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Preliminary Program

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Le Centre Sheraton, Montréal, Québec, Canada

Symposia

- Alloy Development and Characterization
- Computational Materials Design and Engineering
- Innovations in Manufacturing
- Joining and multi-material design
- Materials and Processes for Closed-Loop Circularity in Transport Applications
- Materials for Clean Energy Transition
- Sustainable Metal Supply: Mining, Processing and Recycling

Symposium: Alloy Development and Characterization: Structural and Functional Materials

25134: In-situ insights into adiabatic shear band evolution in the beta titanium alloy Ti-1023

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Abstract: The formation of adiabatic shear bands (ASB) is a deformation mechanism that occurs particularly at high (shear) strain rates in metallic materials with low thermal conductivity, such as titanium alloys. Narrow regions form as plastic deformation becomes increasingly localized during dynamic conditions. ASBs are considered undesirable in applications such as aerospace and defense where structural integrity is compromised during impact scenarios, but beneficial in high-speed cutting processes where cutting forces (and tool wear) can be reduced. Understanding the microstructural mechanisms that suppress or promote adiabatic shear band (ASB) formation can guide alloy design to improve material performance under extreme conditions. The conventional thermo-mechanical understanding focuses on the effect of thermal softening associated with energy dissipation during strongly localized plastic deformation. Recent work strongly indicates that microstructural softening, related to dynamic recrystallization, significantly contributes to ASB formation. Further experimental work is needed to substantiate these observations and to clearly separate the contributions of microstructural and thermo-mechanical effects. In this contribution, we present a planar S-shaped sample geometry that allows an in-situ characterization of shear banding. The applicability of the sample geometry is validated by dynamic experiments using Ti-10V-2Fe-3Al alloy in a Split-Hopkinson Pressure Bar (SHPB) under nominal strain rates of $> 10^2$ s^{-1} (local shear rates up to 5×10^4 s^{-1}). Local shear deformation in a geometrically well-defined shear zone occurs during uniaxial compression of the S-shaped samples. The plane surface of this sample geometry considerably simplifies an in-situ observation of deformations by digital image correlation for local shear strain and shear rate calculations as well as temperature measurements by infra-red thermography during ASB formation. Considering both numerical simulations and experimental measurements, we demonstrate that the predominant shear stress can also be superimposed with either tensile or compressive stresses by slightly varying the geometry of the shear zone. Furthermore, our special experimental set-up allows to limit the deformation of the samples with low increments and high accuracy to investigate the evolution of shear band microstructures at high rates. Metallographic preparation of the samples prior to testing even enables in-situ microstructural investigations during dynamic deformation. We show that, with optimized lighting for high-speed camera observations, the evolving microstructure can serve as an indicator of mechanical deformation, particularly during stress-induced martensitic transformation in the investigated metastable β-titanium alloy. Our experimental approach contributes to a deeper understanding of the formation and growth of adiabatic shear bands in titanium alloys.

Symposium: Alloy Development and Characterization: Structural and Functional Materials

25135: Analyzing alternative approaches for Equal-Channel Angular Pressing of AA5083 sheet materials

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Abstract: The mechanical behavior of metallic materials is strongly influenced by their microstructural characteristics. In particular, the generation of ultrafine-grained (UFG) microstructures can result in materials with outstanding properties. Specifically, UFG materials often exhibit increased strength compared to their coarse-grained counterparts. Equal-Channel Angular Pressing (ECAP) is a well-established method for achieving significant grain size reduction. Although the method is well understood for bulk materials, its application to thin sheets introduces several complications, including buckling, intense friction, and surface damage. In this work, two different strategies for ECAP of thin sheets of an AA5083 aluminum alloy are investigated and compared: (i) the deformation of individual sheets in a specially designed ECAP die, and (ii) the processing of a stacked configuration of sheets in a conventional ECAP die. Electron Backscatter Diffraction (EBSD) is used to study microstructural and grain size changes during cumulative ECAP passes. Different characteristics in terms of local deformation and grain refinement are observed for these strategies. The material deformed in the stacked configuration exhibits a significant increase in strength at room temperature as the number of ECAP passes increases, and relatively large elongations to failure, especially at elevated temperatures. Considering these results, we address the challenges and assess the suitability of the different ECAP strategies for producing (ultra-)fine-grained sheet materials.

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25138: Elastic Characterization of Beta-Ti15Mo by Transient Grating Spectroscopy
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Abstract: The elasticity of single crystals of metastable beta-phase of the Ti15Mo alloy with particles of both isothermal and athermal omega phase was studied by the Transient grating spectroscopy . This laser-ultrasonic method utilizes a pulse infrared laser for thermoelastic generation of high-frequency surface acoustic waves (SAWs) in an examined material and a 532nm-continuous laser beam for their contactless heterodyne detection. By attaching a sample to a rotational stage, an angular dispersion of SAWs can be measured. Since the hexagonal isothermal omega-phase forms from the bcc beta-phase as a result of low-temperature aging, the measurement was performed both on a sample in the solution-treated state and on samples that were aged after solution treatment at different ageing temperatures (300°C, 350°C) and durations (4h, 32h). A 360deg-angular scan of SAWs over examined samples showed that the ageing conditions affect the number of isothermal omega particles whose presence leads to stiffening and isotropization of shear elasticity of the aged samples. The resulting experimental datasets of angular dependencies of SAW velocities were then used for the determination of three independent elastic constants c11, c12, and c44 of examined samples with cubic symmetry. An inverse approach was used, i. e. a method which is based on an iterative numerical minimization of the misfit between experimentally determined velocity distributions of SAW velocities in general directions and those obtained using the numerical Ritz-Rayleigh method .The second part of our experimental work focused on the effect of the athermal omega-phase on the elasticity of the sample that was left in the solution-treated state. In-situ measurement of SAW velocities during temperature cycling from 20°C to -190°C was performed. According to the results obtained, it can be concluded that just as the isothermal omega-phase, the presence of the athermal omega-phase also lead to elastic stiffening and isotropization. This work was financially supported by the Ministry of Education, Youth and Sports of the Czech Republic in the frame of the project 'Ferroic multifunctionalities' (project No. CZ.02.01.01/00/22_008/0004591), co-funded by the European Union.

Symposium: Alloy Development and Characterization: Structural and Functional Materials

25139: Characterization of Elasticity in Beta Titanium Alloys with Different Phase Composition. An Ultrasound Based Study.

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Abstract: Secondary phases play a very important role in the mechanical performance of beta metastable titanium alloys. The relationship between the microstructure of secondary phases and the mechanical properties of metastable β −Ti alloys is currently an intensively studied topic. Understanding the mechanism of secondary particle formation is crucial for the development of alloys with desired properties.

We want to show ultrasonic methods, especially RUS (Resonant Ultrasound Spectroscopy), as a useful tool for understanding the processes occurring during thermomechanical processing of alloys. RUS is a suitable method for determining the elastic properties of many types of materials. This method allows us to determine the full tensor of elastic constants from a single piece of material. The method is suitable for both single crystals and polycrystals, and is especially advantageous in the case of newly developed materials available in limited quantities. Moreover, thanks to the non-contact setup, RUS allows in situ observation of phase transformations and growth of secondary phases directly during the thermal process. We would like to demonstrate the capabilities of this method on several examples of characterization of beta metastable alloys, such as high-throughput characterization of compositionally graded Ti-Zr-Nb-based alloys prepared using FAST (Field Assisted Sintering Technique) or monitoring the temperature evolution of the volume fraction of individual phases in the Ti15Mo alloy. This is possible due to the fact that even very small changes in the volume fractions of secondary phase particles have a measurable effect on the elastic constants of the two-phase material due to the large difference in the elastic moduli of individual phases, especially the β and ω phases, and the different evolution of the elasticity of individual phases with temperature.

This work was financially supported by the Ministry of Education, Youth and Sports of the Czech Republic in the frame of the project 'Ferroic multifunctionalities' (project No. CZ.02.01.01/00/22_008/0004591), co-funded by the European Union.

Symposium: Alloy Development and Characterization: Structural and Functional Materials

25140: Microstructure and Mechanical Properties in CoCrNi(N) Medium-Entropy Alloys Processed by Laser Powder Bed Fusion

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Abstract: This study examines the effects of nitrogen addition on CoCrNi medium-entropy alloy (MEA) focusing on the correlation between printing parameters, microstructure, and mechanical properties - specifically hardness. The alloys were processed via Laser Powder Bed Fusion (LPBF) of pre-alloyed powders, with parameters optimized to achieve highest densification. The microstructural analysis highlighted the role of nitrogen in defect suppression and densification upon LPBF processing. While optimized CoCrNi-N samples exhibited a higher microstructural integrity, i.e., a nearly full densification (~100% apparent density) with no evidence of hot cracking, CoCrNi samples showed minor cracks and pores even after parameter optimization. This is suggested to be attributed to the elevated high-temperature strength of the alloy containing nitrogen. Also, porosity analysis revealed notably a lower pore volume in CoCrNi-N, demonstrating the densification-enhancing effect of nitrogen, likely attributed to its melt-pool stabilizing effect (e.g., via improving fluidity). Additionally, mechanical characterization and study of phase evolution (prior and after a post-LPBF heat treatment) further correlated the microstructural integrity with enhanced mechanical performance in the nitrogen-containing alloy. This study underscores the importance of LPBF processing optimization for the production of defect-free MEAs with tailored properties. Furthermore, the insights gained contribute to the broader understanding of advanced alloy design, paving the way for the development of MEAs with exceptional mechanical performance and processability.

