper and nickel smelting, converting, and refining. One of our proposed process changes was the use of hydrogen for copper refining and slag cleaning. To this day, I vividly recall how our audience reacted to the idea, thinking we were two lunatics who had not learned our history and did not know the fate of the Zeppelin some 50 years earlier. Our hosts generally listened to us politely but never contacted us again, at least not on the topic of hydrogen. Those who were

frank and honest would ask us: “Who on earth would be crazy enough to even consider installing a ticking bomb on their property such as a cryogenic reservoir of liquid hydrogen?” With this memory vividly in mind, I considered myself extremely privileged in 2001 when an iron and steel powder manufacturer in Canada offered me to do just this and lead a project to replace the use of ammonia in their annealing furnaces by hydrogen. Twenty years later, with the hype on decarbonization, hydrogen has become synonymous with great hopes of transforming the industrial world, including the field of nonferrous pyrometallurgy. This COM2022 symposium on “Deep Decarbonization Pathways for Pyrometallurgical Processes: Opportunities & Challenges” offers me an opportunity to dig into my technical archives in search of these old lunatic ideas, review the theoretical background behind hydrogen use in copper refining and slag cleaning, and revisit the research and experimental work that was done in the 1980s, in particular by Air Liquide in France at its research centre in the Paris region. To complete my journey, I will also attempt to evaluate some of the economical aspects related to the use of hydrogen in nonferrous pyrometallurgy.

COM22152: Iron Segregation Roasting as a Potential Decarbonization Pathway for Ironmaking

Patrick Kerr, Minepromet

Abstract: Ironmaking accounts for 80% of steelmaking greenhouse gas (GHG) emissions, while steelmaking accounts for 8% of global GHG emissions. Hence the value of decarbonizing ironmaking through the implementation of Iron Segregation Roasting where applicable. Iron Segregation is ideally used with difficult to beneficiate iron ores where the ore roasted at an elevated temperature (900°C) with a carbonaceous reductant and a chloride additive in a closed reactor to allow for reducing conditions and contain the volatile chlorides. The process is followed by some form of physical separation to liberate the metallic iron from the gangue. Iron segregation lends itself well to decarbonization as the reactor type is ideally an indirect fired kiln, in order to contain the volatile chlorides, which act as a transport catalyst within the reactor. So in turn, an electrically heated reactor can take advantage of renewable electrical energy source. An additional benefit that comes from the transport catalyst phenomena is that communtion energy requirements can be significantly reduced by avoiding the necessity of ultra-fine grinding. Unlike coke required to maintain bed stability and reducing properties in traditional blast-furnace ironmaking, Iron Segragation can use different types of renewable biochar, as the bed is not fluidized. At the same time, hydrogen injection at the end of the process can also be used to increase metallization and further reduce the amount of carbon reductant necessary for ironmaking. Although the exact ratios possible have not been optimized, the concept has been proven. While iron segregation roasting has only been tested in the laboratory and up to the small-pilot scale, it holds great potential for difficult to beneficiate ores, especially in the context of decarbonization in ironmaking.

COM22030: Is Hydrogen the Silver Bullet for Decarbonization?

Mansoor Barati, University of Toronto

Abstract: The production of metals is directly responsible for producing up to 10% of the anthropogenic carbon dioxide. To decarbonize the industry with an eye to carbon neutrality by 2050, a roadmap is emerging that involves interim measures such as carbon capture and storage. The use of hydrogen as both fuel and reductant is however viewed as the ultimate solution towards a net-zero extraction of metals. In this talk, this view is analyzed from technical and economic perspectives. The potential to use hydrogen as a reductant and the challenges against it are discussed.

COM22121: Predictive Furnace Refractory Maintenance Procedures to Extend Campaign Life and Reduce Waste

Afshin Sadri, Matthew Cramer, and Wai Lai (Winnie) Ying, Hatch Ltd.

Abstract: As furnace lining concepts and designs have improved over the last 100 years, the smelter management and maintenance approach has also changed significantly within this period. One of the fundamental approaches that have changed is the view of the furnace lining. In traditional thinking, the lining was viewed as a consumable with unpredictable service life, but a new and modern idea is to see the furnace lining as a piece of equipment that should be maintained. Simply burning through the lining and hoping for the best is no longer acceptable or economically viable. Modern actively managed freeze lining approaches have, in theory, infinite life and must be proactively managed. If refractory linings need active management, it flows logically that the causes and costs must be understood so that the appropriate measures and strategies can be developed to manage the equipment. The strategies must be turned into operating and maintenance procedures that are followed on a regular basis, and the data generated should form the basis of any decisions. Throughout the campaign life of a furnace, successful refractory maintenance procedures will ultimately reduce relining costs, furnace downtime, waste disposal volume, and carbon footprint of the smelter. In this paper, the authors will discuss the reasons and costs of a furnace run-out and the benefits of data-driven predictive maintenance in decision-making leading to the extension of a furnace campaign life.

COM22133: Pyrolytic Decarbonization and Characterization of Biogenic Silica from Rice Husk, a Source of Sustainable Material for Metallogical-Grade Silicon

Benedict Ayomanor, Federal Polytechnic Nasarawa; Cookey Iyen, Federal University Wukari; Sunday Anikoh, Federal Polytechnic Nasarawa; Ifeoma Iyen, Federal University Wukari; Vitalis Mbah, Suleiman Ndiriza, and Erasmus Ikogho, Federal Polytechnic Nasarawa

Abstract: Rice husk (RH) is a biomass product found in large quantities in several countries including Nigeria. This agricultural waste product is very rich in siliceous materials when pyrolysed under controlled temperature and time. The low production cost makes this biogenic silica most viable for preparing high purity silica needed for silicon. Nigeria has the benefit of transforming large volume (960,000 tonnes per annum approximately) of its agricultural waste into a partial solution to the country's issue with energy distribution. In this work, high percent silica ~ 95% was prepared from RH pyrolyzed at 700^{o}C for 5 hours via thermal extraction. The rice husk ash silica was leached using a hydrometallurgical process. The residual was characterized by X-ray fluorescence spectroscopy (XRF), scanning electron microscopy, thermogravimetry, and X-ray diffraction analysis. Elemental analysis using XRF found major impurities as Fe_2O_3, K_2O, Na_2O, MgO, CaO, SO_3, P_2O_5, Mn_2O_3 and Al_2O_3.

COM22143: Stabilizing Chromium in Ferrochromium Slag for Utilization as Aggregate Material

Leili Tafaghodi, McMaster University; Tahmeed Tasnim, BC Research Inc.

Abstract: The Canadian economy relies largely on natural resources, yet processing of these resources and/or associated by-products are well known to negatively affect the environment. Reusing slag, a common waste stream of pyrometallurgical extraction processes, as construction materials serves to reduce the impact on the natural resources currently used in construction industry such as sand, gravel,

and crushed stone. Every year, 12–16 million tonnes of ferrochromium slag is produced, a majority of which is dumped in landfills. The mechanical properties of this slag make it a potential material to be used as an inexpensive construction material, the utilization of which can reduce the use of natural resources. Despite its potential use, ferrochromium slag is treated as a waste due to environmental and health concerns regarding the leaching of its heavy metal content, the most concerning of which is carcinogenic chromium (VI). Research has shown that the spinel phase in ferrochromium slag stabilizes chromium by trapping it in the spinel structure and preventing its leaching to the environment. This study examined slag samples of the $MgO-Al_2O_3-SiO_2-CaO-FeO-Cr_2O_3$ synthesized at 1650°C. The slag was synthesized to mimic the possible composition of the Ring of Fire's ferrochromium slag. Samples were heat treated before quenching. Leaching tests on heat treated slag samples showed that samples held at 1400°C have the lowest chromium leachability. Higher Cr leaching is observed from samples as the Al_2O_3 content increases. An increase in basicity in the range of 0.3–0.7 increases the amount of Cr released from the samples during leaching experiments.

COM22091: Technology Developments and the Metals Industry in a Low Carbon Economy

Phillip Mackey, P J Mackey Technology Inc.

Abstract: The energy transition now underway to renewables recognizes that global carbon emissions need to be reduced. A more sustainable economy largely based on renewable energy will take decades to achieve and will require mining and metallurgical operations to provide the base for new energy sources. The metals industry will therefore play a crucial role in this transition to a low-carbon world economy. Historically, Canada with its relatively small population and important mineral resources and land area has played a major role in technology and developing mineral exports of metals such as nickel and copper. Today, Canada can capitalize on the growing demand throughout the world for the critical minerals and metals required and our country has the technology and resources for a range of these metals for the renewable energy age. Technology developments for metal production processes having a lower CO_2 footprint are also required. The role of research and development for this transition are also discussed.

COM22076: Utilization of Carbon Fibers (CF) as an Alternative Reduction Agent for Slag Valorisation Processes

Ludwig Blenau, TU Bergakademie Freiberg; Manuela Wexler, Jonathan Mahl, and Werner Baumann, Karlsruhe Institute of Technology; Dieter Stapf and Alexandros Charitos, TU Bergakademie Freiberg

Abstract: We describe a method for utilizing and thereby "chemically recycling" carbon fibers (CFs) in a pyrometallurgical slag valorization process. Since the utilization of CFs as a lightweight construction material is rising, especially with windmills being decommissioned, end-of-life carbon fibers with no established recovery route will accumulate. Combustion in waste incineration plants has proven inefficient. We prove in crucible experiments on different PAN-based CF types and sizes (powder to 2 cm fibers) that CFs can be utilized energetically and as a reduction agent in fayalitic copper slag reduction. In this process, CFs are consumed while a pig iron and a secondary glassy slag phase are created. High temperatures (above 1400°C) and constant contact with reactive molten slag in a high turbulence environment (created via Ar-blowing lance) are critical for CF disintegration. Reaction kinetics are monitored by off-gas measurements of CO and CO_2. A comparison with coke is drawn. While up to 90 wt.% of fibers can be consumed in one batch, leftover CFs can be back cycled into the same process. The produced pig iron is utilizable in the steel industry and the secondary glassy slag for various glass fiber

applications. A scale-up into a high turbulence top submerged lance furnace and tests on end-of-life CF components are planned. The results shown open the way for CF use in other metallurgical reduction processes and may be a promising solution to the current CF disposal challenge.

COM22086: Utilization of Pretreated Mn-Ore in a Pilot-Scale Ferromanganese Furnace: Effect of Ore Pretreatment on Carbon and Energy Consumption

Tichaona Mukono, Norwegian University of Science and Technology; Jonas Gjøvik and Heiko Gærtner, SINTEF Industry, Metal Production and Processing; Trine Larssen, SINTEF; Maria Wallin, Norwegian University of Science and Technology; Eli Ringdalen, SINTEF; Merete Tangstad, Norwegian University of Science and Technology

Abstract: The production of high carbon ferromanganese (HC-FeMn) alloys is an energy intensive process where manganese ores are smelted in a submerged arc furnace (SAF) using carbon reductants thereby generating CO_2 emissions. In the prereduction zone of the SAF, higher manganese oxides in the ore are reduced to MnO through solid-gas exothermic reactions and at a temperature around 800 °C, the unwanted endothermic Boudouard reaction is also active. As such, the total coke and energy consumption is highly dependent on if the prereduction occurs by CO gas or solid C. Improvement of existing SAF ferromanganese process in resource and energy efficiency as well as reduction of CO_2 emission is being explored in the EU H2020 funded PreMa project. In PreMa, the considered solution is pretreatment of manganese ores in a separate unit prior to feeding it into the SAF. A successful pretreatment limits the extent of Boudouard reaction thereby reducing the carbon and energy footprint of the process. Pilot-scale experiments have been conducted at SINTEF/NTNU in a 440 kVA AC electric furnace utilizing different feed mixtures of untreated manganese ore, manganese ore preheated in air and manganese ore prereduced with solid carbon. The results include off-gas compositions, and quantities of tapped products from the pilot experiments, degree of prereduction, carbon consumption as well as overall energy consumption (kWh/t alloy) based on HSC calculations accounting mass and energy balances of the pilot experiments. This paper illustrates how use of pretreated manganese ores affect carbon and energy consumption in the production of HC-FeMn alloys in the submerged arc furnace.

Electrochemical Degradation of Multi-Component Materials

KEYNOTE

COM22169: Temperature-Dependent Oxidation of FeCoNiCrCu High-Entropy Alloy: Experimental Investigation and Density-Functional Theory Calculations

Jing Liu and Meifeng Li, University of Alberta

Abstract: Cantor high-entropy alloys (HEA, the original equiatomic FeCoNiCrMn and its derivatives), are promising structural materials for high-temperature applications, and have the potential to replace Ni-base superalloys as the next generation high-temperature materials. Among the group of Cantor HEA, FeCoNiCrCu (H5C) shows the highest valence electron concentration, which favors the presence of two separated ductile FCC phases, resulting in excellent deformability and thermal stability. In recent years, H5C has been developed broadly to extend its applications for extreme service environments such as in the nuclear, turbine, and aerospace industries, wherein a high risk of high-temperature oxidation is involved. In this work, equiatomic H5C, a dual-phase FCC HEA, is chosen as the starting model alloy to investigate the temperature-dependent oxidation behavior of Cantor HEA in ambient atmosphere through both experimental and density-functional theory (DFT) calculating approaches. It is expected to construct a common model for predicting oxide scale evolution in support of designing and validating Cantor HEAs with good and selective oxidation performance at high temperatures. Oxidation experiments of the H5C HEA were conducted at 700, 800, and 900 °C, respectively. A range of techniques, such as X-ray diffraction, scanning electron microscopy, focused ion beam and rransmission electron microscopy were used to determine the morphology, phase components, and compositions of the obtained oxidation scales. Diffusion coefficients of the principal elements in H5C as well as O were obtained through DFT calculations. Characteristic results showed that the oxide scales on H5C mainly consisted of three layers for all temperatures although the morphology and structure of the outmost layer were strongly dependent on temperature. It was found that the outmost layer in the oxide scale evolved from pure CuO to a mixture of $CuO+Cr_2O_3$ with increased temperature. Cu possessing the highest diffusion rate favored the fast formation of a pure island-shaped CuO scale from the Cu-rich FCC phase at 700 °C, which indicated a weak protective response. Cr_2O_3 grew outwards and formed a continuous $CuO+Cr_2O_3$ outmost layer when temperature gradually increased up to 900 °C, providing an improved protection from hot oxidation. Together this study suggested that the competition in oxidation activities and elemental diffusion coefficients across dual FCC phases determined the final oxide scales yielded on the H5C surface at different temperatures. In addition, mechanisms of the temperature-dependent oxidation of H5C HEA were discussed in detail from a comprehensive thermodynamics and kinetics perspective.

COM22182: A Novel Method for Analysis of Complex Oxides on Ni-Cr-Mo Alloys Using XPS and QUASES

Adam Morgan, Jeffrey Henderson, Brad Kobe, Mark Biesinger, and James Noel, The University of Western Ontario

Abstract: X-ray photoelectron spectroscopy (XPS) is widely used for studying the composition of thin oxide films, due to its extremely high surface sensitivity. The QUASES (Quantitative Analysis of Surfaces by Electron Spectroscopy) software package developed by Sven Tougaard (University of Southern Denmark) allows one to obtain additional information beyond that typically extracted from traditional XPS analysis, specifically depth and lateral distribution information that is encoded into the inelastic background signal. This presentation will demonstrate the analysis of four Ni-Cr-Mo alloys using QUASES, enhanced by a novel inelastic mean free path (IMFP) determination method. Due their high corrosion resistance, Ni-Cr-Mo alloys are often used to replace conventional materials (e.g., steels) when the exposure conditions are very aggressive. Their exceptional corrosion resistance is a consequence of the formation of a highly insoluble and unreactive surface oxide film, which provides protection to the underlying metal. The film consists primarily of CrIII oxides, and is usually on the order of a few nanometers thick; furthermore, alloying additions of Mo have been shown to increase the performance of the oxide film under conditions that can challenge the CrIII oxide. Using the QUASES software, we determined the air-formed oxide thickness on the four alloys to lie within the range of 2.5–3.6 nm and found the film to be comprised of an inner Cr_2O_3 layer and an outer $Cr(OH)_3$ layer that sandwiched a transition zone where the two coexisted. Oxidized Mo species, MoO_2 and MoO_3, were found in trace amounts in approximately the middle of the Cr-rich oxide. Auger depth profiles were employed to confirm the film thickness results obtained from QUASES modelling and showed comparable trends.

COM22119: Atomic-Scale Growth and Dissolution Kinetics of Ni-Cr Alloys

Penghao Xiao, Dalhousie

Abstract: Passivation oxide formation is the key for corrosion control of metal alloys. The kinetics of competing oxide formation and dissolution determines alloy corrosion behaviors in aqueous solution. Despite the important role of the multi-component oxide evolution, little has been known on the kinetics from the atomistic level. To this end, we have built a computational framework that enables simulations of competing kinetic processes in multi-component oxides from first principles. The effects of applied voltage, pH and temperature on oxide growth, dissolution and reprecipitation can all be captured in this model. Combining with our experimental measurements on alloy 22, we identified three voltage regimes with distinct oxide thicknesses and compositions. In the low voltage regime, oxide growth is the dominating process. The Cr/Ni ratio in the oxide is close to that in the alloy. In the medium voltage regime, Ni dissolves from the mixed oxide, NixCryO, and reprecipitates back as Ni oxide, NixO, to achieve phase separation. The resulted oxide film is significantly thickened with a duplex structure formed. In the high voltage regime, Ni dissolution dominates, and the Cr/Ni ratio increases. The temperature and pH dependencies have also been simulated. Higher temperature moves the dissolution-reprecipitation to the lower voltage; lower pH suppresses Ni reprecipitation and results in a thinner oxide film. These trends are also in agreement with the experiments.

COM22179: Corrosion in Transported Supercritical CO_2 (s- CO_2) Streams

Yimin Zeng, CanmetMATERIALS, Natural Resources Canada

Abstract: Carbon dioxide is the primary greenhouse gas which is being increasingly emitted to our ecosystem as a result of intensive human activities and needs. Carbon capture, utilization and storage technology has developed as one of the most promising pathways for still utilizing fossil fuels as reliable energy resources while significantly reducing CO_2 emission and protecting our environment. This talk will present a very general overview of CanmetMATERIALS corrosion researches in the fields of advanced oxy-fuel combustion, high temperature s- CO_2 Brayton cycles, and CO_2 conversion, and then focus on the corrosion and stress corrosion cracking of s- CO_2 transportation pipeline steels. Except for our most recent results in this area, this talk will also introduce why and how to apply electrochemical noise technique to explore corrosion mechanisms in unique s- CO_2 transportation environments.

COM22159: Corrosion of Mg Alloy AM60B Microalloyed with As

Joey Kish, Beth McNally and Dong Fu, McMaster University; Kumar Sadayappan and Amjad Javaid, Natural Resources Canada; Darren Feenstra, McMaster University

Abstract: The effect of micro-alloying AM60B (Mg-6Al-0.3Mn) with As (well-known cathodic hydrogen gas (H_2) evolution poison) on the reducing corrosion in 3.5 wt.% NaCl (aq) was determined. Custom permanent mold casting AM60B material, with and without, 0.23 wt.% micro-alloyed As were made for this purpose. Microstructure characterization was carried out using light optical microscopy and scanning electron microscopy with associated X-ray energy dispersive spectroscopy. Corrosion rates were measured using mass loss and volumetric hydrogen gas evolution measurements. Potentiodynamic polarization measurements were made to reveal the global anode and cathode kinetics. Micro-alloying with As is somewhat beneficial in reducing corrosion, but not to the extend reported for unalloyed Mg. More importantly, corrosion involves toxic arsine gas (AsH_3) evolution, in addition to H_2, consistent with thermodynamic predictions. Alternative micro-alloying routes are proposed from improved corrosion control via micro-alloying with non-toxic cathode poisons.

COM22157: Electrochemical Corrosion of Pipeline Steels Under a Thin Layer of Solution

Frank Cheng, University of Calgary

Abstract: Corrosion of metals in electrochemical in nature. Various electrochemical measurements techniques, such as potentiodynamic polarization, electrochemical impedance spectroscopy and linear polarization resistance, have been used in corrosion research, including mechanistic investigation and corrosion rate determination. For corrosion occurring in a solution layer as thin as tens microns, the conventional electrochemical techniques encounter difficulties in either experimental setup (e.g., installation of reference electrode) or avoidance of an electric field disturbance resulted from change in solution composition, corrosion product deposit and limited geometry in a solution cell. Moreover, the mass transfer and charge transfer steps in thin layers of solution are quite different from those occurring in a bulk solution. Corrosion of metals in thin layers of solution is common, which is encountered in atmospheric corrosion, corrosion under disbonded coating, corrosion under water condensate, etc. This talk will review the speaker's research in the topic conducted over the last decade, focusing on pipeline corrosion in environments associated with thin layers of electrolyte. Along with introduction of the uniqueness of corrosive environments, novel facilities and techniques including home-made microprobes, scanning Kelvin probe and Kelvin probe force microscopy are used to study the mechanistic aspect of steel corrosion in a thin layer of solution. In addition to corrosion information, topographic changes accompanying with corrosion reaction are in-situ characterized on the steel. The advanced micro- and nano-electrochemical and surface characterization techniques enable corrosion research in the thin layer of solution at a more mechanistic level.

COM22180: On-line ICP-MS in Electrocatalysis Research: Platinum Dissolution Studies

Valentin Briega Martos and Serhiy Cherevko, Forschungszentrum Jülich GmbH

Abstract: The degradation of electrocatalysts as a consequence of their dissolution in the operating conditions of fuel cells and electrolysers remains as one of the main challenges in electrochemical energy conversion. In order to investigate and predict the kinetics of dissolution of electrocatalysts in real conditions, the electrochemical on-line inductively coupled mass spectrometry (ICP-MS) technique was

developed. This approach is employed in electrocatalysis research as a tool for enabling detection of dissolved elements in the electrolyte going down to the parts-per-trillion (ppt) range, and providing at the same time multielement analysis and a wide linear dynamic range of quantification. In this way, on-line ICP-MS has been successfully applied in the investigation of several electrocatalytic reactions such as HER, OER, HOR and ORR. Amongst the different ways for connecting the ICP-MS to an electrochemical cell, the scanning flow cell coupled to the ICP-MS (SFC-ICP-MS), in which the outlet of a V-shaped SFC is directly hyphenated to the sample introduction system of ICP-MS, stands out for its ability to screen stability and high-throughput activity of gradient composition libraries. After a broad view about the applications of on-line ICP-MS carried out in our group, the present work will focus on the crucial case of Pt-based electrocatalysts dissolution. Fuel cell cars use polymer electrolyte membrane fuel cells with Pt nanoparticles for ORR at the cathode, primarily because of their better long-term stability in comparison to other electrocatalysts. However, even pure Pt catalysts degrade under real-life conditions, and this degradation is mainly linked to electro-oxidation and dissolution processes. Polycrystalline platinum dissolution was studied in both acidic and alkaline media by SFC-ICP-MS, and it was observed that the oxidation and subsequent reduction of the surface lead to transient dissolution, which is higher by a factor of two in base. More recently, investigations with Pt single crystal electrodes have been carried out, which offer the possibility of a more detailed understanding of these processes at the atomic level. These works combine the results from on-line ICP-MS and in situ surface X-ray diffraction (SXRD), and they have shown for example differences in the onset potential for anodic dissolution on Pt(100) and Pt(111) that have their origin in the different atomic structures of the initial oxide. The knowledge obtained from model bulk electrodes can be used for the understanding of Pt dissolution from nanostructured electrodes, both in half-cell aqueous electrolyte and fuel cell environment.

COM22165: Studying Corrosion Using Scanning Electrochemical Probe Methods

Samantha Gateman, The University of Western Ontario

Abstract: The microstructure of metals and alloys is far from homogeneous, where features including precipitates/inclusions, crystallographic orientation, and grain boundaries are present on the micro/nano scale. Many corrosion failures are due to dangerous localized corrosion mechanisms that initiate at such features, which are difficult to predict and quantify before detrimental damage has occurred. Scanning electrochemical probe methods (SEPMs) can be used explore the influence of microscale features on corrosion initiation mechanisms for innovative materials used in biomedical implants, corrosion barrier coatings, additive manufactured alloys, and thermal spray coatings. SEPMs involve scanning a miniature probe along the substrate's surface while measuring a local electrochemical response. Tailoring the probe (micro-electrode or pipette) allows different techniques to be employed, which gives these methods maximum versatility and flexibility. This talk aims to promote the use of SEPMs in corrosion and metallurgy by exploring two cases where SEPMs were utilized to study corrosion behaviours of various metallic materials. Scanning electrochemical microscopy will be first introduced, where local fluxes were monitored at the tip of a microelectrode to show that Ti-rich inclusions in ferritic stainless steels act as local hotspots where localized corrosion can initiate. The second SEPM presented will be the scanning micropipette contact method, which was used to directly measure local electrochemical corrosion along the chemical concentration gradient of an Al-Mg diffusion couple. The future of SEPMs in corrosion science will be discussed, including assisting in designing future material generations to minimize degradation and accelerate new Canadian corrosion mitigating technologies.