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25141: Magnesium Alloy Development for Additive Manufacturing of Biodegradable Implants: The Effect of Powder Size and Morphology on the Sinterability
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Abstract: The use of biodegradable magnesium (Mg) alloys for bone fixation devices have potential to improve patients' quality of life by avoiding the necessary secondary operations conducted regularly for the removal of implants fabricated from conventional non-resorbable alloys. Having excellent biocompatibility and biodegradability along with a low modulus of elasticity (decreased bone-shielding) lead to clinical uses as bone-fixation screws (Magnezix®, Syntellix) and coronary stents (Magmaris®, Biotronik). Next generation Mg implants necessitate patient-specific designs which can be realised most effectively via Additive Manufacturing (AM). AM processes based on Powder Bed Fusion have not been widely adopted for Mg-alloys due to safety concerns raising from the intrinsic properties of Mg, such as high affinity to oxygen, low boiling temperature and high vapor pressure. Fused Deposition Modelling (FDM) is a cost-efficient 3D-printing technique commonly used to produce polymer-based components from filaments. Employing FDM that operates at low temperatures (<200˚C) can offer key technological advancement in the customisation of patient-specific Mg alloys with maximum design flexibility. The key limiting factor is the low sinterability of Mg and its alloys. This study focuses on the development of novel Mg-based alloys with superior sinterability. Thermodynamic calculations are used to predict the liquid phase fraction in order to optimise sinterability and porosity levels. Materials characterisation was conducted to validate the thermodynamic modelling results using optical and scanning electron microscopy (SEM/EDS) as well as X-ray Diffraction (XRD). Final porosity levels were determined using X-ray Computed Tomography (CT). Mechanical performance was evaluated in comparison to cast alloys via

compression testing.

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25145: Exploring the Impact of Ce Addition on Phase Transformation, Texture Development, Tensile Instability Pattern, and Corrosion Resistance in Al-5Mg Alloys
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Abstract: Cerium is increasingly recognized as a valuable alloying element for aluminum alloys due to its unique ability to enhance material properties. It significantly improves castability by reducing the susceptibility to hot tearing during solidification. Additionally, Ce forms thermally stable intermetallic phases, such as $Al_{11}Ce_3$, which enhance high-temperature stability and help maintain microstructural integrity during prolonged exposure to elevated temperatures. These characteristics make Ce-added aluminum alloys ideal for energy-sector applications, including heat exchangers, powertrain components, and structural parts. Due to its limited solubility in aluminum, Ce primarily forms intermetallics, and the resulting Al-Ce compounds exhibit exceptional creep resistance at elevated temperatures, making these alloys promising candidates for aerospace and automotive applications. Furthermore, Ce-containing intermetallics possess inherent corrosion resistance, offering excellent durability in aggressive environments. By suppressing the formation of the Mg-rich β-Al_3Mg_2 phase, Ce further enhances the corrosion resistance of Al-Mg alloys. Ce also affects the interaction between dislocations and solute atoms during deformation, thereby influencing the Portevin-Le Chatelier (PLC) effect and tensile instabilities. This study provides a comparative analysis of Ce-added and Ce-free Al-5Mg alloys produced using two distinct casting techniques: direct chill (DC) casting and thin-strip (TS) casting. The TS method by Hazelett-CASTechnology™ enables continuous casting of 2-5 mm aluminum strips, achieving cooling rates up to ~100 times faster than conventional DC casting. This rapid solidification leads to the development of a unique microstructure, characterized by finer grains and a significantly reduced volume fraction of intermetallics. The innovative TS method also simplifies sheet production by eliminating intermediate steps (i.e., scalping, homogenization, and hot rolling). This not only reduces production costs but also enhances sustainability by minimizing the environmental footprint. The impact of Ce addition on grain structure, phase transformation, and identification was analyzed using microscopy techniques and further verified by thermodynamic simulations via Scheil plots. The quantification of phase fractions was performed using image analysis and correlated with the properties examined. Crystallographic texture development in cast samples was studied through electron backscattered diffraction (EBSD), with the effect of rapid solidification and Ce addition on the formation of preferred orientations being discussed. The mechanical behavior of the fabricated Al-5Mg alloys was investigated under tensile deformation, with the rate-dependent instability patterns and the onset of heterogeneity analyzed at strain rates ranging from 10^{-4} to 10^{-2} s^{-1}. The analysis of serrated flow under these strain rates revealed distinct instability patterns, marked by the formation of various types of PLC bands. The frequency of band formation, stress-drop magnitude, band type, and their mobility were compared and discussed between Ce-added and Ce-free alloys from both DC and TS cast methods. Strain localization patterns were obtained using digital image correlation (DIC) analysis, and these patterns were linked to the microstructural evolution in the alloys. The aqueous corrosion resistance of the cast alloys was evaluated through immersion corrosion and polarization tests in different concentrations of HNO_3. The findings of this study contribute to the understanding and potential applications of rare-earth elements in widely used Al-Mg alloys for various industries.

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25158: Microstructure prediction from cooling rate at liquidus temperature for AlZn5Mg1–Fe1.2 and AlSi10Mg0.3 alloys in unidirectional axial solidification
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Abstract: Rapid solidification processes (HPDC and AM) in the Automotive industry have no valid computer simulation that correlates transformation source term, with grain size and morphology. In this work, instantaneous cooling rate at liquidus temperature, is used to define semi-empirical formulations for transient solidification parameters namely dimensionless temperature, θ, dimensionless time of solidification, τ, total mushy zone residence time, $\Delta t_{m,}$ fraction of solid and solidification rate (). Further the grain size and phase fraction are also defined as a function of cooling rate at liquidus temperature. Axial upward solidification experiments have been carried out under unsteady-state conditions on typical structural net shaped casting alloys for automotive applications - dilute eutectic cast Aluminum alloy, Nemalloy HE700 (AlZn5Mg1)–Fe1.2 and eutectic cast Aluminum alloy, A383 (AlSi10Mg0.3), both with grain refiner TiB, to generate the necessary correlations. The experimental apparatus consists of an insulated cylindrical mold with a casting of 58mm x 200mm::diameter x height, with 12 thermocouples mapping transient thermal data as the melt solidifies unidirectionally through a continuously chilled copper plate at the bottom; the solidification front moves upwards against gravity. Grain size and phase characterization of the cast microstructure along the center axis will be presented.

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25034: Effect of Hot Deformation Temperature on the Performance of Al-Sc and Al-Sc-Zr Conductor Alloys
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Abstract: This study aims to determine the optimal hot deformation temperature for 1xxx aluminum conductor alloys containing Sc and Zr, enhancing their suitability for electrical bus bar applications. For this purpose, uniaxial hot compression tests were carried out to simulate the manufacturing process of extruded conductors. The tests were conducted at five temperatures between 350°C and 550°C, with a constant strain rate of 1 s^{-1} and a true strain of 0.8, followed by isothermal aging. The aged alloys showed that deformation at 350°C and 550°C produced a favorable balance of electrical conductivity and hardness, achieving 57-58% IACS and 50-57 HV, respectively. In contrast, deformation at 450°C resulted in a 20–30% reduction in hardness. TEM analysis showed that deformation at 350°C and 550°C minimized Sc and/or Zr precipitate coarsening during hot deformation, promoting nano-scale precipitation during isothermal aging.

However, deformation at 450°C induced coarse Sc and/or Zr precipitates, resulting in a microstructure less favorable to precipitation hardening during aging.

Symposium: Alloy Development and Characterization: Structural and Functional Materials

25192: Investigation Through Deformation Mechanisms in Cold-Sprayed Cantor Alloy Using Critical Resolved Shear Stress Evaluation

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Abstract: Over the past decade, the Cantor alloy, i.e., CoCrFeMnNi, has received much attention due to its promising mechanical properties, such as strength and ductility, representing it as a particular high-entropy alloy. However, the deformation mechanisms are still not fully understood. The critical resolved shear stress (CRSS) for slip and twinning must be considered as key factors in evaluating deformation mechanisms and mechanical properties. This study investigates the Cantor alloy's deformation mechanism while impacting the mild steel using the cold spray technique at 950°C and 4.9 MPa. Molecular dynamic (MD) simulation was employed to evaluate the deformation mechanism and to reveal the general stacking fault energy (GSFE). For single-crystal's CRSS evaluation, the Kibey equation yielded a result of 122 MPa. Then, considering the Cantor alloy as a polycrystal with an average grain size of 3.4 microns extracted from EBSD results, the Hall-Petch equation was used to determine its CRSS at room temperature, resulting in a value of 323 MPa. To find the slip CRSS, we employed the Peierls-Nabarro (P-N) model; in this regard, the CRSS was 175 MPa. Results indicated that, due to the lower CRSS for slip, it can be the dominant deformation mechanism near the interface. However, as observed in the EBSD results, twinning can also dominate regions farther from the interface, owing to the higher strain hardening rate associated with slip deformation than twinning.