COM22160: Studying Stress Corrosion Cracking Mechanisms Using Novel Nanoscale Characterization

Suraj Persaud, Queen's University

Abstract: Stress corrosion cracking (SCC) is an insidious form of degradation which is of concern for structural materials across several industries. SCC requires the synergistic contribution of a corrosive environment, a susceptible material, and a tensile or residual stress. Thus, SCC is dependent on numerous variables and inherently multi-disciplinary in nature. Several SCC mechanisms have been proposed across different material-environment systems where the phenomenon is known to occur. However, due to its complexity, conclusive evidence for SCC mechanisms remains mostly elusive, apart from some model systems. For example, SCC is known to occur in Fe-based alloys when exposed in laboratory experiments to environments simulating the extreme end of conditions in heat-transfer crevices in nuclear power systems. There are several SCC modes and mechanisms in this complex environment driven by pH, which can vary from acidic to alkaline, and the impurities present, such as Pb, Cl, or S species. This research will review recent progress made in understanding the mechanisms of SCC in Fe-based alloys exposed to the mentioned nuclear-relevant environments. The approach involves the application of novel nanoscale microscopy techniques to characterize SCC from the mechanical, metallurgical, and (electro)chemical perspectives. It is demonstrated that by combining multiple, carefully selected, electron microscopy and surface science techniques previously unclear SCC mechanisms may be discernible. Specifically, for Fe-based alloys, dealloying (selective dissolution) plays a substantial role in SCC initiation in alkaline solutions, where as a film rupture mechanism may be operating in acidic solutions when S is present. SCC is an insidious form of degradation which is of concern for structural materials across several industries. SCC requires the synergistic contribution of a corrosive environment, a susceptible material, and a tensile or residual stress. Thus, SCC is dependent on numerous variables and inherently multi-disciplinary in nature. Several SCC mechanisms have been proposed across different material-environment systems where the phenomenon is known to occur. However, due to its complexity, conclusive evidence for SCC mechanisms remains mostly elusive, apart from some model systems. For example, SCC is known to occur in Fe-based alloys when exposed in laboratory experiments to environments simulating the extreme end of conditions in heat-transfer crevices in nuclear power systems. There are several SCC modes and mechanisms in this complex environment driven by pH, which can vary from acidic to alkaline, and the impurities present, such as Pb, Cl, or S species. This research will review recent progress made in understanding the mechanisms of SCC in Fe-based alloys exposed to the mentioned nuclear-relevant environments. The approach involves the application of novel nanoscale microscopy techniques to characterize SCC from the mechanical, metallurgical, and (electro)chemical perspectives. It is demonstrated that by combining multiple, carefully selected, electron microscopy and surface science techniques previously unclear SCC mechanisms may be discernible. Specifically, for Fe-based alloys, dealloying (selective dissolution) plays a substantial role in SCC initiation in alkaline solutions, where as a film rupture mechanism may be operating in acidic solutions when S is present.

Energy and Environmental Materials

COM22062: Adsorption of Naphthenic Acids from Oil Sand Process-Affected Water (OSPW) Using Commercially-Viable Petcoke-Sourced Activated Carbon

Elmira Nazari, Tyler Roy, and Andrew Vreugdenhil, Trent University

Abstract: The oil sands deposits of Northern Alberta, Canada are estimated to constitute the world's largest bitumen reserve, containing approximately 1.7 trillion barrels of bitumen. The bitumen extraction procedures produce large volumes of slurry wastes contaminated with naphthenic acids (NAs). Because of a zero-discharge policy, the oil sands companies currently do not release any extraction wastes from their leases. The resulting oil sands process-affected waters (OSPW) contaminated with NAs are contained onsite primarily in large settling ponds. These fluid wastes from the tailings ponds can be acutely and chronically toxic to aquatic organisms, and NAs have been associated with this toxicity. Commercially viable activated carbon adsorbents synthesized from petroleum coke wastes from the oil sands extraction process are an appealing means of reducing NA concentrations in OSPW. To better understand the factors affecting specific classes of NA adsorption, seven individual naphthenic acids were selected for investigation using various adsorbents such as KOH activated carbon, commercial activated carbon, and phosphoric acid activated carbon. The NAs investigated were: 2-methyl-1-cyclohexanecarboxylic acid, diphenylacetic acid, dicyclohexylacetic acid, cyclohexane acetic acid, 1,4-cyclohexanedicarboxylic acid, succinic acid, and heptanoic acid. The kinetics of adsorption and adsorption isotherms (Langmuir, Freundlich, and Redlich-Peterson) were investigated for these naphthenic acids to evaluate the order of adsorption capacities after 48 hours among these NAs and to evaluate the impact of surface chemistry and morphology of the activated carbons on NA adsorption. The order of adsorption is as follows: diphenylacetic and dicyclohexylacetic acid have the highest adsorption extent among other compounds and in contrast, 1,4-cyclohexanedicarboxylic acid and succinic acid show the lowest adsorption capacity consistently. The removal of NAs at pH 8 using 0.01 M phosphate buffer was evaluated comparing the total organic carbon and electrospray ionization mass spectroscopy of the solution before and after the adsorption process. Investigation of the adsorption isotherms and kinetics demonstrate that NA adsorption is heavily influenced by surface area, pore size distribution, and chemical functionality. Comprehensive control of these features for all activated carbon substrates is essential for optimizing NA uptake.

COM22088: Adsorption Thermodynamics of Model Naphthenic Acids for Determining Uptake Mechanisms on Commercially-viable Petroleum Coke Sourced Activated Carbon

Tyler Roy and Andrew Vreugdenhil, Trent University

Abstract: Naphthenic acids (NAs) are a broad classification of organic acid contaminants commonly found in oil sands process affected water (OSPW) in Alberta, Canada and thought to be predominantly responsible for the high toxicity impeding the release of tailings ponds water (Brown, 2015). A promising remediation strategy for OSPW has involved the use of commercially viable petcoke sourced activated carbon (PAC). The optimization of PAC requires a detailed characterisation of the adsorption system containing NAs, including an understanding of the adsorption mechanism. Here we present an investigation of three model NA species: diphenyl acetic acid, cyclohexane acetic acid, and heptanoic acid. To elucidate the mechanism of adsorption, a thermodynamic approach was taken, which involved the studying of adsorption isotherms over a range of temperatures to determine an approximate energy of

adsorption for each model NA. Kinetic modelling of adsorption data was also explored to further characterize the adsorption of the model NAs. The understanding of how the adsorption of these contaminants occurs within PAC will help us further improve the use of activated carbon for remediating OSPW.

COM22063: Crystallization of Nanoscale Garnet-Type Li-Ion Conductors for All-Solid-State Batteries (ASSBs)

Senhao Wang and George Demopoulos, McGill University

Abstract: Al-doped garnet-type Li-ion conductors are among the most promising ceramic electrolytes for all-solid-state Li-ion batteries (ASSBs). The synthesis and processing of garnet-type fast Li-ion conductors depend on conventional sol-gel and solid-state syntheses and sintering is usually done at temperatures above 1100 °C to reach the high Li-ion conducting cubic phase. This process results in micron-sized particles and potential Li-loss, which are unfavorable for further processing and electrode-electrolyte assembly. Here, we tackle this problem and report a novel low-temperature synthesis-processing route to stabilize the cubic phase of $Li_{6.1}Al_{0.3}La_3Zr_2O_{12}$ (Al-LLZO), while keeping the nanocrystallites at ~100–200 nm. Cubic $Li_7La_3Zr_2O_{12}$ (c-LLZO) phases are obtained at temperatures as low as 600 °C by reactive calcination of an aqueous co-precipitated metal hydroxide intermediate of controlled crystal orientation. After extensive characterization, a two-reaction phase transformation mechanism is proposed to explain the evolution of c-LLZO crystallization at 600 °C from a morphological and structural point of view. The low-T synthesized nanostructured (~29 nm grain size) LLZO is found to be at par in terms of ionic conductivity after only one step pellet compaction and sintering, compared to multiple and longer high-T sintering duration steps LLZO prepared by benchmark wet or solid-state reaction methods. This new nanoscale Al-LLZO garnet material is particularly attractive in promoting compatibility between cathode materials and solid electrolytes for ASSBs.

COM22153: Economic Analysis of Electrolytic Treatment of Waste Cyanide

Jacob Schmidt and Eduard Guerra, Laurentian University

Abstract: An economic analysis of the viability of electrolytic oxidation of cyanide on 304 stainless steel electrodes with parallel plate geometry for waste gold effluent versus the SO_2-air process is presented. Both total replacement of the INCO SO_2-air process and applying electrolysis prior to applying INCO SO_2-air are studied. The analysis was performed for an applied current density of 20 A/m^2 in the presence of copper ions at pH 10, which previous experiments establish as a likely in the mass transfer limiting regime for cyanide oxidation and reasonably fit using a pseudo-first order decay model. The optimal electrolysis plant size is estimated through comparing the internal rate of return over 20 year projects and payback period of required estimations of capital costs. Total replacement of INCO SO_2-air is found to be economically unviable, while partial replacement is found to be potentially viable, though with a large payback period.

COM22110: Enhanced Strength and Electrical Conductivity of Al-Mg-Si Conductor Alloys by Adding Ag and Cu and Applying Preaging

Siamak Nikzad Khangholi, Mousa Javidani, X. -Grant Chen, and Alexandre Maltais, Université du Québec à Chicoutimi

Abstract: The behaviors of strength and electrical conductivity of the Al-Mg-Si conductor alloys were studied by adding Ag and Cu and applying the preaging. In the conventional thermomechanical treatment (solution treatment, quenching, cold wire drawing followed by aging), the impact of the Ag and Cu additions on the strength of Al-Mg-Si conductor alloys was to some extent counteracted. The results indicated that the conventional thermomechanical treatment led to a less positive impact of the Ag and Cu additions on the strengthening. However, modifying the thermomechanical treatment (preaging at 120 °C prior to cold wire drawing) resulted in maximizing the efficiency of Ag and Cu additions on the strengthening above the minimum required electrical conductivity (52.5% IACS). The precipitation of the alloys under different thermomechanical treatments was characterized and quantified using the transmission electron microscopy. The results revealed that the higher number densities of the strengthening precipitates were acquired for Ag-/Cu-added alloys in the modified thermomechanical treatment compared to the conventional thermomechanical treatment.

COM22079: Resin Technologies to Improve Battery Metal Recovery

Jeffrey Sehn and Mike Weatherill, Purolite LLC

Abstract: The emerging electric vehicle industry has resulted in an increased demand for metals used in the production of batteries, most notably nickel, cobalt and lithium. These minerals need to be recovered, either extracted as ores and from recycled battery materials. When the ore is recovered, ion exchange resins are used to extract metals to a lower level than with conventional methods. Ion exchange resins can be used in lithium brine purification to reduce impurities down to certain levels. In conventional precipitation and solvent-extraction, methods are not always able to produce liquors of the desired purity. Ion-exchange resins are highly suitable for the task. The mandate from battery producers is for metal salts of high purity, with the majority of impurities extracted from the liquors. When higher purity is required for final products, specialty resins are available to improve contaminant extraction or material isolation. In cases where ion-exchange resins lack the appropriate selectivity for certain target impurities, but solvents do exist, such as impurities in cobalt or nickel sulphates, solvent-impregnated resins have been developed that combines the selectivity of the solvents with the ease of engineering of ion-exchange resins. This paper discusses the application of specialty tailored resins for impurity separation throughout the metal recovery process.

COM22036: Solvent Controlled Association of Natural Polyaromatic Molecules on Silicon Nanoparticles as High-Performance Lithium-Ion Battery Anodes

Wen Tan, Shenzhen Key Laboratory of Interfacial Science and Engineering of Materials, Southern University of Science and Technology; Zhouguang Lu and Zhenghe Xu, University of Alberta

Abstract: Carbon coating is one of the most common methods to improve the performance of Li-ion batteries, especially for materials such as silicon with poor electronic conductivity and large volume changes during cycling. The ideal carbon coating layer should have improved mechanical properties to maintain its structure during the repetitive volume change of Si so as to prevent the direct contact between Si and the electrolyte during cycles. In this work, a scalable and low-cost synthesis method is

proposed to deposit a high-elastic fullerene-like protective carbon layer on silicon nanoparticles by molecular-level controlled association of natural polyaromatic molecules in heavy oil. The fullerene-like carbon layer is shown to recover by > 90% after deformation, which ensures the structural stability of the carbon coatings during cycling. Fullerene-like carbon coated silicon nanoparticles exhibits a high cycle stability with a reversible capacity of 1230 mAh g^{-1} and a capacity retention of 94.6% after 600 cycles at 1 C. The fullerene-like carbon coating can be further applied to improve the electrochemical performance of SiO microparticles, showing a capacity of 970 mAh g^{-1} and capacity retention of 77.5% after 300 cycles in full cell test. These results demonstrate the great commercial value of this synthesis method in producing anode materials of high-performance lithium-ion batteries.

Light Metals for the Transportation Industry

KEYNOTE
COM22176: Microstructural study of containerless solidification of Al-20wt%Ce

Hani Henein, Akankshya Sahoo, and Jonas Valloton, University of Alberta

Abstract: Aluminum alloys are heavily used within the transportation sector due to their excellent mechanical properties, high strength to weight ratio, corrosion resistance and high thermal conductivity. Cerium containing aluminum alloys have become a focus of interest for high temperature alloys. Al-Ce based alloys consist primarily of fcc aluminum and $Al_{11}Ce_3$ intermetallic. Due to the near zero solubility of cerium in fcc aluminum (less than 50 ppm at the eutectic temperature), the strengthening $Al_{11}Ce_3$ intermetallic is very stable against high temperature dissolution. Furthermore, while Cerium is the most abundant of the rare earth elements, it has yet to have any substantial high-volume use. It currently remains relatively inexpensive as an alloying element. In this work, containerless solidification of hypereutectic Al-20wt%Ce is carried out using ElectroMagnetic Levitation and Impulse Atomization. The effects of rapid solidification on the microstructures are analyzed using neutron diffraction, X-ray and electron microscopy and Electron Backscattered Diffraction.

KEYNOTE
COM22008: Titanium – From Ore Extraction and Processing to its Applications in the Transportation Industry

Carsten Siemers and Fabian Haase, Institute for Materials Science, Technische Universität Braunschweig

Abstract: Titanium alloys combine outstanding mechanical properties with excellent corrosion resistance that make them desirable for challenging light-weight constructions in the transportation industry like fuselage frames or aircraft engine components. On the other hand, titanium production is energy-consuming and expensive, since the current method of extraction of titanium from the ores includes smelting, chlorination and reduction by magnesium (Kroll's process). Hence, cost-reduction is one of the main driving factors for titanium research to broaden its field of application. In this overview presentation, the conventional production route from titanium ore to semi-finished products and components is presented. This includes ore winning and processing, melting and remelting for ingot production, forging, casting, machining of (semi-finished) products and scrap recycling, all of which are discussed through several examples. Additive manufacturing (AM) processes, such as powder-bed fusion (PBF), can help to increase titanium usage, since even complicated geometries can be directly produced without much material loss. On the other hand, rapid cooling and directional solidification result in anisotropic properties and martensitic or lamellar microstructures of the AM parts. In addition, defects like pores are always present in the as printed condition, which have a detrimental impact on the mechanical properties. These defects can only slightly be reduced by using a dedicated building strategy or by post-processing. The state-of-the-art in powder bed fusion and selected research activities are also discussed in this presentation.

COM22051: A Novel Experimental Set-Up for Generating Microbubbles for Removal of Inclusions

Ajay Panicker, Dengyang Lu, and Rohit Tiwari, Luis Calzado, Mihaiela Isac, and Roderick Guthrie, McGill University

Abstract: The empirical relations that govern multiphase interactions between microbubbles and inclusions indicate a strong dependence between bubble size and overall inclusion capture efficacy. Established probability models highlight the need for bubbles less than 1 mm in diameter for optimal inclusion capture. To achieve bubbles in this size regime, tangential shearing flows and turbulence can be used to facilitate bubble formation and fragmentation. A novel set-up consisting of nozzles submerged within a melt or an aqueous bath analog has been designed, manufactured, and operated, to test the bubble sizes produced for different speeds of rotation and effluent gas flowrates. Increasing gas flow rates lead to larger bubbles whereas larger RPMs lead to much smaller bubble sizes. Bubbles are captured through high-speed digital photography and then analyzed using ImageJ postprocessing software. All experiments were conducted in an aqueous medium.

COM22100: A Study on Aluminum-Based Lightweight Entropic Alloys with High Strength at Elevated Temperature

Liying Cui, Zhan Zhang, Dilip Sarkar, Duygu Kocaefe, and X. -Grant Chen, Université du Québec à Chicoutimi

Abstract: Entropic alloys are a category of emerging advanced materials derived from the novel design concept of high-entropy alloys, which are also known as multicomponent alloys or complex concentrated alloys. In this study, two Al-based lightweight entropic alloys, $Al_{74}Cu_{16}Cr_1Zn_7Mg_2$ and $Al_{78}Cu_{18}Cr_2Zn_1V_1$, were designed using a strategy based on physical thermodynamic parameters and Thermo-Calc simulations. The microstructures of the as-cast alloys revealed a multiphase feature, including fcc-Al solid solution and several intermetallic compounds. The maximum compressive fracture strengths at 20 °C of both alloys exceeded 620 MPa, while the compressive yield strengths at 300 °C were found to be >200 MPa; these values are two to three times higher than those of conventional Al alloys. The strengthening mechanism was mainly arising from solid solution hardening and intermetallic network hardening. During the thermal exposure at 300 °C for 100 h, a phase transformation occurred in the $Al_{74}Cu_{16}Cr_1Zn_7Mg_2$ alloy, which deteriorated the yield strength at 300 °C. In contrast, the $Al_{78}Cu_{18}Cr_2Zn_1V_1$ alloy exhibited a barely changed yield strength at 300 °C with a value of as high as 201 MPa after the thermal exposure, indicating its excellent thermal stability and great potential for high temperature applications.

COM22046: Aluminum Auxetic Structures Produced Using Combined Stereolithography and Investment Casting

Nicholas Alfano, Hari Simha, andAbdallah Elsayed, University of Guelph

Abstract: Investment casting is a process to which samples with high complexity, surface finish, and mechanical properties are yielded desirable for many applications. Additive manufacturing processes that rely on powder bed fusion and direct energy deposition offer high design freedom but require high capital equipment. This study combines additive manufacturing through the utilization of a stereolithography 3D printer and investment casting to produce complex geometry, lightweight structures for transportation applications. Investment cast 319 aluminum alloy with various investment mold temperatures, pouring temperatures and vacuum levels was used to produce open celled, non-stochastic auxetic structures. The aluminum auxetic castings that were produced using higher vacuum levels and higher investment mold temperatures had fewer filling defects and were best able to replicate the stereolithography model.

Increasing pouring temperature had minimal influence on filling capacity. The higher vacuum level castings also had higher mechanical properties due to a reduction of filling defects and the finer microstructure from higher cooling rates during filling and solidification. The resulting aluminum auxetic structures and their production route offer an accessible method to produce high integrity, highly complex castings for transportation applications.

COM22066: Asymmetrical Rolling of Aluminium Alloy 6061

Julie Lévesque and Alexandra Béland, Quebec Metallurgy Center

Abstract: Aluminium alloy 6061 in sheet form is interesting for automotive applications because of its good mechanical properties. However, its use is limited by a low formability when compared to steel sheets developed for the same applications. Asymmetrical rolling can improve the microstructure and texture of sheets, leading to a better formability. In this work, sheets have been produced by different processing routes, including cross rolling and asymmetrical rolling. The effect of these processes on the microstructure, properties and formability of aluminium alloy sheets has been studied and will be discussed.

COM22073: Castability and Thermal/Electrical Conductivity of Al-Fe-Ni Alloys

Stephanie Kotiadis and Abdallah Elsayed, University of Guelph

Abstract: The modern demands of electric and hybrid vehicles have required modern aluminum alloys that demonstrate high castability, electrical and thermal conductivity, and moderate strength. The use of transition metals Fe and Ni present potential alloy additions to meet these goals due to their low solubility in solid Al (0.04 wt.%) and the potential of their intermetallic phases to be modified. Permanent steel mold castings and the Weidman-Franz Law were used to establish the electrical and thermal conductivity, hot tear susceptibility, and strength properties. The alloy compositions of Al-(0.8–1.2) Fe-(0.2–0.6) Ni and varying amounts of Si and Mg have shown promising results with an electrical conductivity of more than 45 IACS% and hot tear susceptibility similar to that of Al 319, a common casting alloy. Castability was further assessed by determining the die soldering behaviour of various Al-Fe-Ni alloys using pure iron wire submerged in a liquid melt. The potential for Al alloys that take advantage of the low Al-Fe eutectic (1.8 wt.) have shown high castability through hot tear susceptibility and die soldering, high conductivity, and moderate strength. These properties speak to the industrial applicability of this range of alloy compositions for use in hybrid and electric vehicles, aerospace, and technological components such as heat sinks.

COM22189: Characterization of the Microstructure of Al, Mg and Ti Alloys with State-of-the-Art Electron Microscopy

Raynald Gauvin, Nicolas Brodusch, and Stephanie Bessette, McGill University

Abstract: The development of light metals, like Al, Mg and Ti alloys, for the transportation industry relies on controlling the size, distribution, and volume fraction of nano-sized precipitated to improve their mechanical properties. These mechanical properties and corrosion resistance are also related to the size and texture of the grains of these alloys, among other factors. Electron microscopy is a key technique to perform such characterization and this work will present state of the art results with field emission low voltage scanning electron microscopy with EDS and EBSD and with scanning transmission electron

microscopy at 30 keV with a unique electron microscope that has a 0.15 nm spatial resolution with EDS and EELS capabilities. Three-dimensional electron microscopy imaging of these alloys will be presented with 3D BSE, EDS and EBSD maps acquired with a state of the art three column focus ion beam.

COM22168: Cr-Oxide – Why Should You Have It in Your Refractories?

Dean Gregurek, Philip Schantl, Jürgen Schmidl, and Alfred Spanring, RHI Magnesita GmbH

Abstract: Chromium-oxide is one of the oxides within chromite (Fe^{2+}, Mg^{2+})(Cr^{3+}, Al^{3+}, Fe^{3+})$_2O_4$ that belongs to the spinel group of minerals. It is an important strategic raw material particularly in the production of refractories, widely used in non-ferrous metal vessels. In the non-ferrous furnaces (e.g. copper, nickel, lead) the refractory linings are subjected to either continuous wear by hot erosion or discontinues wear caused due to batch-wise processes and frequent thermal shocks. The refractory wear will begin usually by weakening of the brick microstructure after infiltration by foreign substances (e.g. slag, sulphate, matte, copper/lead, etc.) and corrosion of the brick inherent components. The continuous wear is caused by corrosion of refractory due to diffusion-controlled dissolution in slag or by hot erosion, triggered by fluid motion at the interface between refractory and slag. The main advantage of the chromite within the magnesia-chromite bricks is high corrosion resistance against acidic slags (e.g. fayalite slag). The lower chromite solubility in such a slag can be explained by phase diagrams (i.e., miscibility gap between chromium and silica in the Cr_2O_3-SiO_2 phase diagram) and FactSageTM calculations. In comparison to the fayalite slag, the contact with calcium-ferrite slag led to a much higher infiltration depth and corrosion of the magnesia but also of chromite. The additional chemical wear parameter in the non-ferrous metals production is refractory exposure to chemical attack by sulfate. Hereby, chromite shows a higher corrosion resistance than magnesia and thus prevent chemical attack and continuous mass loss by dissolution.