Symposium: Alloy Development and Characterization: Structural and Functional Materials

25161: Microstructure and Corrosion Properties of Mild Steel – Martensitic Stainless Steel Functionally Graded Material Fabricated by Wire Arc Additive Manufacturing

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Abstract: Additive manufacturing has recently gained significant attention as a new method for producing functionally graded materials (FGMs). This study explores the fabrication of an FGM composed of martensitic stainless steel (MSS) and mild steel (MS) using wire arc additive manufacturing (WAAM). The microstructural evolution and phase formation across different regions of the FGM were initially analyzed using scanning electron microscopy (SEM), optical microscopy (OM), and X-ray diffraction (XRD). Subsequently, the corrosion resistance and mechanical properties were evaluated through potentiodynamic polarization and microhardness analysis. The analysis revealed that the microstructure in the MSS region is predominantly martensitic with some delta ferrite, while the MS region exhibits acicular ferrite. Corrosion resistance testing revealed that the MSS region exhibits the highest corrosion resistance, while the interface region has the lowest resistance among all regions. Additionally, microhardness

testing revealed that the interface region has the highest hardness (444± 2.5 HV 3kgf), compared to the MSS (341±1.5 HV 3kgf) and the MS regions (345±2.1 HV 3kgf).

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25162: Low-Temperature Hot Stamping of a Prototype Higher-Mn PHS
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Abstract: Press-hardened steels (PHS) are widely used in the automotive industry due to their capacity to create thin, high-strength automotive body components, enabling reduced fuel consumption, carbon emissions, and increased electric vehicle battery range while upholding safety standards. Zn-coated PHS has the advantage of providing robust cathodic protection to the steel substrate, but widespread use of these materials has been restricted due to the possibility of liquid metal embrittlement (LME) when direct hot press forming (DHPF) is performed above the Fe-Zn peritectic reaction at 782°C. One strategy to overcome this challenge is to increase the hardenability of the steel by modifying its chemical composition, thereby enabling DHPF at below 782°C and eliminating the risk of LME failure while maintaining mechanical properties. In this study, a prototype PHS with 0.23C–2.0Mn–0.25Si–0.004B–0.01Ti–0.03Nb (wt%) was used in an effort to move toward Zn-compatible PHS grades with enhanced mechanical properties. Quench dilatometry was performed to identify the transformation temperatures and create a continuous cooling transformation (CCT) diagram. Direct hot press forming was conducted using a U-channel die on bare panels of the prototype steel, yielding baseline mechanical properties ranging from 1500 to 1600 MPa, depending on the sampling location and stamping temperature. Recent developments on this project will be summarized and discussed.

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25039: Development of Ultra-High Strength Al-Mg-Si Conductor Alloy Enhanced with Copper Addition and Modified Thermomechanical Processing
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Abstract: This study investigates the effect of Cu addition on the mechanical properties and electrical conductivity of Al-Mg-Si conductor alloys. The alloys were subjected to a modified thermomechanical processing (MTMP) approach, which included pre-aging at 120 °C for 24 hours, to achieve ultra-high strength. Results indicated that the addition of 0.5 wt.% Cu led to a significant strength increase of approximately 20%, while maintaining a moderate electrical conductivity of about 50.5 %IACS. Differential scanning calorimetry (DSC) analysis showed that Cu addition shifts the formation of β'' phases to lower temperatures, suggesting an accelerated precipitation rate. Transmission electron microscopy (TEM) revealed that nanoscale precipitates play a critical role in enhancing alloy strength, with a higher number density observed in Cu-containing alloys compared to those without Cu.

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25205: The Suitability of Cassava Leaves for Carbonitriding of Low Carbon Steel

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Abstract: This paper determined the suitability of cassava leaves for carbonitriding of steel. It also evaluated the effect of temperature and time on fatigue strength, case depth and hardness of the resulting cases and examined the phases that are responsible for case-hardening of steel in cassava leaves. These were with a view of improving the wear resistance of the case for a longer service life in application. AISI 1018 steel samples were carbonitrided at 900 °C and 500 °C in 250 µm cassava leaves powder without energizer, at different soaking times in muffle furnace. The heat-treated samples were ground, polished and etched. An advanced optical microscope equipped with Clemex Vision image analyzer was used to identify and measure cases formed. Scanning Electron Microscope equipped with an energy dispersive X-ray spectroscopy detector was used to reveal the microstructural details while the case hardness and fatigue strength were measured using microhardness and fatigue testers. X-ray diffractometer was used to identify the phases that constituted the case-hardened samples.
The results showed that appreciable cases were formed in samples treated. The fatigue strength, case depths and hardness increased with soaking time. Highest fatigue strength, case depth and hardness were obtained for the samples soaked for 5 hrs, for both high and low temperatures treatments. The X-Ray diffraction analysis of the carbonitrided samples revealed Fe_3C, SiC, FeSiC and FeSi phases for high temperature treatment at the case, and Fe_2N and Fe_4N for samples case hardened at low temperature. The study concluded that cassava leaves can be used for carbonitriding of low carbon steel.

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25044: On-line XRD for galvannealed steel monitoring: Helping automotive and steel industry achieve its sustainability goals

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Abstract: The emergence of charging stations in cities from Liuzhou to London, highlights the significant changes occurring within the automotive sector. As the rationale for the manufacture of electric vehicles is becoming increasingly compelling each year, it is not surprising that the steel making industry is doubling efforts to optimize production processes aiming at reducing CO_2 emissions and meeting climate targets. In this regard, improving the efficiency of the galvanneal process for the coating of automotive body panels can yield substantial advantages in cost savings and sustainability, marking a crucial advancement toward achieving a net-zero economy. Steel galvannealing is known to be more energy-intensive than traditional galvanizing, as the zinc-coated metal undergoes a secondary treatment at elevated temperatures in an annealing oven to induce alloying between zinc and iron. When compared to standard galvanized products, galvanneal coatings offer several benefits for automotive applications, including easier painting and spot welding, increased hardness, and reduced undercutting corrosion at exposed edges, scratches, or other paint imperfections. To produce galvannealed products that meet the stringent quality standards of the iron industry, closely monitoring the phase fraction and stoichiometry of the iron-zinc intermetallic phases present in the coatings is of outmost importance. In fact, common performance issues observed in galvannealed products, such as poor paint adhesion, brittleness during forming, and powdering, often stem from a suboptimal balance in the coatings of three specific zinc-iron intermetallic phases, namely gamma, delta, and zeta. In addition, the steel industries have long grappled with the dual challenge of ensuring consistent monitoring of galvannealing process while minimizing downtime. Most galvannealing monitoring solutions requires laboratory sampling, which is a time-consuming off-line process taking up to 8 hours per sample. This delay makes it difficult to make prompt onsite informed decisions based on process failures that could lead to melting steel coils or selling them at reduced prices. The implementation of on-line X-ray diffraction (XRD) technology addresses this issue by allowing for continuous measurement of the total and individual thicknesses of the gamma, delta, and zeta intermetallic layers along with their stoichiometry and lattice parameters. This real-time quality control during the galvannealing process allows for immediate access to critical information, resulting in reduced waste, lower energy consumption, enhanced production capacity, optimized zinc usage by preventing overcoating, and decreased labor time for lab testing.

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25046: Advanced High Pressure Die Casting Magnesium Alloys in Electric Vehicles
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Abstract: The utilization of lightweight materials to enhance vehicular efficiency and handling characteristics has gained paramount importance with the proliferation of electric vehicles (EVs). Magnesium alloys, recognized as the lightest structural metals, are increasingly favored due to their low density, exceptional strength-to-weight ratio, and superior die castability. High-pressure die casting (HPDC) of magnesium alloys results in a refined microstructure attributed to the rapid cooling rates inherent in the HPDC process, yielding high strength and ductility in the as-cast condition. This study investigates the conventional applications of HPDC magnesium alloys within internal combustion engine (ICE) vehicles, alongside their prospective applications in EVs. Our findings indicate that the structural applications of AM50, AM60, AZ91, and AE44 magnesium alloys, traditionally employed in legacy vehicles, can be effectively adapted for modern EV frameworks. Moreover, magnesium alloys exhibiting enhanced thermal conductivity, improved castability, and superior high-temperature performance are being developed for critical battery and structural components in EV applications, all while adhering to stringent safety standards. We also review several newly engineered magnesium alloys that demonstrate exceptional thermal and physical properties, coupled with robust HPDC castability potential, highlighting their promising applications in the future automotive landscape. Overall, the integration of magnesium alloys in EVs holds significant potential for advancing performance and operational efficiency.