COM22024: Development of Fe-Based Metallic Glass Coating on Mg Alloys by Cold Spray

Gbenga Asala and Oyedele T. Ola, Technology Access Centre for Aerospace and Manufacturing, RRC Polytech; Olanrewaju Ojo, University of Manitoba

Abstract: Magnesium alloys (Mg-alloys) are an attractive class of materials for structural engineering applications in the defence and transportation sectors due to their unique properties, including low-density and high specific strength. Unfortunately, their adoption has been limited due to these alloys' inherent poor corrosion and wear resistance. One of the successful methods to mitigate some of these limitations is applying a high-dense, well-adhered protective coating layer to the alloy. Metallic glass (MG) is a unique set of amorphous materials that possess excellent corrosion and favourable mechanical properties, including high hardness, toughness and good wear resistance. It has shown the potential to be applied as a protective coating on several substrate materials. However, metallic glass materials are temperature sensitive, so producing dense coatings that retain the materials' amorphous structure and avoid the formation of process-related defects such as oxidation by using conventional thermal coating techniques is challenging. In this work, developmental coating of Fe-based MG was deposited on Mg ZE41A alloy using cold spray – a solid-state materials deposition process. The influence of the cold spray deposition parameters on the physical, microstructural and mechanical properties of the coating is evaluated.

COM22155: Development of LiMCA (Liquid Metal Cleanliness Analyser) Since its Invention to Date

Giacomo Daniel Di Silvestro, Rohit Tiwari, Mihaiela Isac, and Roderick Guthrie, McGill University

Abstract: Non-metallic inclusions less than 50µm, are those that impact steel quality the most. These deleterious inclusions are difficult to be monitored, and more difficult to be removed during steel processing. One method to monitor such inclusions, is LiMCA (Liquid Metal Cleanliness Analyser). Its development since its inception to date will be reviewed. This will include the successful contributions of McGill Metals Processing Centre, Alcan, Bomem, and ABB to the development of LiMCA for the detection of inclusions in aluminum, magnesium, or copper melts, as well as the contribution of Heraeus Electro-Nite LiMCA ESZPas in the detection and monitoring inclusions in steel.

COM22095: Experimental and Numerical Study of 3003-H14 Aluminum Alloy Welded Joints with Different Clamping Conditions

Maribel Hernández, Ricardo Ambriz, Christian J. García, César Mendoza, and David Jaramillo, Instituto Politécnico Nacional

Abstract: Arc welding processes are largely used in the industry, but it is well known that several physical phenomena induced by the electric arc induced a lost of strength for the welded material. However, it is not as clear how to control the physical phenomena to avoid the lost of strength. The present work analyzes thermal and mechanical processes induced by GMAW welded joints of work hardened Al alloy 3003-H14. Restricted and unrestricted clamping conditions were used during welding, in conjunction with a customized measurement system for the welding temperature. Post-welding residual stresses were measured with the hole drilling method. In addition, an ANSYS FE model was developed, where a moving double ellipse heat source was implemented to capture the temperature distribution induced by the welding simulation. Residual stresses were resolved by the FE model by coupling the thermal analysis with a structural one. A temperature error of less than 10% was obtained between the experimental measurements and FE results. In the case of the residual stresses, the best correlation between the experimental and numerical results were for the longitudinal component in the unrestricted condition with a maximum root mean square error (RMSE) of 1.95 MPa. The maximum RMSE in the transverse component was for the restricted condition with a value of 22.74 MPa. In general, a good correlation was observed between the FE model and the experimental measurements.

COM22050: High Strength, Low-Modulus Nanostructured Ti 13Nb 13Zr Alloy

Lina Klinge, Carsten Siemers, and Clemens Jahnke, Institute for Materials Science, Technische Universität Braunschweig

Abstract: High strength nanostructured titanium alloys with a low Young's modulus play a key role in biomedical applications, especially in the field of dentistry. On the one hand, the high strength avoids implant and abutment breakage and on the other hand, the low Young's modulus improves the growth of bone cells as stress shielding is diminished. Furthermore, the nanostructured implant surface also improves the adherence of bone cells and additionally reduces the colonization of bacteria which in turn reduces the occurrence of the so called periimplantitis. Periimplantitis is a disease which in the worst case can lead to the loosening and loss of the implant. By using the Ti 13Nb 13Zr (TNZ) alloy these risks can be minimized. TNZ is a second-generation biomedical β-rich (α+β)-titanium alloy with an improved biocompatibility as critical alloying elements such as aluminum and vanadium are not present. In addition, the corrosion resistance is improved compared to the standard Ti 6Al 4V alloy used for implants.

Nanostructured materials can be produced through Severe Plastic Deformation (SPD) processes like Equal Channel Angular Pressing (ECAP) which was used for this study. To strengthen the material and to regain a sufficient elongation at fracture to fulfill the requirements of related medical standards, the material must be recrystallized (short-time heat-treatments) and precipitation hardened after the forming process. Thereby, different phase constitutions, namely α- and β-phase as well as α''-martensite, can be used to optimize the Young's modulus and the mechanical properties. The studied effects should be transferrable to other β-rich (α+β)-titanium alloys like Ti 6Al 2Sn 4Zr 6Mo which is applied in aircraft engines so that the thermo-mechanical treatment strategies presented here are of interest in other fields of application as well, e.g. in the transportation industry.

COM22020: HSBC Back-Meniscus Stability for a Double Impingement Liquid Metal Feeding System

Daniel Gonzalez-Morales, Mihaiela Isac, and Roderick Guthrie, McGill University

Abstract: Metallurgically, financially, and environmentally, Horizontal Single Belt Casting (HSBC) enjoys several advantages over traditional Continuous Casting and Direct Chill casting methods for producing thin strips of aluminium alloys. Nonetheless, "back meniscus" stability is a critical factor for obtaining good quality cast strips. In the present work, the effects of air gap dimensions, and belt speeds, on the stability of the "back meniscus" has been studied for a double-impingement metal feeding system for a AA2024 aluminum alloy. Using the Computational Fluid Dynamics software ANSYS-Fluent 19.1, various combinations of these process parameters were tested, to obtain optimum results for promoting "back meniscus" stability. Additionally, the effect of these parameters on other phenomena e.g., air entrainment and heat transfer, is assessed. A new feeding system, without "free stream fall" is proposed, and for this case the effect on the "back meniscus" stability is also analyzed.

COM22031: Microstructure and Texture in Additively Manufactured Maraging Steel Lattice Structures

Farzad Khodabakhshi, University of New Brunswick

Abstract: Cellular lattice structures additively manufactured using the laser powder bed fusion technique was considered in this study. In this case, a body-centered cubic design was deposited using maraging steel powder. The diagonal cross-section of the cellular lattice was considered to characterize the microstructural details. Electron backscattering diffraction analysis revealed the microstructural evolutions and crystallographic texture across the struts and junctions depending on the lattice geometry. The progression of martensitic phase transformation in the material upon layer-by-layer process was studied tracking the fraction of austenite and martensite phases.

COM22191: Natural Ageing of Al-Fe (Zn,Mg) Alloy Castings for Structural Automotive Application

Chimaobi Orji, McMaster University; Anthony Lombardi and Glenn Byczynski, Nemak USA/Canada; Mohamed Hamed and Sumanth Shankar, McMaster University

Abstract: Novel Al-Fe based eutectic alloys with Zn and Mg as precipitation strengtheners were used in the manufacturing of test plates using high vacuum high pressure die casting process; to evaluate the feasibility of manufacturing structural automotive components with a higher strength to weight ratio than the present. Natural ageing at room temperature is a typical behaviour of this new alloy due to the continuous precipitation reactions of the Zn and Mg atoms dissolved in the primary solid Al phase in the microstructure. The sequential stages of precipitation include, formation of self clusters of atoms,

dissolution of self clusters, formation of GP1 zones, dissolution of GP1 zones, formation of GP2 zones and stabilization of GP2 zones; all these stages distinctly affect the tensile properties.Uniaxial tensile tests of castings coupled with the Differential Scanning Calorimetry experiments were carried out to elaborate the mechanisms of natural ageing in these alloys. The results show that the elongation of the castings seems to be unaffected during natural ageing and the strength increases to almost its double, with time, before stabilization. The properties of as-cast and stabilized state were significantly improved when compared to the contemporary Al-Si-Mg alloy such as the Aural 5.

COM22096: Out of Plane Bending Assessment of Heat-Treated Aluminum Alloys Subjected to Free-Fall Impact Loads

Alvaro Frutos, Edu R. Barragán, Ricardo Ambriz, Christian J. García, César Mendoza, David Jaramillo, Instituto Politécnico Nacional

Abstract: A property impact drop tower was used to study impact loads. The tower has a capacity to apply impact loads of up to 1600 J with a maximum velocity of 10 m/s. It was used in this work to compare the out of plane bending behavior between 6061-T651 and 7075-T651 aluminum alloys. Plate-type coupons of 6.35 mm thick were used with a square shape of 300 mm-side. Low, medium, and high energies were used in the impact tests. Coupons were fully clamped during the impact tests. The impact drop tower was instrumented, so that the impact absorbed energy was analyzed in terms of force-time and force-displacement curves. The induced damage in the plates was also analyzed in terms of out of plane bending displacement and crack length evaluation. In addition, a FE model was developed to simulate the impact tests and resolve the absorbed energy by the aluminum plates during the impact loads. In spite that 7075-T651 Al alloy poses a larger strength than 6061-T651 under conventional tensile loading test, this work reveals that 7075-T651 aluminum alloy exhibited a lower capacity to absorb energy under out plane bending impact. FE results of absorbed energy presented a good correlation with experiments, specially for low and medium impact energies.

COM22141: Prediction of Hot Tearing in the AA6111 Alloy during DC Casting of Flat Ingots

Hamid Khalilpoor and Daniel Larouche, Université Laval; X. -Grant Chen, University of Quebec at Chicoutimi; Josee Colbert, Arvida Research and Development Centre, Rio Tinto Aluminum

Abstract: Hot tearing is caused by thermally induced stresses and strains in the last stage of solidification when the solid fraction is close to one. Flat ingots of AA6111 alloy with a rectangular cross-section were produced in the Rio-Tinto experimental facilities using two different cooling conditions at the start-up, one giving sound ingots and another producing hot tearing on the surface. Characterization of the alloy and thermomechanical modeling of the DC casting process with ABAQUS linked with FORTRAN was achieved to understand the formation of hot tearing via the stress-strain evolution in the ingots during solidification. The thermomechanical behavior of the alloys was calculated by taking into consideration the solidification path and the microstructure of the alloy. Finally, the pressure drop in the interdendritic liquid phase was calculated to evaluate the potential correlation between the location of actual hot tears and the pressure drop.

COM22188: Processing, Properties and Applications of Lightweight Al and Mg Alloys for Next Generation Vehicles

Payam Emadi, Bernoulli Andilab, Belcastro Adam, and Comondore Ravindran, Ryerson University

Abstract: The future of materials engineering will be focused on environmental sustainability. Improvements in material processing and properties have the potential to reduce greenhouse gas emissions. With the ongoing accelerated development of next generation vehicles, lightweighting of components must be promoted, property enhancement becomes critical and sustainability challenges will need to be addressed. At the Center for Near-net-shape processing of materials, our research is focused on the future of automotive light metal casting. The current article summarizes our recent progress towards improving the properties of cast magnesium and aluminum alloys in the fields of alloying, grain refinement, thermal conductivity enhancement, melt cleanliness and processing using modern techniques. Examples of our present research as well as a glimpse of the rapidly evolving outlook of the materials science field will be presented.

COM22137: Rapid Solidification of 2XXX Aluminium Alloys

Julien Zollinger, Victor Moudin, and Jean-Philippe Tinnes, Institut Jean Lamour - Université de Lorraine

Abstract: Laser welding of aluminium alloys in one of the hindrance to promote them to greater use in the automotive industry. One cause is that such alloys easily exhibithot cracking during solidification, due to a combination of columnar dendritic growth, solidification path and stress induce by the high temperature gradient in laser processing. In this paper, a rapid solid solidification model is developped including a refined solute trapping description in order to quantitatively predict the solidification path and microsegregation in aluminium alloys. The results are compared to microstructure obtained during laser welding for a wide range of processing parameters. The fraction of eutectic, the microstrucural characteristic length and the microsegregations are compared and discussed.

COM22081: Reliable Maintenance Strategy for Instruments in Gas Treatment Center (GTC) of Aluminium Smelter

Stanly Johnson, Maaden Aluminum Company

Abstract: In an Aluminium smelter, the metal is separated by electrolysis process and in the process hydrofluoric gases and dusts are emitted, that are hazardous, corrosive and pollution to the environment. The material should not escape in the work space as well as to the atmosphere. Gas Treatment Center (GTC) is built with the reduction plant to provide a draft to the pots, so that the personnel in plant may not be exposed and the chemicals are removed, before venting the residual gas to the atmosphere, to have sustainable operation. Generally, a smelter, has multiple GTC units, that are fully automated and operated continuously and in each GTC there are approximately 900 equipment and 2500 instruments. To have reliable operation, the instruments should be maintained optimally. In this paper a systematic analysis and implementation of reliable maintenance strategy for instruments in GTC is disseminated. This methodology is developed for a GTC unit in a smelter, that can also be reused and scaled up for similar units.

COM22134: Scanning Electron Microscopy Analyses of Horizontal Single Belt Casting Thin Strips of AA6111 Alloy

Mihaiela Isac, Roderick Guthrie, Carlos Riviere, and Dengyang Lu, McGill University

Abstract: Horizontal Single Belt Casting (HSBC) is a promising Near-Net-Shape Casting (NNSC) technology for the future production of thin metal strips, given its outstanding economical and environmental benefits, compared with present day commercial Direct Chill (DC) technology. In this research, thin strips of AA6111 aluminum alloy were obtained via HSBC, wherein the molten metal was solidified on a moving, water-cooled steel belt. Pilot scale HSBC experiments were used to validate the experimental results of thin strips processed via the HSBC simulator. Scanning Electron Microscopy (SEM) was used to study the cast microstructures of the thin strip products. Electron Back-Scattered Diffraction (EBSD) was used to measure the average grain size, identify the chemical elements, and determine the composition of intermetallic compounds inside the grains and at the grain boundaries. The microstructural and SEM analyses confirmed the capability of HSBC in producing high-quality, as cast microstructures, suitable for minimal rolling and annealing operations to produce AA6111 aluminum strips.

COM22190: Self-Piercing Riveting of High Ductility Al-Zn-Mg Casting Alloy (Nemalloy HE700) in F Temper

Yunsong Guo, McMaster University; Anthony Lombardi and Glenn Byczynski, Nemak USA/Canada; Mukesh Jain and Sumanth Shankar, McMaster University

Abstract: Nemalloy HE700 (high elongation) automotive Al alloy, a newly developed Al-Fe hypoeutectic based alloy for high vacuum high pressure die casting, provides higher strength and elongation even without heat treatment compared to current mainstream structural automotive Al casting alloy. This study aims to systematically investigate the application of HE700 in the field of self-piercing riveting (SPR): the joinability of HE700 castings with dissimilar materials, directed by automotive industry standards. Several rounds of exploratory experiments amply showed the feasibility of obtaining valid SPR joints of HE700 castings (2.5 mm thick) with Al 6082 alloy (2.5 mm) and DP600 steel (1.2 mm) sheets with acceptable automotive quality standards. The influence of the die shape, rivet geometry and maximum punch force were the critical process parameters investigated. Finally, this article endorsed the viability of significant automotive lightweighting with a lower carbon footprint while integrating novel casting alloys such as HE700 into the automotive superstructure through economical joining processes such as SPR.

COM22037: Si-Containing Titanium Alloys for Laser Powder Bed Fusion (PBF-L)

Fabian Haase, Carsten Siemers, and Maximilian Goldapp, Institute for Materials Science, Technische Universität Braunsch

Abstract: Titanium alloys possess a high specific strength as well as good corrosion and oxidation resistance up to 600°C and are, therefore, very well suited for high demanding applications in the transportation industry. Normally, such parts are manufactured by casting, forging, or machining leading to a large amount of (contaminated) scrap, which is difficult to reuse. In contrast, additive manufacturing of titanium parts via laser powder bed fusion (PBF-L) allows the realization of complex geometries with fewer waste and good recyclability of the feedstock powder. However, due to the PBF-L process (sharp thermal gradient) and the material (little constitutional supercooling, lack of potent solidification nuclei), a columnar structure of the prior β-grains is formed during solidification, which usually leads to a crystallographic texture after the β to α transformation and, hence, to anisotropic mechanical properties.

The use of printed titanium parts is, therefore, limited to non-safety-critical applications so far. In the present study, Si-containing titanium alloys on the basis of Ti 0.44O 0.5Fe 0.08C 0.4Si 0.1Au, a high-strength alloy developed in our team on the basis of CP-Titanium Grade 4, with Si-contents between 0.4 to 1.5 wt.% have been developed, produced in laboratory scale, and studied with the emphasis on improving the resulting microstructure after PBF-L. Silicon was used as alloying element because literature research, on the one hand, suggests silicon as an effective element for β-grain refinement during conventional casting and additive manufacturing due to its beneficial impact on constitutional supercooling. On the other hand, silicon promotes the formation of Ti_5Si_3 silicides, which might act as solidification nuclei. Both effects have been investigated in the present study in the as cast state, after multi-track laser-melting experiments conducted on a PBF-L machine, and via Thermo-Calc© simulations. Additionally, Ti 0.44O 0.5Fe 0.08C 0.4Si 0.1Au and CP-Titanium were analyzed as reference materials. Current results show that, in the as cast state, Ti 0.44O 0.5Fe 0.08C 0.4Si 0.1Au exhibits a much smaller α-colony size and a higher variety of lamellae orientations compared to CP-Titanium. An increase in Si-content from 0.4% to 0.7% leads to a decrease in β-grain size and a saturation point seems to be reached, so that an Si-content of more than 0.7% does not further reduce the β-grain size. Visible dendritic solidification and precipitation of silicides along α-grain boundaries occurred in some alloys with higher Si-content. Those silicides, therefore, precipitated after solidification and, as a consequence, could not act as solidification nuclei. After multi-track laser-melting experiments, improvements in β-grain size are hardly evaluable due to the martensitic microstructure. However, there are indications of silicide precipitation within the melt pool in some of the studied alloys. Therefore, silicides might have a beneficial impact on solidification during PBF-L, but further investigations are necessary.

COM22151: Solidification cracking during laser powder bed fusion of Al 6061

Anubhav Singh and Mathieu Brochu, McGill University

Abstract: Additive manufacturing (AM) has recently reached high popularity in high-end aerospace, biomedical and automotive industrial applications owing to its ability to manufacture complex structures, tailored designs, etc. Among various AM techniques, laser powder bed fusion (LPBF) has proven successful in manufacturing medium strength aluminum-based alloys, mainly for the Al-Si family. The main challenge is now to further extend the reach of LPBF for the printing of high strength alloys such as Al 6061. However, inherent to LPBF is the complex thermal cycles, resulting the development of residual stresses, as well as the presence of liquid film at terminal solidification. Also, high energy input during LPBF results in Mg evaporation. All these factors favor solidification cracking. In the present study, noble printing strategies have been developed to circumvent this cracking issue.

COM22131: The Development of the HSBC (Horizontal Single Belt Casting) Process from Inception to Present Day

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

Abstract: Horizontal Single Belt Casting (HSBC) has been developed and studied over the last forty years, proving to be a viable alternative to traditional casting processes e.g., Direct Chill and Continuous Casting for aluminium and steel, respectively. The present paper will summarize the evolution of the process as carried out in Australia, and then in Canada, since the eighties, culminating with our most recent experimental results at MetSim. These are at both the pilot and industrial scales, as they pertain to the casting of thin strips, or sheets, of various difficult to cast, alloys of aluminium, copper, and steel.

Successful industrial applications will be presented, including parallel Salzgitter-Clausthal R&D. The paper will summarize the theoretical, experimental, and process modelling work that has been carried out. It is anticipated that HSBC will flourish, given the urgent need, worldwide, to optimize metal processing operations, by reducing the degree of energy consumption and associated green house gas emissions; HSBC boasts significant environmental advantages, with far lower capital and operating costs.

COM22154: The Effect of Hydrogen Embrittlement on Aluminum Alloys Used for Hydrogen-Fueled Internal Combustion Engine

Rashiga Walallawita, Josh Stroh, and Dimitry Sediako, University of British Columbia

Abstract: Due to hydrogen's unique characteristics, such as high energy density, low mass, and the capability of using it as a zero/low emission fuel, it has become a viable contender towards fulfilling current and future emission goals. Hydrogen has been considered a fuel source for internal combustion engines for more than two centuries; however, the development of hydrogen internal combustions engines (HICE) has been intermittent. With the recent development in high pressure hydrogen storage, green hydrogen production, and breakthroughs in highly efficient fuel delivery systems, there has been an increasing interest in HICE. The increased hydrogen concentration and the high working temperatures inside the engine's combustion chamber will create an environment that can increase the rate of hydrogen diffusion into the engine components, leading to hydrogen embrittlement. Therefore, this study is focused on the effect of HE on automotive aluminum alloys.

COM22029: What is Thermal Analysis for Advanced Aluminum Foundries

François Audet and Yohan Tremblay, Solutions Fonderie Services Métallurgiques Inc.

Abstract: Foundries can take different samples of the aluminum melt before and during the casting process to measure melt properties: RPT, chemistry, temperature, hydrogen, inclusions, oxydes and thermal analysis. The thermal analysis sample provides information on the solidification properties of the melt within 7 minutes on the shop floor. Recent advances in thermocouple signal processing allow automatic cooling curve analysis to provide more than the well-known grain refinement and eutectic modification potentials. Using a variant of the Newtonian approach, phases forming during solidification of the sample are measured as an energy % over the total energy absorbed or released. For aerospace casting applications, for example, this means that the presence of the Mg-Si or Al-Cu phases can be understood in order to adapt the melt treatment for a specific foundry on the shop-floor, as well as heat treatment temperatures. The goal is to reach higher, more consistent mechanical properties with solid aluminum A356 according to AMS-A-21180 and avoid porosities. Measuring the solidification properties of aluminum A201.0 to exceed AMS-A-21180 allowed the melt treatment to be adapted for each batch. The fraction solid curve from the thermal analysis result was used for casting filling and solidification simulation inputs. Filling the molds with the same melt quality helps understand non-conformities; if the melt properties are the same, what else might be the cause of casting defects ?

Processing of Critical Materials

COM22124: Carbon Negative Cement and Battery Materials

Jeremy Ley and David Dreisinger, Negative Emission Materials; Niels Verbaan, Mike Johnson, and Sridevi Thomas, SGS Canada

Abstract: Decarbonization is the challenge of the century, and net negative materials production and supply chains are part of the solution. Negative Emissions Materials, Inc (NEM) has developed a process for production of carbon negative nickel and cobalt battery material intermediates using a chloride based hydrometallurgical process route applied to saprolite ores. Amorphous silica, a supplementary cementitious material that can reduce the clinker content of cement mixes by 30%, is a coproduct. Magnesium hydroxide, a specialty chemical with several environmental applications, is the other major coproduct of the NEM process. The NEM process uses HCl leaching of saprolite to produce the silica residue, and the leachate is neutralized to produce an iron/aluminum/chromium residue as a potential co-product. The iron-free solution is further neutralized to produce a mixed hydroxide precipitate (MHP) of nickel and cobalt followed by a high purity magnesium hydroxide precipitate. The final solution is a concentrated sodium chloride solution which is directed to chlor-alkali processing to produce HCl and NaOH for acid leaching and neutralization. The process has advanced quickly through bench and pilot testing and is moving towards the development of the first large scale demonstration plant. The process and the supporting testing will be presented.

COM22023: Catalytic Dissolution of Metals Using Deep Eutectic Solvents

Rodolfo Marin Rivera, Guillaume Zante, Jennifer Hartley, and Andrew Abbott, University of Leicester

Abstract: Printed Circuit Boards (PCBs) are essential for most electrical and electronic devices. The growth in consumer electronics coupled with the increase in ownership and shortened lifespan of electronic devices has led to a significant global increase in the volume of electronic waste. However, due to the content of base and precious metals in PCBs, such as copper, nickel, gold, silver, it renders PCBs as an attractive 'urban mineral resource' for metal recovery. Pyro- and hydrometallurgy are the primary processing route for the recovery of metals from waste PCBs, but they are normally high-energy intensive and are not exempted of producing a large amount of waste residues. Deep Eutectic Solvents (DESs) can provide an alternative approach to recover metals from e-waste, as metals can be directly recovered from solid matrixes by following a similar principle to the conventional hydrometallurgical route, but with higher selectivity and lower toxicity. Electrochemical oxidation has already been demonstrated as an alternative methodology for solubilising metal oxides in DESs. However, the methodology demands a high volume of chemicals. The use of a redox catalyst can circumvent this issue, as it makes use of a chemical oxidising agent that can be recovered in situ by an electrochemical reaction. This study investigate, on the one hand, the use of iodine/iodide as a redox catalyst to solubilise copper, nickel, gold and silver in the DES Ethaline (a 1:2 molar ratio of choline chloride and ethylene glycol, ChCl: EG) with different water content. It was observed that the dissolution rate of metals tend to increase when increasing the water content mostly due to the oxidative effect of [I2Cl]– species – the solubility of [I2] tends to decrease when increasing the water content. Optical profilometry was used to measure the dissolution rate of metals. Thus, copper and gold had the fastest dissolution rate, particularly when the iodine concentration was high. The dissolution of nickel and silver, however, significantly decreased when the water content in the eutectic mixture was high, due to the formation of passivating layers. On the other hand, $FeCl_3$ and $CuCl_2$

were used as catalysts for selective metal recovery from PCBs in an eutectic solvent formed from calcium chloride hexahydrate and ethylene glycol ($CaCl_2$·6 H_2O: EG). This mixture has higher conductivity, lower viscosity and lower glass transition temperature compared to traditional DESs based on quaternary ammonium salts. In addition, $CaCl_2$ is produced on a large scale as a by-product in the Solvay process for the production of sodium carbonate. $FeCl_3$ and $CuCl_2$ demonstrate a significantly high solubility in $CaCl_2$·6 H_2O: EG, and both display reversible redox behaviour. These properties allowed the use of both inorganic salts as relatively benign, strong, electrocatalytic oxidising agents. The catalysts selectively etched copper, allowing gold and nickel to be recovered by filtration. Leaching rates determined with an optical profiler showed that $CuCl_2$ enabled faster leaching kinetics compared to $FeCl_3$. This offers a potentially autocatalytic method to recycle PCBs and associated e-waste.

COM22021: Deep Eutectic Solvents for the Recovery of Technology Metals

Guillaume Zante, Rodolfo Marin Rivera, Jennifer Hartley, Andrew Abbott, and Shannon Stodd, University of Leicester

Abstract: Emerging energy sources will rely on critical materials, particularly technology metals. Waste electronic and electrical equipment could be a major source of metals. Recovery of rare earth elements (REEs) and silver from secondary sources currently uses expensive and toxic chemicals such as nitric acid. To address these issues, we developed new processes based on deep eutectic solvents (DESs) for the recovery of silver from spent solar cells and the recovery of REEs from spent magnets. The process developed for silver recovery uses inexpensive and environmentally friendly chemicals: water, iron chloride and choline chloride (an ammonium salt mainly used for animal feed). Iron dissolved in the DES allows oxidation and dissolution of silver. The dissolution of silver is complete in less than 10 minutes; the overall silver recovery rate is over 90%. Then, the simple addition of water to the DES allows the precipitation of silver chloride with a purity>99%. Different DESs were applied to NdFeB magnet scrap and resulted in REEs recoveries above 90%. The difference in metal solubility in the DESs allowed the selective dissolution of Nd, facilitating subsequent purification steps. In addition, lactic acid-based DESs allow the separation of REEs such as Nd and Dy, which are usually very difficult to separate. Overall, DESs provide a new medium for the separation of critical metals, enabling cheap, fast, environmentally friendly and efficient recovery of metals.

COM22082: Detailing of Mineral Processing Operations within Strategic Mine Planning Algorithms: A Quantitative Cornerstone for Enabling Process Innovation

Aldo Quelopana, Javier Ordenes, and Alessandro Navarra, McGill University

Abstract: Critical materials are essential in a spectrum of products in diverse economic sectors. Currently, there is an increasing demand for energy storage materials (Li, Ni, Co, Mn, Vn, graphite, etc.) that suffer from supply risk. Consequently, innovative technologies have emerged to enable the mining industry to satisfy the forecast demand, ideally leading toward processes that are equitable and environmentally sound. Nevertheless, quantitative methods are needed to determine whether promising technologies in the lab could translate into solutions at a specific mine site, taking into account the geological uncertainty of how much of the material is in the orebody, and under what form, and how the technologies and processes would be operated differently in confronting this uncertainty. Any new process that is enabled by a technology must be characterized in terms of system-wide operational modes; this establishes how the technology is coordinated with the adjacent processes. Particularly for open-pit mines, there are well-

established strategic planning algorithms that determine the economic viability of different processing options, under varying degrees of geological uncertainty, over the mine life. However, these algorithms have tuning parameters that obscure the representation of new technologies. Our work has addressed this issue. Sample calculations are being developed based on an open-pit manganese mine. Adaptation of the approach to underground mines is also discussed.

COM22011: Developing A Commercial Heavy Rare Earth Processing Facility At Browns Range

Louis de Klerk and Robin Jones, Northern Minerals Limited

Abstract: Northern Minerals Limited (NML) has been developing a Heavy Rare Earths (HRE) project based on the Browns Range xenotime mineral resources since 2011. The project has followed a rigorous development process going through exploration, resource development, laboratory test work and laboratory pilot programs, and scoping, pre-feasibility and detailed feasibility stages. A 10 tph pilot plant that consists of a beneficiation plant and a hydrometallurgical plant was constructed in 2018 and has been operated through to 2022, testing both circuits. This pilot plant facility has enabled NML to produce sufficient quantities of both Rare Earth Concentrate (20-30% Total Rare Earth Oxides (TREO)) as well as a Mixed Rare Earth Carbonate (REC) (50% TREO) to test at potential offtake partners and REC has been sold to several rare earth refineries. Running the large scale pilot plant continuously has allowed NML to understand the process in much more detail than was possible from laboratory scale pilot test work, and a range of process and equipment improvements have been tested that will allow for a more effective commercial flow sheet. This paper will discuss the development process starting with the mineralogy and resource base, the minerals of economic interest and the characteristics of these minerals that shaped the process flow sheet. The stages of laboratory test work, laboratory piloting and interaction with the project development through scoping, pre-feasibility and detailed studies will be discussed. The decision to pilot at large scale has allowed NML to resolve process and equipment issues that weren't evident from laboratory scale test work and has allowed customers and off-take partners to gain confidence in the product quality. NML is in a favourable position to develop a commercial facility with a core technical and operating team that are familiar with the process and will transition to the commercial operation.

COM22158: Dissolution Behavior of Fly Ash Components Using Organic Acids in Conventional and Microwave-Assisted Leaching Settings

Sina Shakibania, Alireza Mahmoudi, Yasaman Saeid Bastami, Rojin Eghbali, and Fereshteh Rashchi, University of Tehran; Ehsan Vahidi, University of Nevada, Reno

Abstract: In fuel-fired power plants, a waste material known as fly ash is generated. Fly ash contains precious elements as well as hazardous compounds. The fly ash contains up to 20 wt.% nickel and vanadium. Recycling this waste material can be practiced to prevent pollution and decrease the need to harvest new raw materials. Accordingly, the present study has focused on using organic lixiviant to develop an environmentally friendly process to recover the valuable content of this waste material. Four organic reagents, namely oxalic acid, citric acid, gluconic acid, and ascorbic acid were chosen to study the dissolution behavior of fly-ash components. Considering the available literature on fly ash recovery, the slow dissolution kinetics of fly ash components in a conventional leaching setting was expected. Accordingly, in order to overcome this issue, microwave-assisted leaching was utilized to promote the dissolution rate of fly ash components. The highest vanadium dissolution efficiency was obtained using 1M oxalic acid, in which more than 80% of vanadium was recovered after four hours in the conventional

leaching process while it will only take five minutes in a microwave reactor to recover more than 80% of vanadium. Considering the environmental life cycle assessment of both conventional and microwave-assisted leaching processes, it was observed that microwave-assisted leaching using oxalic acid shows the lowest carbon footprint for vanadium recovery from fly ash.

COM22055: Dynamic Simulation of Uranium Ion Exchange Processes

Kevin Heppner and John McFeaters, SysCAD

Abstract: Nuclear energy is a low carbon form of energy seen broadly as a means to reduce carbon emissions associated with energy generation. A number of uranium deposits around the world are amenable to extraction via in-situ recovery. Pregnant liquors produced from these deposits are commonly processed via ion exchange processes using commercially available resins. The utility of process simulation for design and optimization of a uranium ion exchange plant is demonstrated in this work. A dynamic SysCAD model of an ion exchange loading, washing, and elution circuit is presented. Ion exchange is a sequential batch process circuit operating within an overall continuous process. As a result, significant surge tank capacity is required for operation of connected continuous circuits. This feature of uranium ion exchange plants makes dynamic analysis important for circuit design, optimization, and debottlenecking. The model uses open literature data as input to calculate circuit capacity and equipment utilization as a function of changes in operating conditions. Dynamic models are also important for understanding impacts of equipment reliability and maintenance scheduling. By calculating equipment utilization, the criticality of various equipment in the process can be assessed. This is useful both for design, e.g. identifying where backup units are required, and operations, e.g. understanding the cost and benefits of maintenance schedules.

COM22072: Electrolytic Rare Earth Metal Production to Meet Modern Environmental Standards

Shahid Riaz, Less Common Metals Ltd, UK

Abstract: Fused salt electrolysis has been used globally for commercial production of aluminium for over 130 years. The same process, based on simultaneous dissolution and reduction of metal oxide in a molten fluoride bath, is now the industry standard for production of light rare earth metals, including neodymium and neodymium praseodymium for use in high performance permanent magnet applications. Whereas fused salt electrolysis is a high yield and relatively low-cost process for production of rare earth metals, there are a number of challenges associated with process control, handling of molten materials at high temperatures, generation of greenhouse gases and potential generation of highly toxic fluoride-based gases when the process is operated under unstable conditions. Historically, the production of rare earth metals via fused salt electrolysis has often been carried out with scant regard to environmental, health and safety considerations. This paper will highlight how the process can be operated commercially to acceptable standards via process optimisation, control of emissions and appropriate management of health and safety aspects”.

COM22061: Enhanced Elution Efficiency of Sc from Ion Exchange Resins

Mehdi Mostajeran and Rory Cameron, Natural Resources Canada, CanmetMINING

Abstract: Mild atmospheric leaching of mineralized wastes, such as coal fly ash, is often undertaken by mild lixiviants, such as H_2SO_4 to extract the Sc and REE components in these materials into the pregnant

leach solutions (PLSs). Recovery of parts per million (ppm) level valuable metals requires very selective separation techniques such as ion exchange (IX) resins. In our previous work, two very selective solvent impregnated IX resins were identified with remarkable selectivity for adsorption of Sc from coal fly ash PLS. While 2 M H_2SO_4 was basically unable to recover Sc from these IX resins, addition of some water miscible organic additives substantially improved the elution efficiency of Sc from these resins to as high as 84%. In continuation of the previous work, elution of Sc from these resins were investigated in columns. After 9 bed volumes of elution and under identical operating temperature and flow rates, about four times the mass of Sc was recovered with the blended eluent compared to 2 M H_2SO_4. Moreover, the maximum concentration of Sc in the eluted fractions was significantly increased to over 2200 ppm (in the blended eluent) from about 167 ppm (in 2 M H_2SO_4).

COM22138: Extraction Of Nickel, Cobalt, and Scandium from Low-Grade Philippine Laterite Ores Using Atmospheric Leaching with Reduction Pre-Treatment

Edith Andrea Lucy, Mines and Geosciences Bureau-Metallurgical Technology Division

Abstract: Methods of processing low-grade laterite ores resulting in high purity leaching products are currently being explored due to the rapid depletion of high-grade ores. In this study, reduction pre-treatment is conducted prior to the atmospheric leaching of limonitic laterite ore to produce a nickel-cobalt-scandium-rich leach solution and iron-rich magnetic residues. The leaching of pre-treated ore resulted in higher recovery of Ni, Co, and Sc, with the minimal recovery of impurities, such as Fe and silica (SiO_2), when compared to the yield from the leaching of untreated ore. Effects of reduction temperature and time, lixiviant type, pH, leaching temperature and time, and solid-to-liquid ratio were also investigated using 2k-p Fractional Factorial Design of Resolution IV. Analysis of Variance showed that all the factors have significant effects on the leaching behavior of the following elements, with reduction temperature and type of lixiviant being the most significant in the recovery of Ni, Co, Sc, and Fe while s/l ratio and leaching temperature for the recovery of SiO_2. Recovery values from the screening experiments ranged from 54.23-94.64% Ni, 32.47-90.09% Co, 0.82-79.58% Sc, 1.68-86.69% Fe, and 0.00-41.72% SiO_2.

COM22022: Heavy Rare Earth Ore Sorting at Browns Range

Louis de Klerk, Northern Minerals; Bill Rayson, Total Earth Science Pty Ltd; Angus Todd, Minalyze Pty Ltd; Paul Beukes, Steinert Australia

Abstract: Northern Minerals Limited (NML) has been developing a Heavy Rare Earths (HRE) project based on the Browns Range xenotime mineral resources since 2011. A pilot plant on site has tested metallurgical processes with ore obtained from near surface deposits during a trial mining campaign. The process to upgrade the ore to a concentrate includes crushing, wet scrubbing, ore sorting and then feeding an upgraded ore to a mill for grinding before magnetic separation and flotation. The mill can process 10 tph of ore. The ore sorting process being used is based on X-ray transmission (XRT). The benefit of XRT is that selection of material for further processing can be done after crushing, but before fine comminution - this allows for reduced capital costs and operating costs for the saleable concentrate produced. Whilst conventional processes such as magnetic separation and flotation are well understood and metallurgical performance of these processes are routinely used in determining modifying factors for Mineral Resource and Ore Reserve modelling, this is not the case for ore sorting. This paper will discuss the development of a modelling and test work program to link X-ray fluorescence analytical data from hand specimens and diamond cores, together with results of trial mining and pilot scale sorting test work, to prediction of how

mined ore will sort and how this information can be incorporated into geological model for resource modelling. The aim of this process is to be able to generate reliable Ore Sorting Modifying Factors for use in mine planning for areas of deposits which are not available for trial mining, and in fact more broadly for deposits where only bench scale ore sorting data is available.

COM22116: Hydrometallurgical Flowsheet Options for Treatment of the Wicheeda Lake REE Flotation Concentrate: Acid Bake versus Caustic Crack

Niels Verbaan, Mike Johnson, Tassos Grammatikopoulos, and Jing Liu, SGS Canada; John Goode, J.R. Goode and Associates; Kris Raffle and Craig Taylor, Defense Metals Corporation

Abstract: Defense Metals is currently developing the Wicheeda REE carbonatite deposit in BC, Canada. The deposit is dominated by gangue carbonates including ankerite and dolomite, while the REE bearing minerals include bastnaesite/parisite/synchysite and monazite hosting primarily light rare earths including praseodymium and neodymium. This paper presents the results from a metallurgical testwork program conducted on flotation concentrate samples produced during a flotation pilot plant at SGS Lakefield. The concentrate samples assayed 40 to 50% TREO and contained approximately 21% monazite and 64% REE fluorocarbonates. From 2019 to 2021, a hydrometallurgical flowsheet was developed employing caustic conversion of REE phosphates and fluorocarbonates and hydrochloric acid leaching capable of extracting 90–92% REE into the leach solution. The leach solution was treated in a series of impurity removal processes to remove elements such as iron, aluminum, phosphate, and thorium. REEs were recovered from the purified solution via precipitation. In late 2021, testwork was initiated investigating alternative treatment options. Preliminary acid bake testwork yielded improved metallurgical extraction performance (> 95% PrNd) and also showed the potential to reject thorium into the leach residue. The paper and presentation will provide updated results of the caustic crack and acid bake processes and comparisons between the two routes in terms of metallurgical performance (extraction, reagent consumption) and process simplicity. Mineralogical characterization of leach residues will be used to explain the metallurgical performance of the two process routes.

COM22184: II-VI's Capabilities in Scandium Recovery and Purification

Gomer Abrenica, Ghazaleh Nazari, and Shailesh Patkar, II-VI Incorporated

Abstract: Scandium is one of the highest valued elements in the periodic table and a critical raw material essential to several emerging applications. Sc's technological applications are unique as it is a key component in producing solid oxide fuel cells and high-strength aluminum alloys used in aerospace and 3D printing. Historically, the supply of Sc has been limited due to its scarcity and the high cost of production. Most Sc is produced today as a by-product of other mineral refining processes, such as bauxite residues from alumina production and acid wastes from titanium dioxide pigment production. These sources have Sc concentrations that are at the levels of milligrams per kilogram and are considered exploitable but technologically complicated to recover. II-VI has significantly advanced the availability of Sc through a series of patented processes for the economical recovery of the element. II-VI has the expertise and experience to tailor the Sc recovery process flowsheets to meet customers' requirement. II-VI also uses its advanced technologies to further purify and produce greater than 99.9% scandium oxide.

COM22140: Innovative Solvent Extraction Process Steps to Produce High-Purity Cobalt and Nickel Sulfates from a Sulphide Concentrate

Abdul Halim, Sahil Kumar, Jonathan Chen, V.I. Lakshmanan, Sankar DasGupta, and J. F. NdoutouMve, Process Research Ortech Inc.

Abstract: The use of cobalt and nickel salts is consistently increasing in the production of strategic alloys while easily recoverable oxide ores of these metals are gradually decreasing. Environmentally sensitive sulphide ores have been used widely in commercial plants to produce cobalt and nickel products. Process Research ORTECH In. (PRO) has developed an innovative atmospheric chloride leaching technology through detailed bench and pilot plant testing to recover high-purity battery-grade cobalt and nickel sulphates from a sulphide concentrate. Chloride lixiviant is an effective leachant, which permits rapid leaching rates at modest temperatures and atmospheric pressures, with high metal recovery. This process evaluated both anion exchange and cation extractants in the solvent extraction process steps for producing cobalt sulphate and nickel sulphate from cobalt chloride and nickel chloride solutions, respectively. In this paper, detailed solvent extraction reaction mechanisms, potential process design parameters, important results, and developed flowsheets will be discussed.

COM22010: Integrating Carbon Capture in Mining through Metallurgy. Part 1: Leaching and Reclamation of Asbestos Tailings

Alex Mezei, Planetary Technologies

Abstract: Planetary Hydrogen (PH) is engaged in developing a proprietary carbon capture technology aimed to be integrated within existing and closed mining operations The enabling metallurgical process is based on classic unit operations involving sulphuric acid leaching of magnesium contained in suitable ores and tailings, solution processing and electrolytic acid regeneration with simultaneous magnesium hydroxide precipitation. The resulting hydroxide precipitate is used for either Ocean Air Capture (OAC) or Direct land-based carbon capture or a combination thereof. The main objective is to reduce the atmospheric CO_2 levels whilst generating credits from pay-metals such as nickel and cobalt when present in the ore, along with the hydrogen produced during the electrolytic regeneration. The oxygen produced during the same process is used for the removal of iron and impurities during the solution processing Typical amenable feeds for the process include asbestos tailings and nickel-laterite heap leaching barren solution discharge-streams. Column-simulated heap leaching results to date on an asbestos tailings sample produced recoveries of 84% for magnesium, 90% for nickel and 74% for cobalt after 90 days of leaching. Average asbestos conversion to silica was 83%, with complete conversion (0% asbestos) within the top layer. Vat leaching results produced comparable metallurgical performance after 40 days of leaching. Optimization testwork is underway at the time of writing the paper. The OAC potential of the magnesium hydroxide produced from the asbestos sample tested was estimated to 2.3. t dry tailings-feed per ton of CO_2.

COM22014: Integrating Carbon Capture in Mining through Metallurgy. Part 2: Nickel-Cobalt Laterite OperationS

Alex Mezei, Planetary Technologies

Abstract: Brazilian Nickel PLC (BRN) is developing its flagship PiauÍNickel – Cobalt Project in Brazil. The project is an advanced-staged Battery Metals project with small scale early production commencing in mid 2022 at the PNP1000, which will produce 1,400 tpa nickel. The full-scale project will produce an

average of 25,000 tpa of nickel and 900tpa of cobalt over the life of mine. Planetary Hydrogen (PH) is engaged in developing a proprietary carbon capture technology aimed to be integrated within mining operations The enabling metallurgical process is based on classic unit operations involving sulphuric acid leaching of the pay-metals contained in suitable feed-stocks, solution processing and electrolytic acid regeneration concomitantly with alkalinity generation. When magnesium is present, it is leached along other species, and, it is by large an undesired side-reaction. According to the PH process, the leached magnesium is recovered electrolytically as hydroxide which is used for either Ocean Air Capture or Direct land-based carbon capture or a combination thereof. The main objective is to reduce the atmospheric CO_2 levels whilst generating credits from pay-metals such as nickel and cobalt, along with the hydrogen produced during the electrolytic regeneration. The oxygen produced during the same process is used for the removal of iron and impurities during the solution processing. The two companies are engaged in a partnership aimed to capture 294,270 metric tons of CO_2 per year expected to be emitted by the full-scale PiauÍoperation This target will be achieved in several stages The paper summarizes the results of the initial technical derisking stage that produced the preliminary design criteria for the magnesium hydroxide scrubbing system.

COM22162: Intra-Lanthanide Separation Processes Using Neutral Diglycolamide Extractants

Kevin Lyon, Santa Jansone-Popova, Derek Brigham, Mitchell Greenhalgh, Amy Welty, Melissa Warner, and Bruce Moyer, Idaho National Laboratory

Abstract: Separation of individual rare earth elements (REEs) is often regarded as the most difficult processing step in the production of high purity rare earth oxides for end-use technology applications due to their inherent chemical similarities. Current industrial REE separation practices utilize solvent extraction with organophosphorus extractants, a complex process plagued by poor adjacent lanthanide selectivity, excessive chemical reagent consumption, and adverse environmental impacts. Consequently, research efforts within the Critical Materials Institute (CMI) are aimed at the development of alternative REE separation technologies that improve economic viability and environmental sustainability to enable domestic supply diversification. Recent efforts have focused on electroneutral solvating diglycolamide (DGA) extractants as an alternative method for the separation and purification of critical rare earth elements. DGAs offers distinct advantages over traditional phosphonic acid extractants used in separations including elimination of saponification to achieve high recovery in a solvent extraction circuit and improved adjacent lanthanide separation factors, ultimately requiring fewer solvent extraction stages to facilitate the required separations. Novel DGA extractants have been synthesized and tested to maintain high intra-lanthanide selectivity, high organic phase loading capacity, and proper phase dispersion behavior for high throughput separations. Solvent extraction cascade design principles have been tested to validate separation performance in counter-current solvent extraction equipment to obtain high degrees of REE recovery and purity. Finally, challenges and ongoing research associated with this family of neutral extractants are evaluated within the context of domestic rare earth oxide production from bastnäsite ore.

COM22064: Lithium-Ion Battery Recycling: A Baseline Flowsheet for Processing Black Mass in a Mixed Hydroxide Precipitate and Industrial Grade Lithium Carbonate

Christopher Baxter, Andriy Plugatyr, and Ben Yu, National Research Council Canada

Abstract: Lithium-Ion Battery (LIB) uptake is accelerating rapidly as part of the global push towards energy decarbonisation, particularly in the automotive sector. Increased demand is expected to put a significant pressure on the mining industry to supply critical energy metals (e.g. Li, Ni, Co). In this regard, the rapid development and deployment of efficient processes for LIB recycling as part of a circular economy is of great practical importance for alleviating raw materials supply issues as well as reducing the environmental footprint along the value chain. The development of LIB recycling presents unique obstacles such as the complexity of both individual LIB cells and packs, the diversity of cathode chemistries in use and under development, and the lack of standardization between battery manufacturers. Additionally, effective comparison between proposed processing flowsheets can be complicated by a lack of value quantification and life cycle impact parameters, especially at early stages of development. The following work presents a conceptual recycling flowsheet for the processing of black mass obtained from a mixed LIB feed stream into a Mixed Hydroxide Precipitate (MHP) and industrial grade lithium carbonate. The intent of this exercise is to introduce a relatively robust "Base Case" hydrometallurgical processing route which recovers nickel, cobalt, and lithium in a form which is readily integrated into existing material value chains. A Techno-Economic Analysis was performed, consistent with the level of AACE Class 5 capital and operating cost estimation. In this manner, it is anticipated that alternative recycling strategies can be benchmarked with an additional degree of quantitative comparison. The process plant is designed for a throughput of 2 dry tonnes of black mass per hour containing 5.1 wt.% Co, 23 wt.% Ni, and 4.0 wt.% Li. Using an operating factor of 95%, this equates to an annual capacity of 16,560 dry tonnes per year. Estimated MHP cake production is 8,440 dry tpa containing 44 wt.% Ni and 9.4 wt% Co, on average. 3,150 dry tpa of industrial lithium carbonate is also produced. In all, the facility requires an estimated CAPEX of 44 million USD, an OPEX of 32.9 million USD / year, and provides an added revenue of 63.9 million USD / year. This results in a Net Present Value after 20 years of 220 million USD.

COM22126: Magnet Rare Earth Production Must Double Within Ten Years. Where Will Production Come From?