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25263: Effects on the corrosion fatigue behavior of growing corrosion pits on surface-modified magnesium threads using Murakami modeling
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Abstract: Magnesium (Mg) undergoes degradation in the human body without causing any adverse reactions. This effect can be used advantageous to create biodegrading bone screws. With the aim to impede a second surgery a reduction of the workload for the medical staff can be achieved. In order to adjust the corrosion behavior of biodegradable implants, the surface is modified by plasma electrolytic oxidation (PEO). It passivates the substrate surface with a thin layer and enhances the corrosion and wear resistance with a ceramic spongy like surface . Bone screw threads made of ZX10 (Mg-1Zn-0.3Ca) were produced and modified with PEO to improve the corrosion fatigue behavior. The surface modification was applied to specimens of ZX10 alloy with smooth (reference) and threaded measurement areas. The corrosion fatigue tests were performed under stress control at different horizons, a stress ratio of -1 (fully-reversed loading) and a frequency of 6 Hz. In corrosive environments, Mg-alloys and Mg PEO-modified alloys exhibit a reduced fatigue behavior in general, attributed to corrosion pitting and hydrogen embrittlement. Those pits can be identified as crack initiation area with certain stress concentration factors. Thus, according to Murakami and Endo the square root of a projection of area to a plane surface perpendicular to the maximum tensile stress direction can be used to approximate the critical pitting sizes (Figure 1A). In combination with µCT scans the remaining radius of Mg-alloys after corrosion was measured to identify the critical pit size until failure (Figure 1B+C). The increasing of corrosion pit sizes leads to a reduction of fatigue strength, which could be shown for threaded and smooth samples. On the one hand, threaded and smooth ZX10 samples undergoes a softening and hardening within the first 1.2·104 cycles. On the other hand, the PEO cannot go the full strain due to its brittle behavior. It reacts different, micro cracks growth within the first 1·102 cycles, which expose the substrate material to the media. The randomized surface crack growth along the PEO leads to exposed substrate areas and with that favors inhomogeneous corrosion. It could be shown that inhomogeneous corrosion with small remaining radius has a higher fatigue strength by up to 50% compared to the non-surface modified homogenous corrosion of ZX10. The unmodified surfaces reduce their remaining radius much faster due to a lager exposed direct interface with media. In addition to this, the samples with threads failed significantly earlier with 6·106 cycles compared to reference samples. This behavior was expected due to the threads acting as notches, as the superposition of mechanical and corrosive loads weakens the failure-prone thread areas under the PEO.

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References:
V. Labmayr; O. Suljevic; N. G. Sommer; U. Y. Schwarze; R. L. Marek; I. Brcic; I. Foessl; A. Leithner; F. J. Seibert; V. Herber; P. L. Holweg; Clinical Orthopaedics and Related Research, 2024, 482, 184–197.
S., Sowka; N. Wegner; A. Tiwari; A. Buling; J. Zerrer; F. Walther; Werkstoffprüfung 2023 -

Werkstoffe und Bauteile auf dem Prüfstand, Hrsg.: M. Wächter, J. B. Langer, 2023, ISSN: 1861-8154, 130–135.
Y. Murakami; M. Endo; Journal of the Society of Material Science, Japan, 1986, 35, 395, 911–917.

Symposium: Alloy Development and Characterization: Structural and Functional Materials

25264: Resource-efficient fracture-mechanical characterization of the short- and long-crack behavior of additively manufactured titanium aluminides

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Abstract: Titanium aluminides gain increasing attention in the aerospace and automotive industries due to their high-temperature resistance, low density, and mechanical properties. Compared to conventional nickel-based superalloys, they offer significant weight advantages, leading to improved energy efficiency and reduced CO_2 emissions. Additive manufacturing (AM) offers resource-efficient production of titanium aluminides, high design flexibility, and the fabrication of complex structures. However, because of porosity, the reliable design of additively manufactured titanium aluminide structures for safety-relevant components requires a detailed fracture-mechanical characterization with regard to process-structure-property relationships. This study focuses on determining key parameters to characterize the short-crack behavior of titanium aluminides (TNM-B1 and BMBF3) manufactured additively via electron beam melting (EBM). In this context, a suitable testing methodology, incorporating load increase tests, was developed for the acquisition of R-curves using a single miniature specimen to determine fatigue crack growth threshold values. Various combinations of testing parameters were analyzed and evaluated using a Rumul Cracktronic, while the crack measurements were carried out with the help of a Rumul Fractomat equipped with electrical resistance-based crack length foils (Fig. 1A). The specimens were initially razor-blade polished and pre-cracked by cyclic tensile-tensile loading to induce a defined fatigue crack, followed by R-curve testing. The feasibility of crack initiation using compression-compression loading was additionally investigated and compared. The obtained fatigue crack threshold values were assessed using empirical approaches and compared with literature data [2-4]. Furthermore, metallographic and fractographic analyses were conducted to examine crack growth and failure mechanisms concerning microstructure. Also, the effects of hot isostatic pressing (HIP) and build orientation were characterized to evaluate process-structure-property relationships. The results show that especially the increase and length of loading steps have a significant influence on the final R-curves. The increase should be approx. 10% of the previous level to prevent the crack growth from stopping. In addition, a step length of at least 200,000 is necessary, as otherwise early load increase may occur due to low growth rates. Reliable and efficient testing is possible with the test parameters determined. Using the single specimen methodology, the acquired results revealed a dependence on build orientation, with the TNMB1 in 90° orientation exhibiting higher long-crack threshold values ($\Delta K_{th,LC}$ = 8.7 MPa·m1/2) compared to other conditions ($\Delta K_{th,LC}$ = 6.0 MPa·m1/2). No significant differences were observed for the intrinsic threshold values, which averaged $\Delta K_{th,eff}$ = 2.9 MPa·m1/2 (Fig. 1B). Due to the increased grain size, the HIP specimen result in lower threshold values. Since it has been shown that crack initiation is possible under compression, this method should be preferred to ensure accurate results. The consistency of these findings with previous studies and empirical estimates indicates the validity of the developed testing

methodology, establishing a reliable basis for further investigations, including crack growth rate testing. This ultimately contributes to the possibility of a comprehensive characterization of the fatigue behavior of additively manufactured titanium aluminides and therefore the application of such in safety-relevant components.

References J. Maierhofer; S. Kolitsch; R. Pippan; H. Gänser; M. Madia; U. Zerbst;The cyclic R-curve – Determination, problems, limitations and application. In: Engineering Fracture Mechanics 198, 2018. S. Zeiler; A. Lintner; M. Schloffer; R. Pippan; A. Hohenwarter; Microstructural influences on fatigue threshold behavior and fracture toughness of an additively manufactured γ-titanium aluminide. In: Intermetallics 156, 2023. M. Schloffer; Gefüge und Eigenschaften der intermetallischen TNM-Legierung, Dissertation, Department Metallkunde und Werkstoffprüfung, Montanuniversität Leoben, 2013. B. Lin; W. Chen; Mechanical properties of TiAl fabricated by electron beam melting — A review. In: China Foundry 18 (4), 2021.

Symposium: Alloy Development and Characterization: Structural and Functional Materials

25060: Interaction of Fe- and Mn-containing, secondary Al-Si alloys with ceramic and intermetallic grain refiners

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Abstract: Recycled Al-alloys are increasingly important considering their potential for energy conservation and sustainability because their processing requires 90 to 95% less energy compared to the primary Al production. Furthermore, the volume of available recycled Al alloys is expected to double until 2035 and exceed the primary Al production until 2050. Metallic impurity elements e. g. Fe and Mn enrich in the recycled Al-alloys due to insufficient sorting of scrap or use of steel equipment. These elements have mainly detrimental effects due to the formation of large, primary, Fe-containing intermetallic particles, e.g. θ-$Al_{13}Fe_4$, β-$Al_{4.5}FeSi$, α_h-Al_7Fe_2Si or α_c-$Al_9(Mn,Fe)_2Si_{1.8}$, which cause a decrease of castability and promote crack formation. Unfortunately, the removal of the metallic impurity elements is associated with an unacceptable high energy consumption, loss of material or incomplete removal. Consequently, currently clean high-energy produced primary Al is mixed with the recycled material to fulfil tolerances of the alloy specifications. A new approach is to modify the intermetallic phases into harmless microstructural components or even harness those for particle strengthening. This is achieved when the intermetallic phases exist as finely distributed particles within the Al-matrix. Currently, grain refinement of the Al-matrix e.g. via TiB_2 as grain refiner is an established processing step. However, grain refiners with specific active and reactive effects on refinement of the intermetallic phases are currently not available. Thereby, a functional effect is achieved when the crystal structure of the refiner material allows specifically growth of the intermetallic phase. A reactive effect is present when via reactive diffusion of the refiner material with elements from the melt, in-situ a mediating reaction layer is generated.
Within the present study, the interactions of ceramic and intermetallic refiner materials in contact with Fe- and Mn-containing, model recycled Al-alloys are investigated. For this, model sessile-drop experiments with Al-alloys on the refiner material in form of plates are performed at 950°C and 620°C. Al-alloys are Al1.5Fe, Al0.75Fe0.75Mn, Al7.1Si1.5Fe and Al7.1Si0.75Fe0.75Mn. The refiner material are the ceramics Al_2O_3, Al_2O_3-C, SiC, TiB_2 and the intermetallic phases θ-$Al_{13}Fe_4$, β-$Al_{4.5}FeSi$, α_h-Al_7Fe_2Si or α_c-$Al_9(Mn,Fe)_2Si_{1.8}$. Cross sections through alloy and refiner material were employed for microstructure analysis with SEM/EBSD and SEM/EDS. Thus,

interaction characteristics with Fe- and Mn-containing Al-Si melts in view of wettability, chemical reactions and microstructure in the interaction region with a focus on active and reactive effects on evolved intermetallic particles are derived.
The Al-Si melts in contact with Al_2O_3 represent non-reactive, low-wetting systems acting as reference for the refiner materials, while the other systems show wetting and reactive interactions. It is shown that the interface interactions of the intermetallic phases with the liquid Al are significantly different compared to the interaction with ceramic materials. This insights from this fundamental research provides a valuable contribution for alloy adapted choice of grain refiners for modification of the intermetallic phases during casting and solidification of recycled Al-alloys. The beneficial potential for using grain refiners from ceramic or intermetallic phases will be discussed.

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25062: Observing Magnesium Precipitation in Real Time: An In-Situ SEM Heating Study on Continuous/Discontinuous Precipitation in AZ80
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Abstract: Commercial Mg-Al-Zn alloys, like AZ80 (Mg-8Al-0.5Zn, wt.%), are reliant on strengthening from continuous precipitation to achieve competitive strengths for engineering applications. However, the formation of discontinuous precipitation – that does not contribute significantly to the alloy strength – can form instead, diverting the solute away from continuous precipitation and reducing its volume fraction in the microstructure. This competition has historically been studied using sample heat treatments and then observing microstructural evolution post-mortem, and so risks missing important dynamic behaviour that can only be witnessed when the evolution is time resolved. In this work, the continuous/discontinuous-precipitation competition in AZ80 was studied for the first time using in-situ SEM heating. A specialised automated in-situ SEM system (TANIST) was used to collect correlative backscatter electron images and EBSD maps over 40 hours at 180°C to study the microstructure evolution in real time, capturing precipitation nucleation and competitive interactions as well as linked grain-structure developments.

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25063: High-Strength, High-Conductivity Ultrafine-Grained Hypoeutectic Al-Si Conductor Alloys through Modified Thermomechanical Process
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Abstract: Hypoeutectic Al-Si alloys have emerged as promising materials for aluminum conductor cables, although their industrial applications are often constrained by the trade-off between electrical conductivity (EC) and strength. This study investigates the effect of two thermomechanical processes, conventional (C-TMP) and modified (M-TMP), on the microstructure, mechanical properties, and EC of AA4043 Al conductors. In M-TMP, the rods were pre-annealed at temperatures ranging from 200 to 350°C for 4 and 24 h followed by cold wire drawing (CD). Pre-annealing significantly increased the EC of all samples from 50% to 58% IACS, while reducing their strength. The subsequent CD not only restored the strength but also further improved EC. Among the M-TMP produced wires, the one pre-annealed at 200°C for 24 h exhibited the best combination of EC (59.2% IACS), microhardness (62.2 HV), and UTS (231.4 MPa). Microstructural analysis was conducted using optical microscopy, SEM, EBSD, and TEM. EBSD analysis after CD revealed an equiaxed ultrafine grain (UFG) structure in M-TMP produced wire, while a lamellar UFG structure surrounded by small grains was observed in the C-TMP produced sample. TEM showed that Si nanoprecipitates penetrated the dislocation-free recrystallized UFG in the M-TMP produced sample, whereas a lamellar UFG with dislocation tangles was seen in the C-TMP produced sample. The Si nanoprecipitates enhanced EC by depleting solute Si from the Al matrix, while the improvement in UTS is attributed to grain refinement, strain hardening, and precipitation hardening. These findings provide insights into simultaneously improving EC and UTS in Al-Si conductor alloys, overcoming the traditional trade-off.

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25004: Study on the Dynamic Strain Aging behavior of RE-containing Mg alloys
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Abstract: When deformed under certain conditions, serrated stress-strain curves can be found for almost all RE-containing magnesium alloys. At the same time, the plasticity will be deteriorated and deformation bands form, leading to the poor surface quality and reduced stability of the deformation process. This is because of the dynamic strain aging (DSA) phenomenon due to the interaction between the solute RE atoms and the dislocations. In this study, the high-temperature deformation behavior of various Mg-RE binary alloys is studied. The effects of deformation conditions, types, and content of RE elements on the DSA behavior is investigated. Through high-temperature DIC tensile experiments, the mechanisms for the formation and propagation of the deformation bands are also revealed.

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25065: Novel Ce-Containing Al-Si-Mg Cast Alloys for Electric Vehicle Applications
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Abstract: The advent of electric vehicles (EVs) has led to an increased demand for high-performance materials to address the challenges of modern mobility. Some specific applications, such as electric vehicle rotors, require Al alloys with exceptional properties, including high castability, electrical conductivity (EC), and strength. These properties cannot be achieved using conventional Al cast alloys, as the mechanisms that improve the castability and strength generally lead to a deterioration in EC, making the three requirements often mutually exclusive. The objective of the present research is to design a new castable Al alloy that possesses high EC and strength. To achieve this goal, Ce was introduced to the Al-Si-Mg cast alloys. Experimental results revealed that while Mg addition improved the strength of AlSi3 alloy at the expense of reducing its EC, incorporation of Ce enhanced EC of AlSi3Mg0.5 alloy by 1.5%IACS and slightly increased its yield strength. Interestingly, after T5 treatment the alloy reached the EC of 50%IACS and YS of 210MPa, meeting the required properties for EV applications. X-Ray diffraction analysis and microstructural observations confirmed that Ce addition reduced Mg solutes in the Al matrix and promoted the modification of eutectic Si, and hence resulting in simultaneous enhancement of EC and strength.

Symposium: Alloy Development and Characterization: Structural and Functional Materials

25228: Study of the mechanical and physical characteristics of the AlMgSc alloy proposed for use at cryogenic temperatures

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Abstract: Aluminum alloys are used extensively in construction, automotive, and aerospace because of its lightweight nature, high formability, and resistance to corrosion. With its high specific strength, lightweight structure, and minimum design constraints, the recently launched AlMgSc-alloy, Scalmalloy® CX by APWORKS, treated by Selective Laser Melting (SLM), offers a wide range of potential applications, especially at cryogenic temperatures. Among the aluminum alloys produced by SLM, this one has the highest yield strength (YS), ultimate tensile strength (UTS), and elongation. Research on the mechanical and physical properties for potential cryogenic temperature applications has been spurred by these benefits at the Karlsruhe Institute of Technology (KIT). Comparing the novel alloy to traditional Scalmalloy®, tensile and fracture tests at different temperatures showed that the former had greater fracture toughness. In comparison to the normal version, which had fracture toughness of 9.5, 10.8, and 28 MPa√m at 20K, 77K, and room temperature, the new cryogenic variant shown an increase to 13.4, 20, and 43 MPa√m. Ultimate tensile strength is sacrificed in order to improve fracture toughness, eventhough the decreased UTS value is still within the range of high strength aluminum alloys. The distribution, size, and volume fraction of precipitates all directly affect mechanical properties, as demonstrated by microstructural and microhardness observations.

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25180: 3D Observation of Steel Microstructures Using PFIB-EBSD Serial Sectioning Tomography

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Abstract: Three-dimensional (3D) characterization techniques have demonstrated great potential to provide important insights into the morphology of complicated microstructures. For cases demanding high spatial resolution in 3D, serial sectioning methods have been successfully applied to collect sequential 2D image stacks that can be aligned to reconstruct a 3D representation of the specimen. Among these methods, serial sectioning using Xe+ plasma-focused ion beam (PFIB) stands out for its ability to acquire data from volumes large enough to

reflect bulk material behavior, while preserving sufficient spatial resolution to capture intricate microstructural features . This capability is particularly advantageous for investigating the relationships between microstructural characteristics and mechanical properties in steels, as it facilitates the study of complex interactions at scales relevant to material performance in applications . In this study, we aim to integrate electron backscatter diffraction (EBSD) with high-precision, large-field-of-view PFIB serial sectioning tomography to achieve comprehensive identification and characterization of microstructural components within different steel structures.

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25239: Laser-induced breakdown spectroscopy (LIBS) applied to aluminum alloys characterization
Guillem Vachon, Alcoa, Deschambault, QC

Abstract: Laser-induced breakdown spectroscopy (LIBS) is an atomic emission spectroscopic method that uses a pulse laser to irradiate a sample and generate a plasma. The light emitted from this plasma contains the elemental signature, and the intensity ratio of the contained elements can be determined to obtain a semi-quantitative chemical analysis. The recent miniaturization of such a system has allowed new application development such as in the field of metallographic sample analysis. In this presentation, LIBS system performance will be compared with scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM/EDX) to put its advantages and limitations into perspective. Specific examples will be given on the usage of LIBS for microstructural phase evaluation of various alloying elements and alloys used in the aluminum casting process, on molten aluminum cleanliness evaluation such as the Podfa method, and on foreign material detection or coating evaluation of the finished product.