John Goode, J.R. Goode and Associates

Abstract: Decarbonization to limit climate change requires the replacement of fossil fuel by renewable energy resources, electrification of vehicles, and several other strategies. The technologies that must be deployed consume critical materials including rare earth elements (REEs), and in particular praseodymium, neodymium, terbium and dysprosium. It is generally estimated that between 2022 and 2030 or 2031, the consumption of these elements will increase by a factor of two. To put this into context, a deposit similar to Mountain Pass or Mt. Weld, and associated processing and separation facilities, must be commissioned every second year over the next eight years. This paper reviews the characteristics of available rare earth sources, especially ore deposits, and attempts to identify those sources with the highest potential to deliver the required REE production.

COM22039: Neodymium and Lanthanum Separation by Flat-Sheet Supported Liquid Membrane with EHEHPA (P507) as an Extractant

Lin Li, Krystal Davis, Mauro Dal-Cin, Aaron King, Andrzej Nicalek, and Ben Yu, National Research Council Canada

Abstract: The interest in neodymium (Nd) is increasing due to its key role in high-tech sectors, such as permanent magnets ($Nd_2Fe_{14}B$ alloys). The extraction of Nd from ores and recycling of Nd from the wastes demand effective and efficient Nd and La separation. This research used a supported liquid membrane with EHEHPA (P507) to extract and separate Nd^{3+} and La^{3+}. The effect of Nd^{3+} and La^{3+} concentration in the feed, feed pH, P507 concentration, and the acidity stripping phases on Nd^{3+}/La^{3+} extraction and separation were discussed. The extraction results show effective extraction of Nd^{3+} and promising selectivity of Nd^{3+} and La^{3+}. The extractant concentration and feed solution pH play significant roles in enhancing extraction and separation. When the initial concentration of La^{3+} and Nd^{3+} was 1000 mg/L, 20/80 (v/v)% P507/D80, feed pH of 3, and using a strip solution of 3 M HCl, 99.8 % of Nd^{3+} was extracted, while the extraction of La^{3+} was 22.2%. The tests at 5 v/v% of P507/D80 showed the highest Nd^{3+}/ La^{3+} separation factor of 44.25.

COM22107: On the Solvometallurgical Extraction of Li and Co from Secondary Resources

Georgios Kolliopoulos and Halimeh Askari Sabzkoohi, Université Laval

Abstract: Energy water and metals are interconnected in a nexus shaped by the envisioned electrification of our modern societies. Access to critical and strategic metals (CSMs) is a vital part of this transition. In this work, we studied the solvometallurgical extraction of Li and Co from materials typically found in lithium-ion batteries, using innovative green deep eutectic solvents. Both CSMs were leached in the solvents tested with extraction reaching more than 84% and 70% for Li and Co after 48 h, respectively. These results show a considerable ability to compete with current state-of-the-art metal extraction methods thus generating a strong potential to attain truly circular low-carbon economies via solvometallurgical processing.

COM22087: Potential Processes to Produce High-Purity Lithium Hydroxide: A Critical Review

Abdul Halim, V.I. Lakshmanan, Jonathan Chen, and Sankar DasGupta, Process Research Ortech Inc.; Michael Dehn, United Lithium Corp / Bergby Lithium AB; Sahil Kumar, Process Research Ortech Inc.

Abstract: The demand for high-purity lithium hydroxide has increased significantly with the rapid advancement of lithium batteries for clean technologies including energy storage. By 2030, lithium hydroxide is projected to account for about 57% of lithium compound demand, compared to 24% in 2019. High-purity lithium hydroxide is used to make cathodes for lithium batteries. Currently, lithium hydroxide is produced by the addition of lime into lithium carbonate. While this process produces a low concentration of lithium hydroxide and a significant amount of lithium is lost. To overcome these limitations, substantial studies have been conducted to develop innovative and emerging technologies to produce battery-grade lithium hydroxide from lithium sulfate and chloride solutions. It has been reported that the battery-grade lithium hydroxide can be produced by causticization of lithium sulphate obtained from hard-rock, followed by sodium sulphate crystallization. Furthermore, the membrane electrolysis process utilizing anionic and cationic exchange membranes has been shown to be a promising new technology for producing a high concentration of lithium hydroxide under optimal conditions including current density, pH, temperature, and initial lithium concentration. Therefore, this paper will critically review the existing and the new technologies with emphasis on the important process parameters to produce battery-grade lithium hydroxide. Furthermore, it will also discuss the process chemistry, key flow-sheets, and the challenges and potential improvement opportunities of the technologies.

COM22045: Process Development for Selective Recovery of Lithium from Black Mass of Spent $LiFePO_4$ Batteries

Tianyu Zhao, Harshit Mahandra, Rajashekhar Marthi, Michael Traversy, Yeonuk Choi, and Ahmad Ghahreman, Queen's University

Abstract: Lithium iron phosphate batteries are extensively used in automobile industries as a source of electricity in electric/hybrid electric vehicles and are considered as a high-grade secondary resource for lithium at the end of life. In addition, huge amount of waste generated leads to environmental problems if left untreated. In this work, a method for selective recovery of lithium from black mass of spent $LiFePO_4$ batteries has been developed. Effect of different parameters i.e., pulp density, reaction time, formic acid and H_2O_2 concentration, and reaction temperature have been studied. Experimental results showed that from lithium iron phosphate cathode powder under the optimized conditions i.e., 30 min reaction time, 10% pulp density, 1.0 mol/L HCOOH, 10% H_2O_2, and 30 °C, 99.98% lithium was selectively leached. However, 97% lithium can be leached from black mass procured from a local industry at 20 °C, 10 mL/g liquid-to-solid ratio, 0.5 mol/L HCOOH, and 1.5% H_2O_2 concentration and 2 h reaction time (Or 2.5% H_2O_2 concentration with 40 min reaction time). At the same time, the leaching rates of iron, copper, aluminum, nickel, cobalt, and manganese were <1%. Finally, the work claims high selectivity, and high lithium leaching rate with environmentally friendly and economical aspects.

COM22115: The Beneficiation and Hydrometallurgical Process Development for Lofdal Hree Project

Jing Liu, Niels Verbaan, Micheal Archer, and Tassos Grammatikopoulos, SGS Canada; Barbara Mulcahy, Cnsultant; Rainer Ellmies, Namibia Critical Metals

Abstract: The Lofdal REE project is one of the few rare earth deposits in the world that contains mostly heavy rare earth elements (~75% HREO distribution). The mineralogy of the Lofdal project is complex, with xenotime as the primary rare earth mineral, and silicate, calcite, and iron-oxide as the main gangue minerals. The beneficiation and hydrometallurgical flowsheets developed for Lofdal project in previous studies were complicated and sub-economic. The recent development of the beneficiation testwork largely simplified the flowsheet with improved concentrate grade and recovery. The beneficiation process included ore sorting, magnetic separation, and flotation. The enhanced selectivity of xenotime against high reagent (acid, neutralizing reagent) consuming gangue minerals (calcite and hematite) was beneficial for the CAPEX and OPEX cost saving of the downstream hydrometallurgical process. The original caustic crack-based flowsheet was converted into an acid bake-based flowsheet treating the flotation concentrate capable of recoveries exceeding 95% of key HREE. Following several conventional liquor purification steps, a high-purity rare earth oxide concentrate at >98% TREO with low impurity levels was produced. This paper highlights the findings from laboratory testing programs conducted to develop the process.

COM22111: The Beneficiation and Metallurical Process for the Production of Mixed REE Product from Nechalacho Deposit

Kevin Bradley, SGS Canada Inc.

Abstract: Cheetah Resources, is Canada's first rare earths producer (of modern times) following development of its world-class rare earth Nechalacho project in Northwest Territories, commencing production in June 2021. Nechalacho's North T Zone hosts a high-grade resource at 9.01% LREO. The process developed for North T Zone is able to achieve high recovery and grade of REE from a bastnaesite ore body with relatively low operating costs. In the process, the ore is first concentrated by ore sorting and then further upgraded by dense media separation and Wilfley Table to produce a concentrate with a 40% TREO grade. The beneficiation concentrate is then subjected to calcination to pre-treat the material prior to REE dissolution with hydrochloric acid which achieves partial rejection of cerium relative to other REE. The REE bearing pregnant leach solution is purified by the removal of iron, thorium, uranium and aluminum prior to precipitation of a mixed REE carbonate of 98% purity. The overall Nd recovery from ore sorter concentrate to mixed REE carbonate is 82%. The resulting REE precipitate is further processed to desired products by an off-take partner. This paper highlights some of the findings from laboratory and pilot testing programs conducted to develop the process.

COM22125: The Demonstration of the Cuprion Process for Recovery of Nickel, Cobalt, Copper and Manganese from Seabed Nodules

David Dreisinger, Dreisinger Consulting Inc.; Niels Verbaan and Marlon Canizares, SGS Canada

Abstract: Dreisinger Consulting Inc. (DCI) have evaluated the application of the Cuprion Process for processing of sea bed nodules from the Clarion Clipperton Zone in the Pacific Ocean. A program of bench and pilot plant testing was conducted to demonstrate the reductive leaching of ground nodules in a seawater-based ammonia-ammonium carbonate leach solution. The batch leach testing confirmed that extraction of copper, nickel and cobalt exceeded 90%, leaving a manganese carbonate residue for manganese recovery. The Cuprion leach process was piloted over a 5-day period in a series of continuous overflow reactors with closed loop solution recycle. Pilot metal extractions confirmed or exceeded the lab leach testwork results and led to increased understanding of the Cuprion Process. The pilot plant solutions containing extracted metals were treated by oxidation and solvent extraction to demonstrate co-extraction of nickel and copper. The pilot plant residue contained manganese carbonate formed by the reductive leaching chemistry. This residue may be treated to extract and recovery manganese as EMM along with residual amounts of copper, nickel and cobalt. The results of the batch and pilot testing are presented.

COM22144: The Extraction of Nickel and Cobalt from Laterite Ores with Concurrent Carbon Sequestration

Fei Wang and David Dreisinger, The University of British Columbia

Abstract: The pathway to net zero carbon emissions requires sequestration of CO_2 and the widespread adoption of electric vehicles to minimize emissions from the transportation sector. Nickel laterite ores are rich sources of nickel and cobalt for electric vehicle battery manufacture. These ores are also rich in magnesium and iron silicates in the form of olivine and serpentine mineralization. The carbonation of nickel laterite ores has been conducted at elevated temperature with an overpressure of carbon dioxide. A soluble complexant, (ethylenediaminetetraacetic acid disodium salt (Na_2EDTA)), can be added to the slurry during carbonation to affect concurrent nickel and cobalt extraction. Nickel and cobalt are held in solution and can be washed away from the carbonated residue. This process offers a new route to carbon sequestration and battery metal recovery. The results of this treatment are very encouraging. A sample of olivine ($(Mg,Fe)_2SiO_4$) yielded 88% Ni/Co extraction with 88% mineral carbonation and 5.0% Fe extraction and 0.04% Mg extraction. A sample of nickel laterite ore yielded 73% Ni extraction, 55% Co extraction, 73% mineral carbonation and 6.0% Fe extraction and 0.5% Mg extraction.

COM22099: The revival of the French Rare Earth industry

Alain Rollat and Frederic Carencotte, Carester

Abstract: In the 1980s and 1990s of the last century, France was one of the major countries for the Rare Earth industry and the French RE separation technology was recognized as one of the most advanced in the world. In the early 2000s most of the French separation capacities moved to China. Due to this situation and the development of end-use applications in China the French RE industry has gradually declined and is now very weak. It is the aim of Carester to revive and develop the Rare Earth industry in France through two initiatives: A end of life magnet recycling unit and a Heavy Rare Earth separation hub (HRE Hub). The needs of magnet recycling in Europe have been highlighted by the EU and Carester decided to participate in this ambition. The recycling unit will combine new technologies allowing to improve the environmental footprint with the efficient separation technology proposed and developed by Carester. There is no doubt that in the coming years several plants dedicated to praseodymium (Pr) and neodymium (Nd) production will start outside of China. Most of these projects are based on Light Rare Earths (LRE) deposits with low HRE content. Therefore, the HRE separation step is usually not economic for these companies and not included in their projects. Based on its industrial experience Carester has the ambition to propose to these companies a HRE Hub able to treat their HRE concentrate and give them back the pure rare earths they they need, in particular terbium (Tb) and dysprosium (Dy).

Towards Sustainable Circularity: Mining to Materials

KEYNOTE

COM22186: Using Polymetallic Nodules to Innovate Manganese Markets: A New Manganese Feed for SiMn Alloy Production

Matt Boulby, The Metals Company; Vincent Canaguier, Sintef; Jeffrey Donald, The Metals Company

Abstract: The Metals Company is on track to becoming a leading producer of base and strategic metals obtained from vast high-grade seafloor polymetallic nodule deposits. The Metals Company believes the seafloor minerals industry is an opportunity to develop a more environmentally and societally attractive way to produce cleaner base and strategic metals. Deep-sea nodules from the Clarion-Clipperton Fracture Zone in the Pacific Ocean represent the largest known resource of nickel, cobalt and manganese. The Metals Company is developing a new metallurgical process based on existing nickel flowsheet technologies to maximize the business outcomes consistent with the highest environmental standards, including targeting a near zero waste facility. This work presents an overview and context of the project with a focus on the manganese silicate product and the downstream opportunities to produce SiMn and other manganese products. The work will present a testwork and pilot plant overview, characterization of the manganese silicate, experimental and theoretical results to produce SiMn, and a value-in-use assessment compared to conventional SiMn feeds. The significance of the Manganese Silicate product to a zero-waste flowsheet will be discussed.

COM22156: Analysis of the Environmental Impacts of the Mn Recovery Process from Low-Grade Waste and Comparative Life Cycle Assessment of $MnFe_2O_4$ Synthesis

Rojin Eghbali, Ali Soltanizade, and Fereshteh Rashchi, University of Tehran; Ehsan Vahidi, University of Nevada, Reno

Abstract: Growing attention has been devoted to extraction of Mn from low-grade ores and wastes due to rapid depletion of high-grade manganese ores and increasing demand for manganese in various industries. From an economic standpoint, synthesis of an advanced material at the end of recovery process can add more value to the whole process and make it cost-effective. Despite the fact that extraction Mn from low-grade wastes has various destructive environmental burdens, a limited number of life cycle assessments have been conducted to date. In this study, environmental impacts of manganese recovery from low grade ores and synthesis of magnetic manganese ferrite were investigated. Manganese ferrite ($MnFe_2O_4$) is a magnetic material with a spinel structure crystallized in the form of AB_2O_4. Manganese ferrite is well-known as a soft magnetic material with a relatively high saturation magnetization, high magnetic permeability and susceptibility, and low magnetic anisotropy. Two methods of synthesis were selected: a high temperature synthesis using a furnace and a low temperature method where aging process compensate the absence of high temperature regime. Firstly, the system boundaries were defined which include both the recovery and synthesis processes. The boundary defined the flows of the process and segregated the main area of study from outer environment. In this confined system, production of 1 kg $MnFe_2O_4$ is selected as the system functional system. A life cycle inventory for Mn recovery process from low-grade ore and two methods of $MnFe_2O_4$ synthesis were created in association with with stoichiometry and mass/energy balance. This inventory was based on the LCA standard methodology in ISO 14040. All raw environmental footprints of any input and output to the system were considered in various tables provided by this inventory. Life cycle analysis was conducted using the collected data to quantify and compare the environmental impacts. OpenLCA software tool was used for the inventory analysis and the Ecoinvent 3.0. EPA TRACI (USA 2008) database was used to assess environmental impacts. The environmental footprints of the processes were assessed, and major emissions and key contributors were identified. The environmental results showed that the recovery process has the least and the high-temperature synthesis method surpassed other processes in almost all environmental categories adopted in TRACI model. Additionally, hydrogen hydroxide, which is used as a key element in both synthesis methods, predominated the whole environmental footprints while in the recovery process electricity was the major component. Right after the electricity, sulfuric acid and sulfur dioxide play an important role in the environment impacts of recovery process. The results help us recognize the better synthesis method regarding environmental performance and develop a sustainable manganese recovery process from low-grade ore.

COM22084: Canada as the Trailblazers in Net-Zero Carbon Mining

Susanna Zhang, Ben Steyn, Hakan Mustafa Tunc, and Jim Barrett, BBA

Abstract: Politicians worldwide have committed to net-zero direct and indirect carbon emissions by 2050. Many of the world's leading miners have already committed to this goal, and the mining industry is working hard to reduce its emissions. The Newmont Goldcorp Borden Gold Project in Northern Ontario is an example of such an effort, featuring state-of-the-art health and safety controls, digital mining technologies and processes, and low-carbon energy vehicles. The ambitious emissions target will require a global 10-fold increase in the demand for metals. The future hot commodities will be critical and strategic minerals to improve supply independence, battery minerals, and copper. These are described as the "new oil" in the growing incentive to decarbonize. The increased mining activity will lead to higher energy demands and low resource availability. BBA believes that a net-zero carbon mine in Canada is feasible and even reachable before 2050. Combining energy-efficient (green) equipment, carbon-free energy sources, and auxiliary technology in a circuit will lead to low-cost sustainable operation and provide an additional incentive to attract and retain the next generational fleet of talent. This paper will consider the current energy usage and resource availability for the metal processing lifecycle in Canada, identify available and future alternative energy technologies and initiatives, define the boundaries of net-zero carbon, and offer a vision of a future iron ore mine modeled using green equipment and energy sources.

COM22093: Decanter Centrifuges and Dewatering Technology Selection: A Case Study

Tom Boundy, Paterson & Cooke; Juan Alberto Juarez Garcia and Moises Uriel Raya Sotelo, Koura Global; Kathy Adams, Paterson & Cooke

Abstract: Dewatering of mine tailings is an increasingly recognized value for mineral processors enabling reduced fresh water consumption, lower risk tailings storage facilities, reduced tailings storage volumes, and, in some cases, generation of value-added products. Decanter centrifuges represent a less commonly considered technology for dewatering tailings due to their limited capacities and limited cake solids concentrations that can be achieved compared to pressure filters. As part of a recent design of a desliming circuit in a fluorspar concentrator, decanter centrifuges were evaluated for slimes dewatering suitability in laboratory, mini-pilot, and pilot testing campaigns. Early stage laboratory centrifuge tests indicated 52% to 66%m cake solids by mass should be expected causing this technology to be preferred to thickeners and pressure filtration technologies. When the decanter centrifuge was advanced to mini-pilot and pilot scale tests using true decanter centrifuges, solids concentrations of 73 to 80%m solids were obtained

clearly outperforming early design expectations. Feed stream characteristics such as high clay content and fine particle size distribution that may explain such behavior are discussed. These results suggest that (1) caution should be taken when ruling out decanter centrifuges as a dewatering technology based on insufficient cake solids concentrations in laboratory scale test results and (2) relatively small streams of fine, especially compressible tailings represent an attractive design scenario for decanter centrifuges.

COM22135: Decarbonisation at the Anglo American Barro Alto Smelter through Implementation of the Ecombustible Technology

Daniel Brosig, Paykan Safe, and Matthew Russell, GCT Engineering Inc.

Abstract: As part of the effort to decarbonize the world economy, the advent of the use of hydrogen has awakened interest within the metallurgical industry. Sustainability-driven strategic goals sponsored by the Anglo American Barro Alto industrial complex call for the displacement of fossil fuels with hydrogen to reduce carbon dioxide (CO_2) emissions in existing thermal applications. The environmental and business case strength for the use of hydrogen in thermal processes can vary significantly based on the hydrogen source and the local economic conditions, such as the cost of raw materials and electricity and the price of incumbent fossil fuels. Important safety considerations require close attention as the use of hydrogen as an industrial fuel grows toward becoming ubiquitous in all industries. This paper presents an overview of an on-going project to implement a novel technology that will deliver a hydrogen-based fuel to thermal applications within the Anglo American Barro Alto smelter.

COM22127: Decarbonization of Mining And Metals Industry: A Critical Overview

Ashok D Dalvi, Dalvi Associates

Abstract: This is a follow-up to the discussion on Sustainability Challenges presented during COM2020. Decarbonization of Mining and Metals industry is a major challenge of the 21st Century. In this paper the targets related to decarbonization of Mining and Metals industry are quantified. Corresponding technologies are identified based on a literature review and author's experience. Implementation of these technologies are discussed based on author's 40+ years of hands-on experience in the industry involving all stages of projects from conceptual design to commercial scale implementation. Potential timelines for implementation as well as technological, regulatory and other constraints are discussed. Metals have been an important part of the circular economy; the end-of-life recycling rates for most common metals is greater than 50%. Recycling is an important part of decarbonization and there is scope for increasing it. However, for sustainability and decarbonization it is important that Li-ion battery recycling is ramped up (especially for Li and Co). This is an important challenge going forward.

COM22092: Development of a Smart Database for Wastes from Canadian Mining and Metallurgical Industry

Elhocine Derardja, Ecole de Technologie Supérieure; Arash Rafiei, Mining engineering department of McGill University; Elmira Moosavi-Khoonsari, Ecole de Technologie Supérieure

Abstract: Managing wastes from Canadian mining and metallurgical industry is a multidisciplinary socioeconomic and environmental task. On the one hand, many of the industrial wastes contain metals and materials, which are considered to be strategic and critical for transformation to green technologies and technoeconomic development of the society. On the other hand, the industrial wastes may contain toxic and harmful components for the ecosystem. In addition, the diversity of these wastes in terms of physicochemical properties creates a need for different valorization routes; which is, indeed, a scientific and technological challenge. In this work, we present a systematic and knowledge-based approach to generate a smart database for the wastes from the mining and metallurgical industry with respect to circular economy policy, strategic mineral plan, and waste management regulations of Canada. The generated database and knowledge will form the ground for development of potential metallurgical routes for the valorization of the industrial wastes into in-demand products and recuperation of valuable metals and materials in a responsible and sustainable manner.

COM22075: Dynamic Renewable Energy-Driven Framework Development for Mineral Processing Circuits

Ryan Wilson, McGill University; Andy Reynolds, Inspire Resources Inc.; Alessandro Navarra, McGill University

Abstract: Evolving global economics and socio-environmental factors are driving research and development trends in the mining industry towards the use of 100% renewable energy sources to support operations. In addition to the reduction of carbon footprints, this will be particularly important to improve the feasibility of remote projects that often face significant scheduling and cost barriers related to transmission line installation and/or fuel delivery for generator-based systems. The state of the art is to use rolling element mills, dry grinding and process storage systems to enable intermittent operation of the mill. However, conventional circuits that rely on carbon-based fuels typically require continuous operation in order to remain economically competitive. The notion of an efficient plant that can start up and shut down at a high frequency (e.g. daily) based on dynamic fluctuations in availability of renewables has not been properly tested. To highlight the performance attributes and constraints that would need to be addressed by equipment designers, this paper adapts a systems approach to support solar energy-driven mineral processing facilities. The current quantitative framework utilizes discrete event simulation and mass balancing for the development of suitable operational policies that respond to changes in energy supply caused by weather patterns and related environmental uncertainty. Sample computations are presented in the context of a copper flotation plant.

COM22059: Imaging the Remaining Refractory Lining in Active Furnaces

Rachel Santini and Afshin Sadri, Hatch Ltd.

Abstract: Reliable measurement of remaining refractory lining is essential to ensure the safe and stable operation of furnaces. Carefully monitoring the integrity of a refractory lining can allow for pre-emptive detection of refractory wear and avoid sudden furnace failures or other unscheduled shutdowns. This lining information plays a critical role in allowing furnace operators to confidently push past originally scheduled reline dates. Recent technological breakthroughs have now made it possible to image the refractory lining in active furnaces for the first time. This paper presents the first images ever created of the refractory lining of an active furnace.

COM22118: MICROWAVE IMPACTS ON MORE SUSTAINABLE KIMBERLITE PROCESSING

Muhammad A. Rasyid, Azlan Aslam, and Arash Rafiei, McGill University; Ali Madiseh, University of British Columbia; Agus Sasmito and Ferri Hassani, McGill University

Abstract: Diamond production from kimberlite ore has been facing some sustainability challenges: (1) Recovery of diamond, (2) Waste management cost, and (3) Process water consumption. They can be studied using particle size distribution analysis, and according to the process flow diagram the crusher performance has the most significant impacts on particle size distribution. Ideally, the coarser crushing product with minimum over-crushing will improve the sustainability of kimberlite processing. Microwave pre-treatment has potential to generate cracks inside the ore particles with more concentration along the grain boundary of mineral phases. The selective breakage is improving the diamond liberation. In this research, 500 g samples of Hypabyssal Kimberlite (HK) were microwaved under different power levels (5-15 kW) and exposure times. The fresh and microwave-treated samples were both crushed in a laboratory single roll crusher, then the crushed products were size classified for size analysis. Three parameters were concerned: mean size, uniformity constant, and percentage passing from the crucial size. According to the results, microwave pre-treatment is increasing the mean size (13%) and uniformity constant as well as reducing fraction of the crucial size (10.8%). These positive impacts of microwave on particle size parameters are improving the sustainability of kimberlite processing by increasing the recovery potential of fine diamond from tailings as well as reducing the amount of process water.