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25240: Hardfacing overlay with micro- and nano-scale borides for superior abrasion resistance
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Abstract: Iron-based hardfacing overlays, recognized as environmentally friendly and energy-efficient manufacturing technologies, have demonstrated significant potential in mining, asphalt, power, and oil and gas applications over the past decades. The exceptional wear resistance of these overlays arises from the synergistic effects of high-wear-resistant reinforcements and strong reinforcement-matrix compatibility. However, the non-uniform distribution of reinforcements and poor reinforcement-matrix compatibility have substantially limited the performance of traditional hardfacing overlays. In this study, we developed an innovative borides-reinforced hardfacing overlay featuring a multi-scale structure composed of two sizes of niobium borides and a chromium boride, all with a specific orientation perpendicular to the overlay surface. This structure was synthesized by welding within a eutectic matrix. The two sizes of niobium borides, on the micron and nanoscale, are uniformly distributed throughout the overlay. Indentation testing of the different phases revealed that the hardness of all borides exceeded 20 GPa, while the matrix exhibited a hardness greater than 10 GPa. These factors

collectively contribute to the exceptional wear resistance of the multi-scale borides-reinforced hardfacing overlay, which demonstrates comparable wear resistance to other advanced materials.

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25069: Enhanced mechanical properties of Al-Sc-Zr conductor alloys through Sn and Sr additions and two-step aging
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Abstract: With the increasing demand for electricity, the conductor alloys have garnered significant attention in recent years. The increasing current loads on overhead lines require conductors with superior mechanical properties and enhanced thermal stability. Al-Sc-Zr conductor alloys are known for their excellent electrical conductivity, high strength, and outstanding thermal stability. In this study, trace elements Sn (500-1500 ppm) and Sr (60-130 ppm) were added to the Al-Sc-Zr alloy to further improve its mechanical properties. The two-step aging treatment was applied to enhance the alloy's performance. Transmission electron microscopy (TEM) was utilized to analyze the $Al_3(Sc,Zr)$ precipitates, while electron backscatter diffraction (EBSD) was employed to investigate the grain structure of the alloys. The ultimate tensile strengths of the Sn- and Sr-containing alloys reached 215.9 MPa and 226.5 MPa, respectively, representing an increase of 10 MPa and 11.6 MPa relative to the base alloys without Sn or Sr additions. The improved mechanical properties in the Sn-modified alloys are attributed to the formation of secondary $Al_3(Sc,Zr)$ precipitates after aging at 300 °C for 4 h, driven by the nucleation of inoculant-rich clusters. This process resulted in a higher number density of precipitates during two-step aging. For Sr-containing alloys, strengthening was primarily achieved through the introduction of stacking faults, which created a high number density of obstacles that effectively hindered and pinned dislocations, thereby enhancing the mechanical performance.

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25245: Microstructure Evolution and Superplastic Behavior of Al-Mg 5xxx Alloys under High-Speed Blow Forming Conditions.
Eric Kojo Kweitsu, UQAC, Chicoutimi, QC

Abstract: This study investigates the grain structure evolution and superplastic behavior of two Al-Mg 5xxx alloys under conditions tailored for High-Speed Blow Forming (HSBF). The alloys were annealed at 520°C for a brief duration, and their microstructures were characterized using optical microscopy and Electron Backscattered Diffraction (EBSD). Both alloys exhibited rapid static recrystallization during the short annealing process, resulting in fine, equiaxed grain structures. Notably, Alloy 2 (Al-4.0Mg-1.18Mn) demonstrated superior resistance to grain coarsening compared to Alloy 1 (Al-4.5Mg-0.74Mn), attributed to its higher density of Mn dispersoids. The superplastic behavior of the alloys was evaluated at strain rates of 0.001 and 1 s^{-1} following a 4-minute annealing treatment. Alloy 2 exhibited higher ductility at a strain rate of 0.001 s^{-1} (170% vs. 138%) compared to Alloy 1. At the higher strain rate of 1 s^{-1}, both alloys achieved comparable tensile elongation (135% vs. 132%), demonstrating their potential for high-

strain-rate superplasticity. The enhanced low strain rate performance of Alloy 2 underscores its suitability as a superior material for HSBF applications.

Symposium: Alloy Development and Characterization: Structural and Functional Materials

25074: On the passive behavior of laser-powder bed fused Monel 400 alloy in 0.1 M NaCl

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Abstract: The remarkable corrosion resistance of Ni-Cu alloys has garnered significant interest for their use in challenging environments such as seawater applications. Among these alloys, Monel, a commercially available subclass of Ni-Cu alloys, has demonstrated exceptional resistance to localized corrosion in marine conditions. While the corrosion behavior of conventionally manufactured Monel alloys has been relatively underexplored, the emergence of additive manufacturing (AM) techniques has added a new layer of complexity to this field of research. Given the critical role of passivity in ensuring the corrosion resistance of passive materials like Monel, it becomes imperative to examine the passive behavior of additively manufactured Monel alloys and compare it with their traditionally produced counterparts. This study aims to investigate the passive response of as-fabricated Monel 400 alloy produced via laser powder bed fusion (L-PBF) when exposed to a 0.1 M NaCl solution over a 7-day immersion period. The findings will be benchmarked against those of wrought Monel 400. The microstructure of the samples is analyzed using optical microscopy and scanning electron microscopy (SEM). Electrochemical behavior is evaluated by monitoring the open circuit potential (OCP) during immersion and conducting electrochemical impedance spectroscopy (EIS) on the passivated specimens. The outcomes of this research aim to provide a deeper understanding of the passivation characteristics of L-PBF Monel 400 in corrosive environments, highlighting differences in performance compared to its wrought counterpart. These findings will contribute valuable insights into the corrosion mechanisms and broadens the scope of potential applications for Monel alloys.

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25075: Impact of building direction on the corrosion behavior of arc-directed energy deposited 308 stainless steel in 0.1 M NaCl

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Abstract: Austenitic stainless steels (SSs) are extensively used across key industries such as automotive, aerospace, oil and gas, mining, manufacturing, and shipbuilding, owing to their outstanding combination of corrosion resistance and mechanical properties. Among these, 308 SS stands out as a specialized grade of austenitic stainless steel, recognized for its superior corrosion resistance and frequent application as feedstock material in welding and additive manufacturing (AM). The increasing demand for advanced wire-fed AM techniques has shifted attention toward high-performance metallic materials like 308 SS. Despite this interest, there is a notable lack of understanding the corrosion behavior of 308 SS fabricated via arc-directed energy deposition (arc-DED) technique, particularly concerning how build orientation influences its corrosion performance. This study seeks to address this gap by investigating the electrochemical corrosion behavior of an arc-DED fabricated 308 SS part, emphasizing differences between surfaces parallel and perpendicular to the building direction. The microstructural features of these surfaces are characterized using optical microscopy (OM) and scanning electron microscopy (SEM), supplemented by X-ray diffraction (XRD) for phase analysis. The electrochemical performance is then assessed through potentiodynamic polarization and electrochemical impedance spectroscopy (EIS) in a 0.1 M NaCl solution. The results offer valuable insights into the microstructure-corrosion relationship in arc-DED 308 SS, highlighting its suitability for chloride-containing corrosive environments and expanding its broader applications in demanding industrial sectors.

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25079: Advancing Additive Manufacturing of Lightweight Aluminum Alloys: Enhancing Mechanical Properties of AlSi10Mg through Mn Modification and Tailored Heat Treatments
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Abstract: This research examines the mechanical behavior and microstructural evolution of AlSi10MgMn alloys, which were fabricated using Selective Laser Melting (SLM) and subjected to various heat treatments. The AlSi10MgMn alloy, containing 0.5 wt.% Mn, underwent direct aging (T5) and a combined stress relief and solution treatment and aging (T6), and its properties were then compared to the conventional AlSi10Mg alloy. In the as-built condition (F), the Mn-modified alloy displayed an ultimate tensile strength (UTS) of 486 MPa and a yield strength (YS) of 299 MPa. The T5 and T6 heat treatments improved the YS to 386 and 321 MPa, respectively. The tensile properties of the Mn-modified alloy were significantly higher than those of the conventional AlSi10Mg alloy in the F, T5 and T6 conditions. These enhancements were attributed to the modification of the microstructure and precipitates. Strengthening in the as-manufactured and T5 conditions was aided by the Si-rich network, and the Mn addition promoted both the formation of α-Al(Mn,Fe)Si intermetallic particles inside the Si-rich network and Si-rich nanoprecipitates in the Al matrix, effectively enhancing the strength without significant loss of elongation. In the T6 state, Mn facilitated the formation of α-dispersoids rather than the Fe-rich β-phase observed in the conventional alloy, thereby contributing to a notable increase in strength. This study demonstrates the potential of Mn-modified AlSi10Mg alloys for use in additive manufacturing, offering a viable path toward achieving high-strength, lightweight aluminum components.

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25255: Grain Boundary Segregation and Functionally Graded Alloy Developed in One-Step Friction Stir Process
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Abstract: The demand for lightweight structural materials is essential for reducing energy consumption and emissions, providing a sustainable strategy to address global climate change. An effective approach to achieve lightweight material is grain refinement to the nanoscale.