COM22171: Ni/Co-Cu Sulphide Resources, Key Contributors to Sustainability: A Review of Applications and Processing Challenges

Sinan Arslangil, Sanda Kelebek, and Charlotte Gibson, Queen's University

Abstract: Nickel and cobalt are among the strategic metals contributing to sustainability. Recent statistics have indicated that their domestic production gradually declined, although Canada still ranks among the top five countries in nickel production linked to the co-production of cobalt and precious metals. The sustainability of nickel and cobalt production requires efficient processing, whether this relates to recycling from secondary sources or primary resources. One of the main driving forces in the growing demand for nickel is related to the increasing importance of nickel and cobalt-bearing lithium-ion electric-car batteries to reduce dependence on fossil fuels as part of a sustainable future. In addition, alloys of these metals are essential for solar power facilities towards the same goals. Nickel-copper sulphide ores in Canada are in the category of complex sulphides since they are available with large quantities of pyrrhotite that is undesirable from an environmental point of view. Thus, the rejection of pyrrhotite in the processing of Ni-Cu sulphide ores will continue to be important in the Canadian mining industry due to its dominance in the disseminated matrix of these ores. In addition, in some cases, these ores also present a talc separation problem. When the Ni-Cu Sulphide ores also have talc as a non-sulphide impurity, the DETA/TETA approach for Pyrrhotite depression has an additional complication when used in combination with CMC for talc depression. Selected results from recent literature on nickel-copper sulphide flotation studies are summarized as a basis for an ongoing study on the interactions of polyamines and CMC in the depression of talc and pyrrhotite, both of which represent a serious issue in the processing of nickel-copper sulphide ores.

COM22185: Production of Spodumene Concentrate from the North Carolina Piedmont Lithium Project

Brian Kawenski Cook, SGS Canada / Queen's University; Massoud Aghamirian, Hao Li, and Nima Nabiri, SGS Canada; Jim Nottingham, Piedmont Lithium; Jarrett Quinn, Primero Group Americas; Chris Gunning, SGS Canada; Charlotte Gibson, Queen's University

Abstract: The global push toward sustainable energy has created a surge in demand for electric vehicles powered by lithium-ion batteries. To meet projections, the mining industry is rapidly expanding to develop new lithium mineral projects focused on producing high-quality lithium concentrates. The Piedmont Lithium Project in North Carolina is located along the Carolina Tin-Spodumene Belt and contains high-grade lithium pegmatites well-suited for producing spodumene concentrate. The study investigated chemical-grade spodumene concentrate production using dense media separation (DMS), magnetic separation, and froth flotation. Three composite samples were selected with varying ratios of pegmatite to host rock and different mineralogical compositions. A two-stage DMS circuit processed the –6.4/+3.3 mm and –3.3/+1.0 mm fractions of each sample and achieved 24% to 37% with lithium grades ranging from 6.0% to 6.4% Li_2O. The flotation feed was comprised of DMS middlings and the –1.0 mm fines fraction which were stage-ground to –300 µm. Magnetic separation was used to reject iron silicate minerals prior to flotation. Flotation conditions were optimized in a series of bench-scale flotation tests. Locked-cycle tests were conducted under optimized flotation conditions and resulted in global lithium recoveries ranging from 37% to 53% with lithium grades between 5.7% to 6.4% Li_2O. The combined DMS and flotation flowsheet produced lithium recoveries of 74%, 77%, and 80% at combined concentrate grades of 5.8%, 6.4%, and 6.0% Li_2O, respectively.

COM22026: Selective Depression of Talc in Cuprite Sulfidization Flotation by New Depressant Astragaloside

Qiuyue Sheng, Wanzhong Yin, Yahui Zhang, and Kelly Hawboldt, Memorial University of Newfoundland

Abstract: Talc is a common gangue mineral with natural hydrophobicity, which may lower grades of concentrates in metal mineral flotation and cause problems during smelting. The depression of talc is a common issue in flotation processes and has attracted attention. As an efficient and environmentally friendly depressant of talc, astragaloside was firstly used to separate cuprite and talc in this study. The effect of astragaloside on talc depression and cuprite flotation was studied using Na_2S as sulfidizing agent and sodium butyl xanthate (NaBX) as collector. The flotation and contact angle tests results indicated that the hydrophobicity and floatability of talc were weakened after astragaloside addition. The recovery of talc decreased from 83.46% to 37.98% with the addition of 40 mg/L astragaloside, but the floatability of cuprite was hardly affected. To explore the adsorption mechanism of astragaloside, X-ray photoelectron spectroscopy and Fourier transform infrared spectroscopy analyses were carried out. The results indicated that astragaloside selectively adsorbed on talc surface, thus the flotation separation of cuprite and talc was achieved, and the concentrate grade in the sulfidization flotation of cuprite was improved.

COM22032: Silver Extraction from High Manganese-Silver Ores using Leaching with SO_2 Pretreatment

Flor Lizbeth Salazar, Ximena Nevarez, Daniel Manqueros, Fisher Wang, and Persio Rosario, First Majestic Silver Corp.

Abstract: Silver ores with high manganese contents, in an order of 2–10%, are difficult to process using conventional cyanidation methods. The resulting low silver extraction is primarily due to the intimate association between silver and manganese minerals, which prevents valuable minerals from contacting with solvent agents. The objective of this study was to investigate alternative process methods to improve the extraction of silver. In this research, an extensive experimental program was carried out using high manganese-silver ore samples from the La Encantada mine in Mexico to evaluate the silver extraction from conventional cyanidation process with and without the addition of SO_2 gas for pre-treatment. The results demonstrated significant increase in silver extraction with SO_2 injection prior to the cyanidation process. In addition, the effect of SO_2 concentration, slurry solid density, oxidants addition and agitation speed on the silver extraction was thoroughly investigated in this study.

COM22094: Slag Resource Recovery via Air Granulation

Santiago Faucher, Daniel Park, and Amit Shrivastava, Ecomaister Co. Ltd.

Abstract: Slag remains one of the most important undervalued resources produced by the pyrometallurgical industry, where it accounts for 10% to 98% of the mass and energy flow from a pyrometallurgical process. That is, the slag is commensurate in its material and energy footprint to the metals, mattes, and alloys produced, yet it is treated not as a resource but a waste. Advances in the minerals sector have allowed meager use of this resource in certain applications, but substantial work remains by industry and government to truly valorize the volumes of slag produced. Over the last 30 years, Ecomaister has been contributing to this valorization through the development of its Slag Atomization Technology to both granulate slag into products with air and recover its energy content. These efforts have led to the construction and operation of over 30 commercial Slag Atomization Plants, two of which have been for the last decade successfully recovering energy from slag. This air-driven slag granulation technology has been applied to the steel and non-ferrous sectors at full-scale, granulating up to 200,000 tonnes of slag per year per unit. Recently, we have demonstrated further scale-up of the technology to granulate high slag rates from blast furnaces and have implemented new adaptations of the technology to produce a wider array of slag products. Both historic and arising developments in Slag Atomization Technology and slag applications will be presented and discussed with supporting data. Challenges for further adoption of slag as a resource and air granulation as a technology will be discussed and outlined.

COM22136: Technologies of Processing and Sulfidization of Oxidized Lead-Zinc Ores and Middlings of Enrichment

Tatyana Chepushtanova and Yerik Merkebayev, Satbayev University

Abstract: This research describes the technology that was developed for processing of zinc and lead-bearing enrichment wastes by sulfidizing roasting. It was found that as a result of the sulfidizing-pyrrhotizing roasting process, the flotation ability increases for lead compounds and decreases for iron compounds, while the magnetic susceptibility of lower iron sulfides formed during roasting increases. This allows us to propose a technological scheme for processing refractory lead-containing ores, including activating sulfidizing roasting followed by magnetic and flotation concentration of cinders. It has been established that sulfidizing takes place with sufficient completeness-during subsequent flotation, it is possible to extract up to 95% of zinc and up to 80% of lead into sulfide concentrate. These results have a technological advantage in contrast to the other methods used. It was found that at roasting temperatures of 700–800 °C, pyrrhotites have a maximum magnetic susceptibility of 3.75, 5.43 and 2.18 SI units for Fe0.855S, Fe0.888S and Fe0.909S, respectively. Technological recommendations have been developed for the processing of similar raw materials. The research describes the results of elemental sulfur application as a. It was established that sulphur and pyrite can be used as sulphidization reagents at elevated temperature to transform ZnO to ZnS. This work proved the thermody-namic possibility of the sulphidization. Nevertheless, our findings can be used to set up a technology for treating oxi-dized zinc sulphide ores in order to gain and enhance their separation ability (by flotation or magnetic separation). It was established that addition of small amounts of carbon to the system significantly decreases

formation of SO_2 during the sulphidization roasting. Suitable conditions can be found to carry out the process under N_2 atmosphere. No further iron is introduced into the system when sulphur is used as sulfidizing reagent, which is an advantage, especially in the practical cases where the ore is not monometallic. However, sulphur, a commercial product has to be used. In many cases pyrite is regarded as flotation waste. Pyrite use as sulfidizing reagent converts it in useful material and contributes to the waste amounts decrease. In addition, according to our results, at the same molar ratios of ZnO to the sulfidizing reagent, higher sulphidization extent is achieved by pyrite use, compared to sulphur use. Even more, the treated material can be separated into magnetic and non magnetic fractions and the latter can be directly used for zinc production. The presented technologies are closed-loop technologies aimed at zero waste processes.

COM22080: The Role of Cold Bonding in Sustainable Steelmaking

Richard Elliott, Ian Cameron, and Britt MacKinnon, Hatch

Abstract: All iron and steelmaking processes generate solid ferrous waste. These dusts, sludges, and scales represent a significant environmental liability if not reclaimed and recycled. At present, the most common strategy to recover these iron units in a blast furnace-basic oxygen furnace steel plant is to produce sinter, a technology developed over 100 years ago for this purpose. As pressure to decarbonize intensifies, integrated steelmakers will increasingly seek alternatives to replace carbon-intensive sinter plants. Cold bonding is one possible alternative and has been demonstrated by blast furnace operators in Scandinavia and elsewhere, although complete replacement of the waste recycling infrastructure for an integrated steel plant is a complex task. A parallel challenge exists for direct reduced ironmaking (DRI) plants, which typically do not possess an equivalent integrated waste recycling route. As DRI plants proliferate as a decarbonization strategy, so will demand for low-emissions waste solids recycling. This extended abstract discusses the prospects for widespread adoption of cold bonding technology within the iron and steel industry.

COM22106: Using Bio-Based Surfactants as Frothers in Froth Flotation to Improve Renewable Carbon Index

Laura Benavides, Integrity Mining and Industrial LLC

Abstract: Developing quantifiable environmental social and governance (ESG) criteria is an opportunity for mining companies to differentiate themselves. With a large focus recently on GHG emissions and clean energy, there is a large opportunity for companies to demonstrate “environmental friendliness” and “sustainable supply”. There are several reliable tools that can be easily adapted by the industry to set transparent standards for socially responsible products. Integrity Mining and Industrial bases the carbon signature of its biopolymer-based products on its renewable carbon index. The Renewable Carbon Index (RCI) readily classifies the origin of carbon in a molecule, i.e., modern vegetative sources or extracted petroleum derivatives. Specifically, it measures the number of carbons derived from renewable sources compared to the total number of carbons in the product. Integrity Mining and Industrial has developed a bio-based surfactant technology with a tunable HLB range between 7 and 19. These bio-based surfactants can be used to replace leading synthetics and/or can be blended with other surfactants to meet sustainability and environmental regulations. Currently, IMI bio-based surfactants contain a renewable carbon index between 60–95% depending on the application. Based on preliminary testing, IMI bio-based surfactants with an HLB range of 9, 16, and 19 were evaluated and compared to commodity frothers used in the industry during froth flotation in a standard Cu sulfide lab-scale rougher circuit. Product A (HLB 9) and Product B (HLB 16) had no negative effect on the Cu recovery or grade when compared to the blank, that was evaluated using a standard industry frother. Separate testing was also conducted to determine the foam height and foam half-life compared to standard frothers. In this testing, 10 ppm of Product C (HLB 19) showed the best performance when compared to standard alcohol based frothers. The focus of this paper will be to continue evaluations of various IMI bio-based surfactants, when compared to alcohol-based furthers, propylene glycol, and other glycol ethers. By replacing synthetic frothers with bio-based surfactants, mining companies can take control of the renewable carbon being used in their products.

COM22178: Water Recycling and Seasonal Water Quality Effects in Mineral Processing

Patrick Rankin, Natural Resources Canada; Sanda Kelebek, Queen's University; Tony Di Feo, Natural Resources Canada, Canmet Mining; Jennifer Taylor, Glencore

Abstract: Water management is a crucial aspect of sustainability in the mining industry. Increased awareness of the lack of freshwater resources pushes mining companies to use water from alternate sources and recycle process water. Global trends such as decreasing ore grade, climate change, water scarcity, and stricter environmental regulations have led to the recirculation of greater quantities of water in mineral processing plants. As a result, the ionic strength of process water increases. Detrimental or beneficial effects to mineral flotation depend on the sensitivity of ores in the process. Seasonal variations in temperature, ionic strength, and microbiological activity can contribute to a decrease in metallurgical performance in concentrators during certain months of operation. The seasonal performance of the Kidd Creek concentrator located in Timmins, Ontario is investigated in detail. The purpose of this paper is to provide an overview of water chemistry and seasonal variation effects on flotation. The review will serve as fundamental background knowledge for future research focused on the effects of water quality variation on a complex Cu-Zn sulphide ore.

COM22103: World's First Real-Time Digital Twin Based on First Principle Models in Grinding Area

Sohail Nazari, Andritz Automation Ltd.

Abstract: In this presentation, we will introduce the world’s first real-time digital twin of grinding area based on first principle models that is bringing proven results to the mineral processing operation. This is truly world’s first based on the feedback we have got from various operations in the world, as the concept of digital twit is being introduced by many, but no tangible and concrete results have been shown in the real-time operation until now. First, we will lay out the framework of building a real time digital twin based on fully dynamic first principle models connected to real time operation. Then, we will discuss what are the recent applications in mineral processing and true potential of this new technology. The information generated by digital twin are used for virtual instrumentation, condition monitoring and optimization. To show a concrete value proposition of adopting digital twin technology, this paper summarizes the technical aspects and results achieved of a recent applications on copper concentrators in South America: Grinding area digital twin. Through this installation, a high fidelity model of the grinding area is build and connected to operation control system. In real-time the model generates crucial information regarding the operation status: e.g. SAG mill and Ball mill charge, angle of impact in sag mill, liner wear, and particle size distribution going outside of grinding area. The real time information are used to further optimize the performance of the existing advanced process control. By integrating the new information generated by the digital twin, additional 4% of throughput and 1% of recovery is unlocked.

Poster Presentations

COM22150: Application of Flotation to Selectively Separate Phosphorus-Rich Biomass from Anaerobic Wastewater Digestate

Bailee Johnson and Sidney Omelon, McGill University

Abstract: The primary method of producing agricultural phosphorus (P) fertilizer requires mined phosphate rock. Canada does not currently mine this non-renewable, finite commodity domestically and is dependent on P-fertilizer shipped from abroad. Concurrently, eutrophication from surplus P in municipal wastewater or agricultural runoff can damage ecosystems. Excess P in municipal wastewater is captured as insoluble iron or aluminum phosphate in "biosolids", an anaerobic product of municipal wastewater treatment with limited P-fertilizer value. New technologies concentrate wastewater P in microorganisms as a potential bioavailable P-fertilizer. Dissolved air flotation and centrifugation are common but not efficient solid separation strategies in wastewater treatment. These physical processes do not employ collectors or other reagents characteristic of flotation used in mineral processing. P-rich biomass concentration through flotation could potentially open this processing bottleneck. Preliminary micro flotation experiments were conducted with a P-rich model organism (*S. cerevisiae*). Early results suggest total P concentration to be slightly increased in the flotation concentrate compared to its feed sample. Subsequent tests will verify P-rich biomass separation in the presence of dissolved Fe and Al, and explore the separation of anaerobic bacteria biomass by nitrogen gas flotation, mimicking anaerobic digestion conditions found in some wastewater treatment plants.

COM22078: Circular Economy in Minerals Processing: A Case Study of Gold Ore Processing

Oluwasanmi Teniola, First Technical University, Ibadan; Abraham Adeleke, Obafemi Awolowo Unversity

Abstract: The concept of circular economy is a system intended to drive production and consumption activities towards zero waste. It projects the use, re-use and recycling of products without eventual disposal at any point of product lifecycle. Circular economy is a thriving concept that proffers solution to prominent challenges facing the minerals processing industry which include; resource depletion and environmental fouling. Also, it has inspired the eruption of new and functional business diversity into the mineral processing industry. The mining and subsequent minerals processing operations generate extensive waste volume in form of waste rocks, emissions, tailings, and waste water. The circular economy offers alternative options that can be harnessed within the mining industry. Also, in the smelting and refining stage, primary smelters usually charge scraps alongside primary concentrate and this has been broadly utilized. Precious metal such has gold which is becoming increasingly difficult to realize from primary sources has found circularity useful. The waste of electronics appliances such as smartphones, personal computers, digital devices etc, has boards that contains gold in reasonable quantities. The development in leaching technology using mineral acids and target metal adsorption using bio based adsorbent has facilitated an economical bio-friendly means of recycling the gold. Tailings are also processed using same approach. This paper reviews the evolving technology and processes that has made circular economy relevant in mineral processing with prime focus on gold ore processing.

COM22163: Monte Carlo Simulation of (COOH) Carboxyl-Group Adsorption onto TiO_2, ZnO and $ZnTiO_3$ (101) Metal Oxide Surfaces: for Dye Sensitized Solar Cell Applications

Kacem Cherifi, Abou Bekr Belkaid University; Ali Cheknane, Université Amar Telidji de Laghouat; Jean Michel-Nunzi, Queens Univercity; Khadidja Rahmoun Henaoui, University of Tlemcen

Abstract: Density functional theory calculations have been used to investigate the minimum energy structures of (COOH) carboxyl-group adsorption on TiO_2, ZnO and $ZnTiO_3$(101) metal oxides surfaces. Adsorption of COOH molecule on metal oxides (101) surfaces has been studied computa- tionally using Adsorption locator code in Material studio to indicate the preferred adsorption sites. In this article Monte Carlo simulation has been used to find low energy adsorption sites on both COOH as an adsorbate dye and the metal oxides as photoanodes substrate (101) for DSSC application, while the temperature of the whole system is gradually decreased. The results indicated that $ZnTiO_3$(101) has showed to be more compatible with COOH molecules in aggregation which could have more than 160 sties of adsorption configuration and an energy adsorption up to 400 kcal/mol (-17,57eV), leads to a high energy adsorption surface area with COOH.

COM22098: Next Generation Circular Processing of Silicon

Harald Philipson, Norwegian University of Science and Technology

Abstract: Simultaneous production of silicon (Si) and alumina (Al_2O_3) rich slag by the SisAl process has been demonstrated in pilot scale by a two-step batch process of aluminothermic reduction of calcia-silica slag. Initially, a Si alloy with approximately 70 wt% Si is formed by metal-to-slag ratio corresponding to different values around the Al-stoichiometry and varying basicity of the CaO-SiO_2 slag. This alloy is subsequently refined to the industrial standard metallurgical grade silicon (MG-Si) by reduction of a slag of mainly the same compounds but higher in SiO_2 and metal-to-slag ratio. The empirical data from laboratory and pilot scale trials, supported by theoretical (thermodynamic) calculations, were further used as the basis for an optimal design of a circular SisAl process i.e. that the product slag in the second process step is returned back to the initial process step.

COM22164: Green Development of China Rare Earth Industry

Yan Wang, Baotou Research Institute of Rare Earths

Abstract: Rare earth industry was regarded as the dirty industry in the past decades. Important changes have happened in rare earth industry in China since the new century and the rest of the world. China has taken great efforts to realize green production in rare earth mining, from mining, beneficiation, separation to downstream products and treatment of the tailings. Changes will be discussed in the paper.

COM22149: New Developments in the Recycling of Critical Metals from Spent Lithium-Ion Batteries

Norman Chow, Joey Jung, and Anca Nacu, Kemetco Research Inc.; Zarko Meseldzija and Larry Reaugh, American Manganese Inc.

Abstract: Advances in the commercial development of lithium-ion batteries is facilitating a transformational shift from fossil fuel to electric vehicles (EVs) The global push for a low carbon economy, competitive performance, and costs are contributing to a high predicted cumulative annual EV growth rate of 29% from 2020 to 2030. Cathode materials for high energy density lithium-ion batteries contain several critical metals such as lithium, nickel, cobalt, and manganese. Common chemistries for these latest generation cathode materials are $LiNi_{0.8}Mn_{0.1}Co_{0.1}O_2$ (NMC811) and $LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$ (NCA). The rapidly growing EV market is expected to lead to a parallel increase in demand for these critical metals. This paper provides an overview of a hydrometallurgical process developed to recycle spent lithium-ion battery cathode materials This process involves complete leaching of the critical metals and reformulation of high purity cathode materials for the production of new lithium-ion batteries. The filing of an International Patent Cooperative Treaty patent application and subsequent issuance of a United States patent provide a strategic opportunity to potentially recycle and reformulate materials for lithium-ion batteries in lieu of mined materials This presents a significant market opportunity to provide a consistent and stable supply of critical metals in a cost-effective and environmentally sound manner.

COM22129: Metallurgical Beneficiation Studies of Pyrochlore Composite Sample from Nukittooq Niobium-Tantalum Project, Greenland

Hao Li and Massoud Aghamirian, SGS Canada; John Goode, J.R. Goode and Associates; Jim Cambon, Hudson Resources Inc.

Abstract: The Hudson Resources Nukittooq Nb-Ta deposit is located on the southern margin of the Sarfartoq Exploration License in southwest Greenland. The mineral of economic interest is pyrochlore ($(Na, Ca)_2Nb_2O_6(OH, F)$), containing minor amounts of tantalum, titanium and uranium. Historical drill intercepts and a 2020 exploration campaign reported exceptionally high-grade niobium samples. A mineralogical analysis on a composite of the 2020 samples indicated calcium pyrochlore (37% by mass), aegirine (33%), K-feldspars (22%), biotite (5%), and trace amounts (ca. 2%) of other minerals, including rare earth minerals. Preliminary beneficiation testwork, including magnetic separation, gravity separation, and batch flotation, was carried out in this study and aimed at producing a saleable pyrochlore concentrate. Wet high-intensity magnetic separation and Mozley table processing produced a final niobium concentrate assaying 61% Nb_2O_5, at 45% global recovery. Flotation using a conventional amine-based flowsheet failed to upgrade the composite sample due to the flotation of the K-feldspar and aegirine gangue minerals. Ammonium fluorosilicate ($(NH_4)_2SiF_6$) was tested and proved ineffective for depressing aegirine under the conditions tested. However, the results indicated that a combination of Aero6494 (an alkyl hydroxamate), Florrea F3900 (modified hydroxamic acid) and lead nitrate could selectively float pyrochlore from K-feldspar and that subsequent amine-based flotation with fluorosilicic acid could effectively depress aegirine from pyrochlore. Final niobium concentrates assaying 55.3% Nb_2O_5 at a 66.6% global recovery, was generated through process optimization. About 35~60% of the REE, along with 63% of the uranium, 65% of the tantalum and 51% of the thorium, were reported to the niobium concentrates.

COM22056: New Sustainable Process to Produce High-Purity Lithium-Ion Battery Chemicals from Raw and Recycled Feedstocks

Rob Fraser, Amir Nazari, Lily So, Alexander Sutherland, and Sevan Bedrossian, Hatch Ltd.

Abstract: Climate change is driving electrification of transportation and the need for lithium-ion batteries (LIBs). The demand for LIBs in the next decade is expected to grow ten-fold, which will translate to similar demand growth for battery chemicals, particularly battery-grade nickel and cobalt sulphates. Due to the small consumption of LIBs to date, the supply of high-purity battery chemicals is primarily based on modifications of existing metallurgical plants. Additionally, most existing and proposed facilities produce soluble by-product salts like sodium sulphate that pose marketability and/or environmental challenges. The conventional methods to produce nickel and cobalt sulfates include dissolution of London Metal Exchange (LME) grade metal and refining of metal intermediates such as matte, mixed sulfide precipitate, and mixed hydroxide precipitate, which present challenges of process complexity, high reagent consumption, and generation of low value by-product. This paper introduces a proprietary process that addresses the challenges of conventional methods while enabling production of high-purity nickel and cobalt sulphates from the raw and recycled feedstocks.

COM22015: Value of Analytical Process Monitoring for Critical Minerals – Lithium & Uranium

Marie-Eve Provencher, Uwe König, and Allan Ball, Malvern Panalytical

Abstract: Increasing demand for critical minerals and metals that are essential ingredients to modern economies and emerging technologies boosted the global demand and the need of more efficient exploration and ore processing. The efficiency of ore beneficiation is in most cases directly determined by the ore mineralogy. Modern analytical techniques for exploring new green or brownfield deposits or processing of ores will be discussed. Special focus is given to the use of X-ray diffraction combined with new statistical tools like data clustering and on-line elemental monitoring of process liquids. Case studies from lithium ores as well as uranium leach solutions demonstrate the benefits of frequent, fast and accurate analytical monitoring to react fast changes in ore composition, accurate blending of different ore grades and optimal recovery rates.

COM22193: Effect of End-of-Life Content on Microstructure of High-Vacuum High-Pressure Die Cast Aural2 (AlSi10Mg-T7)

Yuki Ando, McMaster University

Abstract: Cast Al alloys are widely used in automotive applications due to their high strength-to-weight ratio, especially for the components with complex geometry. Additionally, high-vacuum high-pressure die casting (HVHPDC) is a preferred casting method as it mitigates the gas porosity. Recently, the idea of utilizing End of Life (EOL) material to produce so called "secondary alloy" castings is attractive from an improved sustainability perspective. In this research, the effect of EOL content (40, 75, and 90%) on the microstructures of secondary HVHPDC Aural2 (AlSi10Mg-T7) alloys, relative to the primary alloy (0% EOL content) was determined using light optical microscopy (LOM) and scanning electron microscopy (SEM) techniques. The differences between the primary and secondary alloys in terms of Si eutectic distribution were identified and quantified using LOM coupled with image analysis. The intermetallic particle distribution within the skin, relative to the core was also determined using backscattered electron SEM images. The size and distribution of the Fe based intermetallic particles found to be higher around the skin regions of the secondary alloy castings, however, no distinguishable differences were observed in the core. This research provides the microstructure characterization that is requisite for the interpretation of both mechanical properties and corrosion performance.

COM22077: Mechanical Properties and Fracture Behavior of Additively Manufactured A205 Alloy: Effect of T7 Heat Treatment

Ali Shojaei and Mohsen Mohammadi, University of New Brunswick

Abstract: High-strength Al-Cu-Mg-Ag-(Ti) alloy inoculated with TiB_2 nanoparticles was used to additively manufacture horizontal bars using laser powder-bed fusion (LPBF). Samples were post-processed using T7 heat treatment to compare with as-built condition. Mechanical properties and microstructure of both as-built and HTed samples were investigated using scanning electron microscopy, electron backscatter diffraction, transmission electron microscopy, energy dispersive X-ray spectrometry, micro/nano hardness, and uniaxial tensile tests. Results demonstrated that higher thermal supercooling in LPBF can activate numerous TiB_2 particles for heterogeneous nucleation. Thus, the average grain size in the as-built samples were refined to the level that the manufactured materials can be categorized as ultra-fine grain materials showing yield point phenomenon followed by the formation of Lüders bands. T7 heat treatment led to inhomogeneous grain growth and precipitation of different strengthening agents such as GP zones, θ'', θ' and Ω phase in the microstructure, which affected the mechanical properties. In the HTed samples, the discontinuous yielding disappeared, and the yield and ultimate tensile strength increased considerably at the expense of ductility. The formation of intermetallic compounds surrounded by precipitation-free zones along the grain boundaries was responsible for the dramatic decrease in ductility of HTed samples.

COM22166: Microstructure and Corrosion Behavior of Al-Ce Eutectic Alloy Solidified Under Ultrasonic Vibrations

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In the current Investigation, as-received eutectic Al-10 wt.% Ce alloy was prepared by casting and solidified under ultrasonic vibrations. The microstructures of the samples that were prepared under different UST temperatures were investigated. The fragmentation of $Al_{11}Ce_3$ phases was also observed. Corrosion behavior of the alloy was analyzed and related to the microstructure refinement that was achieved by UST at different temperatures. The specimen which showed the best resistance to corrosion is the one which was solidified under the optimum UST temperature, 655 °C, and achieved the finest structure.

COM22097: Statistical Distribution of Spontaneous Recombination Radii of Frenkel Pairs in FCC and BCC Metals

Hao Sun and Laurent Béland, Queen's University

Abstract: The recombination radius of Frenkel pairs generated by incident high-energy particles represents a critical determinant of irradiation-induced microstructure evolution. Mesoscale models of radiation damage evolution that include recombination radii as input parameters can benefit from a better understanding of the atomistic processes controlling recombination. This work used the kinetic activation relaxation technique—an off-lattice, self-learning kinetic Monte Carlo algorithm—in conjunction with molecular dynamics simulations, to study the statistical distribution of the recombination radii in four FCC (nickel, copper, silver, and platinum) and one BCC (iron) structures. We found that recombination can occur from the 2nd nearest neighbor site (neighbor site) to as far as the 18th neighbor site. Such long-range recombination is realized via the formation of crowdions. Vacancies were found to have no effect on interstitial migration, aside from diminishing the recombination energy barriers, which are linearly related with diffusion energy barriers. No correlation was found between energy barriers and recombination radii. Instead, because the interatomic interaction in high-stacking-fault-energy metals has a directional character akin to covalent bonds, the deformation near self-

interstitials distributes mainly along the closest packed directions. As a result, crowdions more readily form between Frenkel pairs at longer distances, resulting in larger recombination radii. Similarly, hydrostatic pressure enhances the recombination radius by extending the distortion induced by self-interstitials along the closest packed directions. Thus, the deformation distribution near self-interstitials is the determining factor controlling recombination radii, not energy barriers.

COM22025: High Temperature Hydrogen Reduction of Bauxite Residue for Iron Recovery

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Abstract: In order to develop a low-carbon footprint process for industrial waste valorization of the Bauxite residues (BR), the hydrogen reduction of BR mixed with limestone was studied for the purpose of simultaneous iron and calcium aluminates production. For this purpose, pellets were made out of a mixture of the BR and limestone, and subsequently were sintered at 1200°C. Then the pellets were reduced in pure hydrogen in a vertical tube furnace at 1070–1200°C where hydrogen was introduced from bottom to the pellet bed. The products of the reduction were then characterized by X-ray diffraction technique, which revealed the complete reduction of Iron. The byproduct of the hydrogen reduction is shown to be Mayenite (calcium aluminates), $CaSiO_4$, and $CaTiO_3$ phases. In the reduction experiments the effect of temperature, and reduction in isotherm/non-isotherm regimes were studied. Microstructural analysis was done by electron microscopy on the sintered pellets and the corresponding reduced pellets. It was found that the size of the evolved iron grains are larger when reduction temperature is higher.

COM22117: Effect of Ultrasonic Impact Treatment on the Microstructure, Residual Stress, and Mechanical Properties of Ti-4Al-2.5V-1.5Fe

Peter Walker, Abu Syed Kabir, and Mostafa El Sayed, Carleton University

Abstract: Ti-4Al-2.5V-1.5Fe is an α+β titanium alloy used mostly as military grade armor, but is becoming increasingly popular in aerospace, biomedical and marine applications for its combination of high strength and ductility. In this study, an Ultrasonic Impact Treatment (UIT) were performed on Ti-4Al-2.5V-1.5Fe, using parameters previously optimized for Ti-6Al-4V. Specimens were analyzed using both optical and scanning electron microscopes for microstructural analysis, X-ray diffraction for residual stress measurement, Vickers microhardness testing for local mechanical properties. Comparing the results with a similar previous study on Ti-6Al-4V, Ti-4Al-2.5V-1.5Fe displays higher compressive residual stress than Ti-6Al-4V after UIT. Unlike Ti-6Al-4V, Ti-4Al-2.5V-1.5Fe did not form any nanocrystalline layer and there was no visible microstructural change after UIT. Ti-4Al-2.5V-1.5Fe showed greater changes in hardness than Ti-6Al-4V.

COM22007: Particularities of Creation, Structure, Chemical, and Phase Compositions of Ni(Co)CrAlY/ZrO_2 -Y_2O_3 Thermo-Barrier Coatings Condensed from Vapor in One Technological Cycle EB-PVD

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Abstract: Thermo-barrier coatings are essential for working conditions and life extension of gas turbine blades. The complex interactions among the four main layers: upper ceramic layer; thermo-grown oxide; hot metal strength (connected) layer; based hot strength alloy (blade body), needs more development to

guarantee stable thermo-barrier coating work in the future at much higher temperatures. Thermally grown oxide connects metal and ceramic layers in the thermo-barrier coating (TBC). A long-term life of TBC at the high temperatures thermo-changes mostly depends on the oxidation of the top metallic connected layer of Ni(Co)CrAlY as a speed of Al_2O_3 film growing on the borderline of Ni(Co)CrAlY/ZrO_2-Y_2O_3 as well as Al2O_3 film adhesion. Slow down of hot straight layer oxidation and its adhesion increase more extended life of ceramic layer integrity and, as a result, longer life of TBC itself. The structure, chemistry, and phases composition were studded in two TBC metal/ceramic layers obtained by EB-PVD in one technological cycle. The authors found an optimal technological regime of coating formation, chemical, and phase compositions of the diffusion barrier layer to slow down diffusion processes between metal and ceramic coatings.

COM22089: Microstructure Contribution in Microparticle Impact Morphology of High Entropy CrMnCoFeNi Alloy

Roghayeh Nikbakht, University of Ottawa

Abstract: In cold spray consolidation method, micron-size particles are accelerated to high velocities and deposit to a substrate as a result of plastic deformation and native oxide removal. Therefore, microstructure variation of powder particles may result in different impact physics and ultimately impact morphology. In this study, a gas atomized spherical CrMnCoFeNi high entropy alloy particles were sprayed on different substrates using helium as a process gas (3.2 MPa and 400 C). The morphology and microstructure of the single particles were analyzed using tilted view secondary electron images, electron channelling contrast imaging (ECCI), and electron backscattered diffraction analyses. The ECCI maps of the cross-sections of powder particles show different morphologies: particles with elongated grains and particles with relatively equiaxed structures. The deformed particles morphology change from perfect half-sphere with jetting zones located at the lips to half sphere morphology with some protuberances in the rim of the particles. ECCI maps and inverse pole figure maps of CrMnCoFeNi particles with an equiaxed grain distribution present a symmetrical half-sphere impact morphology while the particles with elongated morphology deviate from symmetrical half-sphere morphology and are closer to a top-hat morphology. Kernel average misorientation maps demonstrate a higher degree of misorientation at grain boundaries of elongated grains which implies that grain boundaries are involved in the variation of particle impact morphologies by affecting the mechanism of plastic strain transfer or slip transfer (transmission) between particle grains. The generated dislocations at the lower part of the particles can move easily inside the elongated grains—or toward the free surface of the particle—without being forced to transmit to the neighbouring grains resulting in a variety of impact morphologies.

COM22047: Selective Leaching of Vanadium from Salt-Roasted VTM Concentrate and Preparation of High-Concentration Vanadium Solution

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Abstract: Vanadium is an important material almost used in steel industries due to its high physical properties. Also, the commercialization of vanadium redox flow batteries is expected to increase the global demand for vanadium over the next few years, and a novel process for recovering vanadium has been developed. The present study investigated the water leaching behavior to recovery vanadium from vanadium-bearing titaniferous magnetite (VTM) concentrate. To extract vanadium from concentrates,

roasting with sodium carbonate (Na_2CO_3) to convert vanadium into water-soluble sodium vanadate was firstly performed. The water leaching of vanadium from the resultant powder was secondly carried out to investigate the effect of different leaching conditions such as leaching temperature, the duration for the leaching step, and pulp density. To recover the vanadium from leach liquors efficiently, reducing the generation of impurities and preparing a high-concentration vanadium solution in the leaching process is necessary. Therefore, low-temperature multi-stage leaching based on the preliminary leaching results was performed in this study. The 4th stage leaching gave rise to leach liquors of vanadium of 16.9 g/L, and aluminum of 1.68 g/L, and silicon 0.15 g/L, where the leaching efficiency of vanadium was about 88% for each stage. These results indicate that the high-concentration sodium vanadate solution with much low aluminum level can be prepared by low-temperature multi-stage leaching.

COM22053: Recovery of Rare Earth Elements from End-of-Life NdFeB Permanent Magnets Utilizing Deep-Eutectic Solvents

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Abstract: Rare earth elements (REEs) are used in various high-technology industries. Among their many applications, REEs are mainly used in permanent magnets, which have high magnetic strength and exceptional durability. As many countries have recently committed to achieving Net-Zero status by 2050, the use of NdFeB permanent magnets is being expanded to the field of electric vehicles, which are expected to replace internal combustion engine vehicles. Accordingly, it is expected that the number of waste magnets will increase exponentially in the next 5 to 10 years. Because NdFeB permanent magnets generally contain 27–32 wt.% REEs, it is economically beneficial to recover the REEs. To date, many hydrometallurgical magnet recycling technologies in aqueous media have been developed, but they generally consume a large amount of water and chemicals. Thus, in this study, a non-aqueous medium, solvent-based REE recovery method was investigated. As non-aqueous media, deep eutectic solvents (DESs), especially type III DESs, have shown good performance as a lixiviants of REE oxides. The DESs consisting of quaternary ammonium salt and carboxylic acid can selectively leach REEs from a mixture of Nd and Fe oxides. Therefore, in this study, the possibility of Nd leaching was first confirmed by dissolving Nd_2O_3 in 6 different DESs, and the selective leaching of Nd from a synthetic Nd and Fe mixture and actual NdFeB magnets was investigated. Among the 6 DESs, guanidine hydrochloride-lactic acid DES showed the highest Nd_2O_3 leaching efficiency of 99%, and as a result of leaching synthetic Nd and Fe mixture with this DES, 100% Nd and 6.22% Fe showed high Nd selectivity. After NdFeB magnet powder is oxidatively roasted in the air, it becomes form of $NdFeO_3/Fe_2O_3$ instead of Nd-$2O_3/Fe_2O_3$, and the leaching by DES resulted in low leaching efficiencies of 26.51% for Nd and 4.73% for Fe. Therefore, it is significant to oxidatively roast the permanent magnet to produce an independent oxide structure such as Nd_2O_3/Fe_2O_3 to selectively leach Nd. Consequently, for the selective leaching of Nd using DESs, oxidative roasting conditions in which rare earth and iron produce distinctive oxide structures should be established, and this aspect is currently being studied.

COM22034: Indium and Germanium Recovery by Solvent Extraction from Zinc Concentrate

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Abstract: The indium and germanium recovery by solvent extraction from a zinc concentrate was studied. A sample of concentrate from Bolivia, with typical mineralogical characteristics of the Andes region, was used. The concentrate containing 49% zinc, 8.3 % iron, 27.55 sulfur, 120 ppm of silver, 496 ppm In and 57 ppm Ge from Minera Viacha was characterized chemically and mineralogically (atomic absorption, X-ray diffraction, and scanning electron microscopy) and leached in a PARR bench scale reactor. In a first stage, the concentrate was leached and the tailings were treated in order to silver recovery by change of pH, cyanidation and charcoal for concentrate the solution and finally precipitated by zinc dust. In the next stage a solvent extraction study was realized.The methodology used was prepare synthetic solutions of each element and studied the effect of zinc, and iron during the solvent extraction.Then study the effect of extraction of indium in the germanium presence and vice versa. Finally the solvent extraction for indium and germany from the pregnant solutions was studied. Extractans used were D_2EHPA, CIANEX 923, LIX 973N and solvents kerosene, hexane, toluene and acetone. TBP was used like modifier and the variables studied were organic concentrations, organic and aqueous ratio and time of stirring. The studied was realized at constant temperature of 25°C, using a GFL shaker. Reextraction experiences were carry out using hidrochloric acid at diferents concentrations. The extractant D_2EHPA showed to be better than CIANEX and LIX for indium and germanium extraction.

COM22194: A Materials-by-Design Approach to Develop Copper Composites for Thermal Management Applications

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Abstract: To design multi-phase particulate Cu-composite for high-performance heat spreaders used in electronic devices, a computational framework based on effective-medium theory and mean-field homogenization is applied. To design various Cu-composite heat-spreaders, several potential particulate types are considered based on their intrinsic properties, resulting in desirable properties such as low coefficient of thermal expansion (CTE), low density, and improved structural response without compromising required thermal conductivity. The thermal interface of the matrix-particulate is the key determinant for sustaining high thermal conductivity implying that ceramic particles (Beo, SiC, and AlN) are favored options when loaded up to 30% vol percent despite their comparatively poor inherent thermal conductivity. Diamond particle, on the other hand, provides the best results when its wettability with copper is enhanced by surface treatment, owing to its inherent high thermal conductivity and low CTE. At extremely low volume concentrations, controlling the surface wettability of diamond particles by Ni-coating sintered with Cu is reported to produce thermal conductivity greater than the value of pure Cu. Composites sintered with sub-micron particles had higher porosity than composites sintered with micron-sized particles, which has a direct bearing on thermal and mechanical properties, as proved by experimental results. The collected data on densification and particle-matrix interface conditions are utilized to calibrate the models in order to determine their effect on the ensuing thermal and structural properties. The comprehensive computational design, which has been confirmed and calibrated using actual data, is likely to aid researchers and the electronic sector in the development of high-performance heat spreaders with tailored properties.

COM22074: Catalytic Leaching of Common Fe-Cu-S Minerals in a New Calcium Chloride Based Deep Eutectic Solvent

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Abstract: Fe-Cu sulphide minerals are the most important source of copper globally with an estimated 90% of Cu being derived from sulphide deposits. Current technologies process Fe-Cu sulphides through

energy and water intensive pyro-and hydrometallurgical methods that generate significant environmental contamination. With the demand for Cu expected to increase over the upcoming decade due to the implementation of green technologies, expansion of the global middle class, and electrification of transport infrastructure, there is a need to develop new environmentally sustainable sulphide mineral processing routes. deep eutectic solvents (DESs) are an innovative processing technology composed of common, low cost, environmentally benign components that have been demonstrated to be very effective for recovering metals from primary and secondary sources. Here we present the first investigation into the viability of using a new DES based on $CaCl_2$ (CaDES) alongside a redox catalyst for the leaching of a range of Fe-Cu sulphides including chalcopyrite, pyrite, arsenopyrite and pyrrhotite. It was confirmed that $FeCl_3$ has a high solubility in CaDES, allowing its use as a strong, relatively benign, electrocatalytic oxidising agent. Chalcopyrite is effectively leached in this system while the low value pyrite and arseonpyrite remain inert. CaDES therefore offers a low cost, environmentally benign, method for the preferential leaching of copper bearing chalcopyrite from complex sulphide mixtures.

COM22198: Development of Metal Rotary Friction Damper for Non-Structural Components Vulnerable to Overturning

SeungJae Lee, SangHyun Park, SeungHee Kim, and KyoungKyu Choi, Soongsil University

Abstract: Damper systems are mainly used in buildings and facilities to resist against large or moderate earthquake. Dampers, which are mainly used in structures, are based on energy dissipation during plastic deformation of steel components. However, the repeated loading and the energy dissipation of the steel dampers could reduce their durability. Therefore, in this study, a rotary steel friction damper based on frictional mechanism was developed, which does not cause any bad effect on durability. The rotary friction damper system was developed by combining friction pads and the steel plates with high-tension M12 bolts. In addition, the friction pads used for fabricating the damper were made of the friction material used for the brake of the vehicle, with a friction coefficient of 0.4. In order to verify the performance of the damper system, this study conducted a shaking table tests on electrical components that are vulnerable to overturning and a mold transformer with 1000 kVA capacity. The proposed damper system was installed on the bottom side of the mold transformer, and improved the seismic performance of the mold transformer by reducing the lateral deformation during earthquake. The seismic performance of the 1000 kVA transformer retrofitted with the proposed retrofit system was evaluated by performing full-scale shaking table test, and the test results were compared with those obtained by the analytical model. In the shaking table test for a mold transformer using general details without damper systems, an excessive displacement of approximately 180mm in the Y-direction (weak direction) was found. On the other hand, when using rotary friction dampers on the left and right sides of the mold transformer, the maximum displacement in the Y-direction was about 50mm. Seismic acceleration can affect not only the frame and core of the mold but also internal components. From the shaking table test for 0.9g of PGA, the maximum response acceleration in the Y-direction was 3.3g when using conventional details while that was 1.84g when using friction dampers. The use of the dampers showed the reduction in response acceleration by 25.9% in the X-direction and 44.2% in the Y-direction at the top part of the mold. This is because the developed friction damper could mitigate bolt loosening at the bottom main frame of the electrical components during moderate ground acceleration, and prevent overturning or collapse during strong ground accelerations and/or excessive lateral displacements. In addition, the analytical model based on the test results was developed and showed a good agreement with the shaking table test in terms of peak acceleration and displacement.

COM22172: Effect of Hydration Film Formation in Washing Process on Bond Strength of Silane Coupling Treated AM100 Alloy

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Abstract: Effects of the formation of a hydrated film on the adhesive strength during the silane coupling treatment in the pretreatment of the magnesium alloy bonding process, have been investigated. As silane coupling agent forms a condensation reaction with the oxide on the metal surface, the metal surface needs to be a strong oxide film with OH groups having sufficient reactivity. However, since a thick hydrate layer with inferior strength grows in magnesium alloy due to contact with water, it is necessary to avoid the use of water in the rinsing process after pickling. In this paper, silane coupling treatment is performed using a 100-hours solution-treated α-single-phase AM100 mold casting material as a material. The cleaning liquid used for rinsing during the cleaning process before the silane coupling treatment is used as two conditions, distilled water and isopropanol, to change the growth state of the hydrate layer, and the cause and effect of the two types of cleaning process and the tensile adhesive strength of the adhesive joint. Relationship between the state of the formation of the hydrated film and effect of the two types of cleaning process have been discussed.

COM22005: Effect of Strong Collectors and Frothers on Coarse Particle Flotation using the HydroFloat™ for a North American Concentrator

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Abstract: In conventional flotation, particles greater than 150 μm tend to float poorly, especially those with high specific gravity The development of flotation equipment such as the HydroFloat™ has made it possible to increase coarse particle recovery Such equipment has been implemented in the mining industry and has resulted in significant improvements in coarse particle recovery In addition to appropriate equipment such as the HydroFloat™, strong collectors and frothers improve coarse particle recovery A North American concentrator processing copper-molybdenum ore has been having difficulties in recovering particles coarser than 150 μm Presently, the concentrator is using sodium ethyl xanthate and X-133 frother (baseline) Previous tests conducted using stronger collectors and frothers showed that potassium amyl xanthate and FrothPro 630 increased copper recovery by 3% using a conventional laboratory flotation machine In that testwork, the chalcopyrite recovery for particles >300 μm was low (~55%) under a range of testing conditions Thus, the HydroFloat™ was used to perform tests using potassium ethyl xanthate (PEX) and potassium amyl xanthate (PAX) in an attempt to increase copper recovery for particles >300 μm The results showed that the recovery of chalcopyrite particles >300 μm increased significantly when using the HydroFloat™.

COM22196: Effects of Shot Peening on an Aluminum Metal Matrix Composite Used for Automotive Applications

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Abstract: The basic sequence involved in fabricating components via powder forging include compaction, sintering, and forging. Like most parts produced through other manufacturing technologies, powder metallurgy parts are susceptible to fatigue failure at their surfaces. This is because tensile stresses and/or pores, which are known to promote fatigue cracking, are present on their surfaces. Since most fatigue cracks initiate from the surface of metallic components, secondary surface modification operations which can induce compressive stresses on the surface of metals are used to suppress the initiation of such cracks and enhance fatigue resistance. An example of such technology is the already well-established shot peening process. The main parameters which affect shot peening are pressure, flow rate and stand-off distance In this work, the traverse speed of the sample, in combination with the other parameters (pressure and stand-off distance), were optimized to produce different peening intensities. This work explores the effects of Almen intensities on the microstructure and properties of an industrially processed, aluminum metal matrix composite (Al-MMC). Characterization of the microstructure and properties of the shot peened Al-MMC material was performed by evaluating the surface attributes and residual stress.