However, the application of refined-grain materials is limited by grain growth that sets on, even at room temperature, which results in the degradation of mechanical and functional properties over time. The current thermodynamic grain-stabilizing approach is based on the segregation of a carefully-selected solute to offset the excess energy at the solvent grain boundaries (GB) that drives grain coarsening. However, these conventional stabilization methods are mainly produced by thin-film techniques with restricted material thickness; more so, the multi-step mechanical alloying and heat treatment process requires a high-temperature consolidation process that promotes grain coarsening. This study investigates the extension of **friction stir processing (FSP)** as an innovative, green, single-step method to develop bulk stable nanocrystalline materials with decorated grains. The theorized fundamental principle is that the high strain/strain rates generated during FSP will drive grain refinement, while the elevated temperatures facilitate solute atom migration to the solvent GB. Aluminum (Al), a model face-centered cubic (FCC) metal, is chosen as the solvent, and Magnesium (Mg) is identified as the optimal solute based on a GB-segregation map developed using empirical and enthalpic segregation criteria. The selected Mg plate is sandwiched between two Al plates and processed under varying FSP parameters. A lower traverse speed increases heat input, leading to greater material flow, larger stirred zones, the formation of voids, and the development of mechanical hooks near the Al-Mg interfaces. Advanced characterization techniques, including scanning/transmission electron microscopy and atom probe tomography, reveal three distinct zones in the processed material: (1) stirred unmixed, (2) inhomogeneous-mixed, and (3) homogeneous-mixed zones. Further analysis revealed the presence of a nanoscale functionally-graded intermediate region between pure Al and pure Mg in the FSPed samples, consisting of four distinct zones: solid solution, GB segregation, and two intermetallic phases (β and γ). The observation of GB segregation (Mg segregation to the GBs of the Al-rich regions) alongside the experimentally determined enthalpy of segregation (-7 to -5 *kJ/mol*) marks the first evidence of a single-step GB decoration in bulk materials, surpassing the limitations of traditional thin-film electrodeposition and powder metallurgy methods. The formation of the intermetallic phases also aligns with predictions from the GB segregation map—Mg is located in the metastable region of the map.
This study highlights the potential extension of FSP as an eco-friendly, bulk material-processing method for developing lightweight, high-strength, and functionally-graded materials with improved thermal and mechanical stability. The capability to achieve GB decoration and graded material properties in a single processing step marks a significant innovation in materials engineering, opening new possibilities for the widespread application of nanocrystalline alloys in structural components.

Symposium: Alloy Development and Characterization: Structural and Functional Materials

25083: Correlation of Microstructural Evolution with Mechanical Behavior and Thermal Conductivity of B319 Aluminum Alloy Under Heat Treatments

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Abstract: Aluminum alloy B319 (Al-Si-Cu) is commonly used in automotive powertrain component applications, primarily due to its low density and excellent castability. However, in the as-cast state, B319 Al alloy exhibits inferior mechanical properties due to the presence of large needle-like Si particles and coarse secondary phases. Heat treatment of the B319 Al alloy

induces several microstructural transformations that significantly affect its mechanical properties, electrical and thermal conductivity. Optimizing heat treatment conditions is crucial for improving these properties. In this study, B319 Al alloy was fabricated through gravity casting using a permanent cast iron mold. The effects of solutionizing time, natural aging time, and artificial aging time on the microstructure were thoroughly investigated, focusing on the spheroidization or refinement of Si particles and the dissolution or precipitation of Al_2Cu. The relationship between microstructural evolution under heat treatments and the alloy's hardness, tensile strength, and thermal conductivity was also explored.

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25087: Phase transitions induced by friction stir processing in aluminium quasicrystalline alloys

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Abstract: Friction stir processing (FSP) is a thermomechanical process in which material is exposed to extreme plastic deformation and high temperature due to the transformation of mechanical work to heat. The rotating tool moves on the surface of a material and causes plastic flow. There are several regions in the FSP-treated material: stir (SZ), thermomechanical-affected (TMAZ) and heat-affected zones (HAZ). Several processes can take place in the different areas. In this investigation, we used several heat-resistant Al-alloy, which provides a uniform hardness in all zones after FSP, without large drops in TMAZ or HAZ. Special attention was given to phase transitions occurring during FSP. In this work, we studied experimental Al-Mn-Cu alloys (containing 2–3.5 % Mn and 3.5 % Cu) microalloyed with different elements in different combinations (Be, Sc, Zr, Cr and V). Plates with a thickness of 8 mm were gravitationally cast into a copper mould. Each alloy was also heat-treated (single step 400 °C/1 h or two steps 330 °C/24 h + 450 °C/30'). Friction stir processing was carried out on one side of the as-cast and heat-treated samples with dimensions 100 mm × 25 mm × 8 mm using a tool with a shoulder width of 18 mm and pin of 6 mm × 4 mm. The rotation speed was 475 min^{-1}, and the lateral speed was 46 mm min^{-1}. The processed area was investigated by light microscopy (LM), scanning electron microscopy (SEM) with energy-dispersive spectroscopy (EDS), transmission electron microscopy (TEM), X-ray diffraction (XRD), microhardness and atom-probe tomography (APT) to obtain information from macro- to nanoscale.
In all alloys, two regions formed in the stir-zone. The larger SZ1 zone was heavily deformed and thus exposed to higher temperatures. The less deformed zone occurred on the retreating side of the stir zone. The hardness was slightly lower in the SZ1, while the hardness levels of the as-cast and heat-treated samples were identical. The main effect in the stir zones was the refinement of the initial grain structure. Strong deformation and high temperatures caused recrystallization and formation of very small crystal grains, typically smaller than one micrometre. Large primary intermetallic particles were crashed and more uniformly distributed within the Al-rich matrix. Dissolution of precipitates during heating and their renucleation upon cooling occurred in the heat-affected zone. The large grains in the HAZ did not change compared to the as-cast state. On the other hand, in the stir zones, very small and randomly oriented crystal grains were present. In the as-cast state and the HAZ, there was a large fraction of primary phases that formed during solidification. They transformed completely into the $Al_{29}Mn_6Cu_4$ phase in SZ1, and only partly in the SZ2 region. Within the SZ, quasicrystalline and other precipitates completely dissolved,

indicating that their size obtained during heat treatment was too small to survive harsh environments during FSP.

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25185: Characterization of the microstructure of Al alloys with state-of-the-art electron microscopy

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Abstract: The development of Aluminum alloys for the transportation industry relies on controlling the size, distribution, and volume fraction of nano-sized precipitated to improve their mechanical properties as well as the texture of their grains and the distribution of coarse intermetallics. 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.

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25092: Precipitation hardening in the Magnesium-Zinc-Calcium alloy system

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Abstract: In recent years, numerous research results on low alloyed Mg-Zn-Zr alloys with calcium additions have been published, aiming to develop a ductile precipitation hardenable wrought alloy. With calcium additions, a ternary phase becomes stable at the expanse of Zinc-containing phases. This study explores the precipitation hardening response of the alloy 1.6Zn0.3Ca0.4Zr to evaluate the influence of the ternary phase on the mechanical properties. The alloy was developed using the Calphad method to stabilise the ternary phase and suppress the Mg_2Ca phase and Zinc-containing phases. The hardening response was explored in a wide range of annealing temperatures by hardness, tensile tests and X-ray diffraction. Grain growth during solution annealing was also considered and modelled based on the automatic image recognition grain size measurements. Finally, suitable alloy design concepts and heat treatments for good precipitation hardening response are proposed.

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25094: New Aluminum-Scandium Powders Advance 3D Printing

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Abstract: In September 2024, Scandium Canada filed a provisional patent application with the

US Patent Office Titled "Aluminum alloy powders for additive manufacturing. Methods for producing the same and uses thereof." United States Patent and Trademark Office (USPTO, Application Number: 63/695,840. McMaster University has developed for Scandium Canada and successfully printed two new aluminum scandium alloys using Laser Powder Bed Fusion (LPBF). This method uses a laser beam to melt and fuse material powders.
The history of 3D printing with metal powders dates back to the 1980s, with the development of technologies such as selective laser sintering and direct metal laser sintering. Over the years, advancements have been made in materials and processes, leading to increased adoption in the aerospace, automotive, and health care industries. The future uptake of 3D printing with metal powders is promising, with continued innovations driving cost reduction, improved material properties, and broader applications across various sectors.
Scandium Canada and McMaster University's results show a significant reduction of solidification cracks and other defects such as porosity and lack of fusion voids owing to the presence of added metal constituents in addition to scandium in the aluminum matrix. These advancements open new 3D printing possibilities for manufacturing lightweight, high-strength components, particularly in the automotive, aerospace and marine industries.
This paper will emphasize Scandium Canada's approaches to advancing the commercial potential of 3D printing with aluminum scandium alloys. Mainly, we will discuss the importance and the business challenges of developing value chains in the "rare metals" critical mineral sector.