COM22043: Extraction of Rhenium from PWA 1484 Superalloy Scrap Using Electrogenerated Chlorine Leaching in Acid Solutions

Yujin Park, Resource Recycling Department, University of Science & Technology; Min seuk Kim and Sookyung Kim, Korea Institute of Geoscience and Mineral Resources

Abstract: For the development of hydrometallurgical recycling process of Ni-based superalloy scrap containing various valuable metals such as Ni, Co, Cr, W, Ta, Re, etc., the extraction of the most expensive Re from PWA1484 superalloy scrap was studied. The superalloy scrap was pretreated by Ni-Al intermetallic compound formation for easy comminution by a pyro-metallurgical pretreatment at 1500°C. Then, the air-cooled melting was ground as powder under 150 μm by mortar for leaching. As a result of ICP analysis, the ground sample contains approximately 1.5% of Re. The selective recovery of Re was processed by two-stage leaching, the first leaching of hydrochloric acid to dissolve base metal such as Ni, Co, Cr, and Al and the electrogenerated chlorine leaching to leach the Re in the second leaching. In the first stage, over 99% of Ni, Al, Co, and Cr were leached in 60 minutes at 90°C in 4 mol/L hydrochloric acids, whereas only less than 3% of Re was leached in the solid/liquid ratio of 40 g/L. Increasing the solution temperature from 50 to 90°C did not distinguishable effect for the leaching of base metals, whereas Re showed a slight convex-like curve, with the highest value of 11.6% at 70°C. The leaching percentage of Re was increased with the solid/liquid ratio from 2.4% at 40 g/L solid/liquid ratio to 25% at 200 g/L solid/liquid ratio, whereas Ni, Al, Co, and Cr showed a lower leaching percentage at a higher solid/liquid ratio. In the experiment using sulfuric acid instead of hydrochloric acid, the dissolution of Re was suppressed less than 2% at a higher solid/liquid ratio. However, the leaching of Al, Co, Cr was reduced with increasing solid/liquid ratio in sulfuric acid solution. In the second leaching, the remaining Re in the residue from the first stage in 4 mol/L hydrochloric acids at 90℃ in 60 minutes was leached out using the electrogenerated chlorine as an oxidant at 80°C, 0.43 mmol/min chlorine supply, and 10 g/L solid/liquid ratio in 4 mol/L hydrochloric acids. As a result, over 99% of Re was leached in 20 minutes, whereas little leaching of Ta(0.23% in 180 minutes)was observed. Therefore, we could leach base metal(Ni, Al, Co, Cr), and Re selectively by the two-step leaching process while leaving Ta in residue.

COM22105: Formability of Twin-Roll Cast Mg-9%Al-xSn Mg Alloys at Room Temperature

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Abstract: This paper deals with characteristics of twin roll cast of Mg-9%Al-xSn (AT series) alloys. The effect of Sn addition on the precipitation behavior of Mg-9%Al-xSn during twin roll casting has been investigated in the present study. It has been considered that the addition of Sn is effective in suppression of discontinuous precipitation as well as acceleration of continuous precipitation. To enhance formability of magnesium alloys at room temperature, it has been expected that recrystallization with randomized orientation at the Mg_2Sn particles at the grain boundary grain boundaries. In this research, firstly distribution of the Mg_2Sn particles at the grain boundary during twin roll casting has been investigated. The mechanical properties of twin-roll cast Mg-9%Al-xSn alloys have been clarified by tension test, hardness test, as well as V-bending tests of cast strips. Due to rapid cooling of the twin-roll casting process, the crystals size of the cast Mg-9%Al-xSn material were very small. The effects of Sn content affect precipitation of beta phase as well as grain size. The addition of Sn enhances the aging response by solid solution hardening effect as well as by co-precipitation of $Mg_{17}Al_{12}$ and Mg_2Sn in the α-Mg matrix. By applying twin roll casting into fabrication of Sn content magnesium alloys, it has been found that the rapid cooled Mg-9%Al-xSn have possibilities of the practical application of magnesium products due to their better mechanical properties.

COM22033: Increasing the Toughness of HPDC AlSiMg Alloys through Nb-Based Grain Refiner Additions

David Levasseur, Nicolas Dion, and Franco Chiesa, Centre de métallurgie du Québec

Abstract: The high pressure die casting (HPDC) process is well suited to mass production of aluminum complex parts and is increasingly used in the manufacturing of car components. Structural HPDC parts are typically heat treated to the T6 or T7 state using a "low" temperature solutionizing to avoid blistering. Distortion, however, remains a major issue which drives the efforts to use parts in the T5 state, even if the ductility is lower than with the full T6/T7 heat treatment. Most parts manufactured from typical Al10Si-Mg alloys that are assembled by self-piercing-rivets (SPR) in the F or T5 state experience cracking, whereas no cracking occurs in the T6/T7 state. The present investigation seeks to increase the toughness of AlSiMg alloys in the T5 state so they can be assembles by SPR without concerns regarding cracking in the plastic deformation zone close to the SPR. Additions of Nb-based grain refiner was found to increase the Charpy impact resistance of Al10SiMg and Al6SiMg in the T5 state. The effect of the the Nb-based additive on the microstructure will be investigated.

COM22148: Influence of Build Parameters on the Surface Roughness of 316L Stainless Steel DMLS Prints

Lucas Gallant, Amy Hsiao, and Grant McSorley, University of Prince Edward Island

Abstract: Direct metal laser sintering (DMLS) is an established powder-bed fusion technology in metal additive manufacturing. However, printed parts suffer from high surface roughness from stair-stepping, balling, and adhered powder material, particularly on unsupported overhanging features. Some main factors for the roughness of overhangs include laser exposure parameters, part orientation, and thermal conductivity of the powder bed. Improving as-built roughness can reduce post-processing time and support material. This work compares test specimen prints using argon and nitrogen shielding gases and two powder particle size distributions with a focus on roughness and related porosity. Laser power, scan speed, and hatch distance are also investigated using a response surface DOE. Results from contact and optical profilometry show that N_2 does not significantly decrease downskin roughness despite having a lower thermal conductivity and that a finer powder has a greater positive effect on upskin surfaces than

downskin. Optimized exposure parameters reduce the Ra of 30-degree overhangs by over 25% while maintaining high relative density.

COM22041: Influence of Oxidative-Sintering Induration on Reaction Kinetics and Ferrochrome Quality in the $CaCl_2$-Assisted Direct Reduction of Chromite Process.

David Carter, Jason Coumans, and Dogan Paktunc, CanmetMINING, Natural Resources Canada

Abstract: Induration is an integral part of the Outotec Process to promote mineralogical changes and improve chromite reducibility in arc furnaces, and it was hypothesized that the rim developed on pellets during induration would also lead to improved ferrochrome quality in the direct reduction of chromite process. The pellets used in this work were composed of ground chromite ore from the Ring of Fire (consisting of chromite; $(Mg_{0.4}Fe_{0.6})(Al_{0.6}Fe_{0.1}Cr_{1.3})O_4$ and minor clinochlore), calcined petroleum coke, and $CaCl_2$ as a flux. In each experiment, pellets were heated up to 1000°C in Ar, and then indurated by a 20% CO_2 / 80% N_2 containing gas atmosphere for 10 minutes prior to further heating and reduction under Ar at 1300°C for 120 minutes. The CO concentration in the off-gas was measured using an Infra-Red analyzer and correlated with Fe-Cr metallization. Reduced pellet grains were qualitatively analyzed for particle size distribution, shape, texture, and metallization using BSE images. Induration did not improve the ferrochrome quality of reduced pellets. Reduction kinetics at high temperatures were slower for pellets that were indurated, and reductant particles became smaller during oxidative sintering due to their partial combustion, leading to the production of smaller ferrochrome particles. These findings suggest that the additional complexity of indurating chromite pellets for the direct reduction process is not justified.

COM22183: Investigation of Slag in a FeSi75 Furnace

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Abstract: Metallurgical silicon/ferrosilicon is produced industrially in a submerged arc furnace by carbothermic reduction of quartz. In addition to raw materials, oxide impurities are present in the furnace. Accumulated slag is typically found along the furnace walls towards the charge top, as well as the furnace bottom and the taphole, resulting in tapped slag together with the metal. During optimal tapping the small amount of slag will follow the alloy. Accumulated slag in the furnace will affect the furnace operation. Large amounts of accumulated slag in the furnace will have a negative effect on the operation and lead to more CO_2 emissions. Tapped slag samples from a FeSi75 furnace have been collected and analyzed. This slag consists of SiO_2-CaO-Al_2O_3. During the sampling period, limestone was added to the furnace to study its effect on the slag composition and viscosity. In addition, high-viscosity slag samples were collected during challenging tapping conditions. It is found that these samples contain higher SiO_2 concentrations than slag collected during normal operation. Charge samples were also collected and revealed slag containing Si, Na, K, Mg, Al, Fe and Ca.

COM22197: Next Generation Additively Manufactured Sleeve to Mitigate Thermal Stresses in Oil & Gas Severe Service Applications

Fadila Khelfaoui, Velan; Luc Vernhes, Velan

Abstract: Damage has occurred in various oil and gas applications, particularly when equipment is subjected to thermal shock It has been shown that catalyst injection and withdrawal valves in Ebullated

bed hydrocracking reactors exposed to daily thermal cycles are prone to thermal cracking. Several solutions have been developed to mitigate thermal fatigue. The solutions currently in use include the pre-heating of the valves and the addition of thermal barrier coated sleeves. While these solutions have achieved some success, they continue to present shortcomings. Leveraging 3D printing technology, the Hexa-shield sleeve was developed by Velan as an alternative solution. The Hexa-shield sleeve, made of Inconel 718 material, is intrinsically designed to provide thermal insulation. To assess thermal insulation and stress reduction performance of the Hexa-shield sleeve, an FEA simulation was developed and compared with thermal shock results obtained experimentally. Results show temperature gradient and average stress reduction of 50% and 70 %, respectively. This presentation outlines the challenges encountered during design development and additive manufacturing. The successful utilization of additive technology to mitigate thermal stresses will be highlighted.

COM22052: Precipitation Behavior of Ammonium Polyvanadate from Sodium Vanadate Solution

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Abstract: Vanadium plays significant roles in high-tech field such as alloys, catalyst, vanadium redox flow battery, and aerospace for its unique and excellent physical and chemical properties. There are various methods for recovering vanadium from aqueous solution, but a precipitation process is most frequently used to produce V_2O_5. From vanadium-bearing solution, mostly sodium vanadate[$NaVO_3$] solution, vanadium can be precipitated in different crystalline forms depending on the solution pH and it can be recovered as ammonium metavanadate[NH_4VO_3] in alkaline media and ammonium polyvanadate[$(NH_4)_2V_6O_{16}$] in acidic media. Unlike ammonium metavanadate, which is precipitated even at room temperature, ammonium polyvanadate is precipitated at a high-temperature of 80°C or higher by hydrothermal reaction. Although the ammonium metavanadate can be formed at more ambient condition, the reaction has some flaws. An ammonium salt used for precipitation is decomposed into ammonia as the solution pH increase, and the precipitation efficiency can decrease during the ammonium metavanadate forming reaction. In addition, sodium polyvanadate, not ammonium metavanadate, is precipitated at pH 8 or less to lower the purity. In alkaline media, pH of solution has a large effect on precipitation efficiency, whereas in acidic media, pH of solution has little effect on precipitation efficiency. Also, the precipitation of ammonium polyvanadate has a faster reaction rate than precipitation in alkaline media. Therefore, in this study, the precipitation characteristics of ammonium polyvanadate in the acidic media were investigated. As experimental variables, precipitation temperature, solution pH, vanadium concentration, and addition amount of ammonium salt were selected and their effect on ammonium polyvanadate precipitation efficiency was investigated. In addition, the behavior of the ammonium polyvanadate precipitation reaction was investigated through the kinetics of the precipitation reaction.

COM22146: Purification of Natural Graphite Concentrate and Optimization of the Leaching Process

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Abstract: Graphite is a common anode material for electric vehicle lithium-ion batteries (EV LIBs). Among the types of graphite, flake graphite is a suitable feedstock for EV LIB anode production due to its abundant reserves and high graphitization degree. EV LIB production requires 10 times the mass of graphite than lithium, and high purity flake graphite is required for anode production. Raw flake graphite can be concentrated by flotation, but residual iron sulphide and silicate impurity concentrations must be reduced for energy storage applications. Phosphoric acid is an unconventional lixiviant, as hydrofluoric acid, sulfuric acid, and hydrochloric acid are more common graphite impurity leaching agents. Design of experiment was applied to evaluate and optimize the effect of phosphoric acid and condensed phosphate concentrations, leaching time, liquid to solid ratio, and temperature, as well as the interaction between the factors, on impurity removal efficiency. The efficiency of the leaching conditions on the graphite was evaluated with X-ray diffraction and X-ray fluorescence. Microwave plasma atomic emission spectroscopy was used to measure dissolved silicon, aluminum, potassium, sodium, and iron in the leach solutions. Kaolinite was identified as a major aluminosilicate impurity. A kaolinite dissolution mechanism is proposed by protonation of hydroxyl groups and the ligand exchange with polyphosphate for aluminum dissolution.

COM22173: Semi-Solid Direct Cladding from Molten Mg and Al Alloys Using a Twin Roll Caster with a Scraper

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Abstract: This study introduces the semi-solid direct cladding of magnesium and aluminum alloys using a horizontal twin roll caster in one step. A horizontal twin roll caster with a scraper can cast a Mg/Al clad strip with thickness exceeding 5mm at a roll speed of 8m/min in one step, which is difficult for a vertical twin roll caster. Therefore, it is possible to cast a thick clad strip with different melting point alloys using a horizontal twin roll caster at low speed. It is also possible to cast clad strips using as the overlay an alloy that has a higher melting point than that of the base strips. In this paper, effects of scraper on the fabrication of cladding of Mg and Al alloys have been discussed. It also has been analyzed at the interface of the cladded strips by using an optical microscope and by EBSD. By adopting the tensile test of the cladded Mg/Al strips, the bonding strength of the cladded Mg/Al strips have been evaluated. Effectiveness of the scraper has been demonstrated for fabricating molten Mg and Al alloys, to guarantee of the stable formation of the interface in the process. It also has been shown the bonding mechanism of the proposed cladding process.

COM22057: Separation of PGMs from Acidic Solutions by Ion Exchange

Lesia Sandig-Predzymirska, Michael Stelter, and Alexandros Charitos, Technische Universität Bergakademie Freiberg

Abstract: Platinum group metals (PGMs) are essential for the production and utilization of the green energy carrier—hydrogen. Currently, advanced platinum-based catalysts are mainly used for the production of proton exchange membrane (PEM) electrodes. Since PGM resources are very scarce, the development of sustainable and efficient recycling processes for spent PEM electrodes will facilitate the widespread commercialization of hydrogen-based technologies. This study focuses on the selective separation of PGMs by ion exchange from the acidic solution obtained after the leaching of the spent PEM electrocatalyst. The adsorption performance of several ion exchangers (Lewatit TP214, Lewatit TP207, Lewatit MP62, Amberlite IRC748) with different functional groups for the platinum extraction was studied. The hydrochloric acid-based leach solutions with several metal ions and model solutions containing PGM standards with the initial concentration of 150 mg/L were applied. The ion exchange experiments were conducted for 24 h with 50 mL solution in closed beakers to determine equilibrium time. Various eluents were used to investigate the desorption efficiency of metal ions from the resins. The obtained results indicate that the resin with tertiary amine functional group Lewatit MP62 provides a high adsorption capacity and can be used for the recovery of platinum from acidic solutions.

COM22195: Spin Casting of Zin-Alloy: Effect of Process Parameters on the Quality and Integrity of the of Castings

Syed Sohail Akhtar, King Fahd University of Petroleum and Minerals

Abstract: Castings of non-ferrous metals have become increasingly important in the aerospace, military, and automobile industries. Spin casting is a type of integrated casting equipment that is often used to cast non-ferrous metals and alloys, wax, and plastics. Spin casting is a reasonably quick and cost-effective procedure that can be used as an alternative to die-casting for the manufacturing of complicated parts. It saves both money and time when compared to die casting. The cost-effectiveness of this process in terms of processing time, mold forming, tool and equipment maintenance, and space needs are its key features. This research gives a brief overview of the spin casting process, with a focus on the process capabilities, process parameters, tooling design, constraints, and potential ways to improve the process capabilities. To assess the quality features of the TEKALOY spin-cast parts, various experiments with varied process parameters (time, temperature, pressure, and rotational speeds) were performed to determine the effect of these varying factors on the porosity, hardness, and dimensional integrity. The "design of the experiments" was used to see the effect of process parameters on part quality in terms of percent porosity, total volume change, and mechanical strength in terms of hardness. The research yielded useful data, which may undoubtedly be used as important resources to improve the quality of spin casting products.

COM22069: Study of Microstructure and Mechanical Properties of Ceramic Reinforced Magnesium Alloy Composites Made with Friction Stir Processing

Kulbir Sandhu, Punjabi University

Abstract: Lightweight Magnesium alloys have wide application in the aerospace, structural and automobile industry due to their high strength to weight ratio and workability. However, in some applications, these soft alloys lack surface properties. Therefore, some surface modifications are done with different processing techniques. Ceramics are found to have excellent wear and mechanical properties. So, the formation of Metal Matrix Composites (MMCs) with reinforcing ceramic particles of these alloys is now giving promising results. In this research, Nanosized Titanium oxide powder is used as reinforcement particles for making MMC of magnesium alloy by a solid-state Friction stir Processing(FSP) technique. A different set of tool rotation speed and traverse speed with a single tool was used to perform FSP. Optical micrographs revealed that there is a significant change in the microstructure of MMC alloy giving refined equiaxed grains. The formation of composites with titanium oxide confirmed the formation of hardened intermetallics through X-Ray diffraction scans after processing, which appreciably enhances the mechanical properties of magnesium alloy.

COM22027: Synthesis of Nanostructured Coatings with Improved Optical and Photocatalytic Properties

Tolga Tavsanoglu, Mugla Sitki Kocman University

Abstract: Nanostructured and nanoporous coatings have attracted much attention in the recent years due to their interesting optical, electrical and photocatalytic properties. These coatings can be used in many fields, such as optical devices which require high transparency, photocatalysts, electrochromic devices, ceramic membranes, batteries, chemical sensors, solar cells and so on. Because increasing the surface area of the coatings is favorable to enhance the efficiency of such devices, many attempts to fabricate nanostructured/nanoporous coatings have been performed by different methods, among which sol-gel has many advantages such as good homogeneity, ease of composition control, low processing temperature, large area coatings, low equipment cost and the possibility of easy templating. In the templating approach, in order to structure a solid at the nanometer scale the most widely used methods are soft-templating (endotemplating) by organic agents in liquid phase and hard templating (exotemplating) by solid hard materials such as anodic alumina, silica or polymeric latex particles. In this study, a soft-templating approach for the synthesis of nanostructured/nanoporous coatings developed in our research group will be described and the effect of the templating on the structure, optical and photocatalytic properties of the coatings will be discussed.

COM22187: Techno-Enviro-Economic Approach for the Integrated Renewable Energy Model for Northern Remote Mines

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Abstract: The paper looks into renewable energy options for pre-heating the intake air in remote mines in northern communities, which now rely only on diesel fuel to meet their heating demands. The established system is complicated, with several stakeholders, high operating expenses, and a large carbon impact. The possibility for a remote mine to attain 100% renewable penetration form solar energy resources is assessed in this article, with a case study for a mine in the Canadian northern communities. This study examines the current energy situation in remote mines and communities by taking into account various parameters such as economic infrastructure, operating and capital costs of current systems, and installation and operation complexity to identify barriers to switching from conventional systems to renewable energy sources. A comprehensive analysis of two scenarios is also provided. RETScreen Expert software is utilized to identify the techno-economic and environmental sustainability of establishing an integrated solar energy system in these remote communities. The proposed scenarios presented a high potential to minimise fuel consumption, operational costs, and CO_2 emissions.

COM22035: Towards High Energy Density in Supercapacitors: Achieving Ideal Pseudocapacitive Behavior with Quantized Capacitance

Yee Wei Foong and Kirk Bevan, McGill University

Abstract: Supercapacitors store more energy than double layer capacitors through redox reactions. Ideally, these redox reactions should allow multiple Faradaic electron transfers that overlap to form a near rectangular voltammetry profile to mimic double layer capacitance hence the name “pseudocapacitance”. However, current efforts of achieving this ideal pseudocapacitive behavior via synthesizing complex chemistries can be challenging. In this work, we theoretically demonstrate quantized capacitance (also known as solvated Coulomb blockade) as a viable mechanism to achieve ideal pseudocapacitive energy storage within nanoparticles. We analyze the origin of quantized capacitance arising from the energy level quantization at nanoscale. By formulating comprehensive theoretical framework on electron transfer properties, we discover several factors such as nanoparticle size and electrolyte dielectric properties that can be utilized to effectively tune the quantized capacitance behavior to arrive at an ideal pseudocapacitive energy storage. Finally, we propose several engineering strategies to experimentally realize quantized capacitance device and optimize its performance to achieve high energy density comparable to batteries.

COM22128: Unlocking The Operation Potential – Mitsubishi Copper Making

Anil Kumar Singh, Hindalco Industries Limited

Abstract: Campaign life of furnaces play a vital role in profitability of copper smelters. Besides good quality refractories, improved operational practices can also increase the furnace campaign life. One such practice has been started in Mitsubishi copper smelter of Hindalco Industries Limited (unit-Birla Copper), Aditya Birla Group, India to keep the C-furnace blister siphon open which not only increased the furnace campaign life but also improved the working environment. The implementation cost of this practice is less than one dollar and it can save million of dollars to the organization. It is a cost effective, environmental friendly and very safe practice. The C furnace of Mitsubishi copper smelter works strictly on level difference where stringent level control is must. Any imbalance in level between blister and slag may cause serious explosion due to contact of blister copper and water cooled copper jacket. These type of explosions cease the plant operation for at least 10 days and require huge amount to repair the damage apart from production loss.. It affects the plant profitability adversely. Birla Copper, India and LS Nikko , S. Korea experienced five and three such explosions respectively. The improved practice of C furnace operation reduce the magnetite in blister siphon mechanically as well as chemically and thus prevent siphon clogging, which is the main reason for increase in blister level inside the furnace. This practice also helps to operate C furnace at lower temp (1220°C) with high Fe/CaO ratio (2.7–2.8).It creates thick coating in front of furnace wall and protect refractory erosion We have observed absolutely no erosion of refractory during the April 2010 shutdown in C furnace at Birla Copper,India The new practice to keep furnace level well under control and make Mitsubishi Smelters more profitable is nothing but unlocking the operations potential.

COM22177: Wollastonite, an Industrial Mineral Contributing to Sustainability: A Review of its Applications and Beneficiation Challenges

Gloria Owusu-Addo, Charlotte Gibson, and Sanda Kelebek, Queen's University

Abstract: Wollastonite ($CaSiO_3$) is a fibrous calcium silicate industrial mineral, which is undergoing rapid growth in demand across the world for its versatile use. It has gained much attention due to its unique acicularity, high aspect ratio, thermal resistivity, and chemical stability, allowing its application to span industries including plastics and ceramics; construction (as an asbestos replacement); metallurgy (as flux conditioner); agriculture and wastewater treatment. Wollastonite has also shown potential as an abundant source of calcium for CO_2 sequestration – an important process in combating climate change. While China is the world's largest wollastonite producer, contributing to about 35% of global production, economically viable deposits have also been discovered in Finland, Mexico, India, the United States, and Canada. The sole Canadian deposit is Saint Lawrence Wollastonite Deposit, located just north of Kingston, Ontario. Wollastonite is typically concentrated from its ores using complex flowsheets that include gravity separation, magnetic separation, and flotation, depending on the associated gangue minerals. Throughout the beneficiation process, preservation of the needle-like mineral structure is critical and the

separation of wollastonite from silicate gangue minerals (such as quartz, feldspar and diopside) is challenging due to very limited property differences. The separation of wollastonite and diopside is particularly difficult due to a common silicate anion (SiO_2^-) and calcium cation (Ca^{2+}) in the structure of both minerals. This review examines industrial and laboratory activities with a focus on: (1) The mineralogical formation of wollastonite and essential properties for its vast applications; (2) Advancements in the concentration of wollastonite from its ores, with a focus on flotation. Surface chemistry of the mineral in relation to its dissolution and absorption properties will be discussed, along with the potential application of different reagents to produce a flotation concentrate that meets commercial end-product requirements.