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25021: Functional Property Improvement Of The HPDC Alloy AlSi9Cu3Fe Through Sr And Heat Treatment

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Abstract: Aluminium high-pressure die casting alloys (HPDC) are widely used for combustion engine components and structural parts of vehicles. Today, the most relevant alloys used for these applications are often only optimized with respect to their mechanical properties and castability. However, the transition from combustion to electrical engines in the mobility sector is continuously altering the demand for products and properties. Structural components with adjusted functional properties, such as increased thermal conductivity in combination with high mechanical properties in an electric vehicle battery housing, are needed in the transport sector. The electrical and thermal properties of an Al-Si cast component are both governed by the movement of electrons. Defects in the material restrict the flow of electrons and therefore the present microstructure governs the level of conductivity of a part. The microstructure of HPDC components is influenced by the composition, cooling rate and casting parameters. Heat treatments can further be used to adjust the microstructure. The strength of die casting alloys is mostly controlled by precipitation and solid solution strengthening. Both of these mechanisms lower the thermal and electrical conductivity by introducing further electron scattering sites. The aim of this work is a comprehensive analysis of the combined influence of wall thickness, different heat treatments and Sr modification on the physical and mechanical properties of the Al-Si HPDC alloy AlSi9Cu3Fe. This is done by utilising a semiautomatic, quantitatively microstructure analysis in combination with testing methods for physical and mechanical properties. The results indicate that combining short heat treatments with Sr additions improve both mechanical and physical properties. Either high strength or high elongation in combination

with increased electrical conductivity are feasible. Simultaneous improvements of yield strength up to 49 % and electrical conductivity up to 19 % are possible. As well as electrical conductivity increasements of 32 % and elongation at break improvements of 142 %.

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25099: Effect of RheoMetal™ Process Parameters on the Microstructure of A356 Aluminum Alloy slurries

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Abstract: The RheoMetal™ process is an advanced technique designed for the quick production of semi-solid slurries used in the casting of various industrial parts. This method employs an Enthalpy Exchange Material (EEM), which is immersed and stirred in the molten metal, acting as a cooling agent to absorb heat and facilitate slurry formation. This study investigates the influence of key RheoMetal™ process parameters including primary EEM stirring, secondary impeller stirring, EEM content, and melt superheat on the microstructure of A356 aluminum alloy slurries. The slurries, prepared under varying conditions, were rapidly quenched in a copper mold to study the corresponding microstructures. The microstructural analysis revealed that the process parameters distinctly affect the solid fraction (fs), size (dα−Al), and shape factor (Fα−Al) of the primary α-Al solid phases. Higher melt superheat notably reduced fs, dα−Al, and Fα−Al while increased EEM amount led to higher fs, and dα−Al values. Although the EEM stirring had minimal impact on the microstructures, increasing the secondary impeller stirring duration considerably increased the fs, dα−Al, and Fα−Al highlighting the homogenizing effect of secondary stirring. These findings provide valuable insights in to the role of RheoMetal™ process parameters to controlling the microstructure of A356 alloy slurries, contributing to advancements in semisolid rheocasting techniques.

Symposium: Alloy Development and Characterization: Structural and Functional Materials

25101: The role of heat treatment on the microstructure and environmentally induced performance of AA7050 T7651 and AA7085 T7651 commercial thick plate

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Abstract: The environmentally induced cracking (EIC) performance of a commercial 3rd generation high Zn content 7xxx series alloy AA7085-T7651 thick plate material, is compared to commercial thick plate 2nd generation alloy AA7050-T7651, under warm humid air exposure. When tested under equivalent environmental conditions (70 °C and 50% RH), AA7085 exhibited shorter initiation times and a much faster sustained cracking than AA7050. The quench sensitivity in aluminium 7xxx alloy thick plates results from grain boundary precipitation (GBP) of the η-phase ($Mg(Zn,Al,Cu)_2$), which can significantly impact the fracture toughness and sensitivity to EIC. Novel characterization methods, supported by phase field simulations, was used to understand the detail of the grain boundary of the resultant grain boundary microstructure and in turn how this affects the EIC behaviour. Jominy end-quench tests were performed on

AA7050 and AA7085, with samples fractured under cryogenic conditions to expose grain boundary (GB) surfaces. This allowed the GB precipitate size distributions and morphologies to be quantified as a function of cooling rate. To understand the overall trends in the effect of composition and cooling rate on the size and density of the GBPs, 'large'-scale CALPHAD informed phase-field simulations were performed with a simplified particle geometry and nucleation model. Using AA7050 as a baseline, the influence of alloy chemistry on GB η-precipitates was systematically investigated. Increasing Cu and Zn both results in a higher η solvus temperature, which promoted both the nucleation and growth of η- phase grain boundary precipitates and leads to an increased quench sensitivity, whereas reducing the Mg content reduces quench sensitivity.
The quench rate and subsequent ageing treatment is critical to the EIC performance of these materials and fractography revealed AA7050 had a mixed-mode fracture surface with some grain facets showing significant corrosion products and greater localised plasticity, and others a purely brittle intergranular behaviour. This mixed mode behaviour of AA7050 contrasts with that seen in AA7085 which consisted of an entirely brittle intergranular fracture surface exhibiting very little evidence of corrosion. We are starting to better understand how the mechanisms of EIC are affected by the change in grain boundary microstructure and how this is influenced by the processing route.

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25102: Effect of Strontium Addition and Melt Sonication on the Ambient and High Temperature Conductivity of the Aluminum Casting Alloy A356
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Abstract: Aluminum (Al) alloy A356 (Al-Si-Mg) is a common casting alloy widely used in automotive, aerospace, and marine industries. Microstructure refinement and modification of cast Al-Si alloys is a standard practice to increase performance, particularly for creating lightweight and efficient parts. Grain refinement and Si modification are key objectives, especially with the lower magnesium content of the A356 alloy. Adding titanium for grain refinement and strontium for Si eutectic modification has proven highly effective but can potentially reduce conductivity. Melt sonication and heat treatment have shown the ability to alter the microstructure without requiring expensive and potentially deleterious chemical modifiers. In this study, the effects of strontium addition and melt sonication in conjunction with heat treatment on the microstructure and properties of A356 alloy were investigated. Ambient temperature thermal and electrical conductivity, microhardness, and tensile behaviour were evaluated. Additionally, the evolution of conductivity, thermal and electrical, with increasing temperature to above engine operating conditions was compared. The alloy's microstructure was characterized using optical microscopy, SEM-EDS and EBSD to explain the differences in performance. The results revealed that adding strontium resulted in significant refinement of the Si phase, increasing particle numbers and reducing particle aspect ratio. Similarly, melt sonication refined the Al matrix microstructure, including grain size and SDAS. Together, these effects significantly improved the mechanical properties of the as-cast alloys, with minimal impact on the conductivity compared to the heat-treated alloy.

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25112: Effect of Ni and Mo addition on interface bonding between spark plasma sintered TiC preforms and high-chrome white cast iron fabricated by sand casting
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Abstract: This study investigates the bondability between high-chrome white cast iron and titanium carbide (TiC) using Spark Plasma Sintered (SPS) preforms doped with Nickel (Ni) and Molybdenum (Mo) in a sand casting process. The preforms were cast into high-chrome white cast iron matrix, and the interface was evaluated based on three factors: solidification time, chemical diffusion across the interface, and debonding at the interface. Microstructural characterization techniques were employed to assess the bonding quality, with a particular focus on the influence of Ni and Mo doping on the interface structure and properties. The results revealed that the addition of Ni and Mo enhance interface quality, offering insights into optimizing bond performance for applications requiring high wear resistance and durability.

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25020: Influence of Quench and Strain Rate during Hot Rolling on Texture Evolution of a 6xxx Aluminium Alloy with Recycling Content
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Abstract: Texture optimization is key to control hemming and formability of 6xxx aluminium alloys used for automotive panels. The distribution of specific texture components through the aluminium sheet thickness is important to obtain a good balance between bending and roping. Aluminium sheets are produced with a sequence of hot and cold rolling steps followed by a solution heat treatment. All these steps are interlinked and affect texture evolution, but the role that the hot band texture plays in the microstructure development of successive production steps is often difficult to establish methodically. In this work, the influence of quenching and strain rate during hot rolling was studied on a 6xxx aluminium alloy with recycled content (i.e. Fe content higher than 0.15 wt%). Several ingot slices were cut from the same direct chill (DC) casting and hot rolled at different ranges of strain rates. Some of the hot rolled sheets were slowly cooled, while others experienced a rapid water quench. The different hot bands underwent the same cold rolling process (i.e. same strain rate) and same solution heat treatment to assess how the microstructure of the different hot bands affects texture evolution during cold rolling and recrystallization. Samples were collected after hot rolling, cold rolling and solution heat treatment and analysed using electron-back scatter diffraction (EBSD). After solution heat treatment, F-bending tests (i.e. flexural bending tests) were performed for all hot rolling conditions.
Rapid quench after hot rolling preserves a high amount of beta fiber (mainly Brass). On the contrary, slow coil cooling stabilizes a high fraction of exactly oriented Cube grains because of

its preferential recrystallization which consumes components of the beta fiber. Higher influence of strain rate on rolling texture occurs when the hot band is quenched and results in a large amount of Goss stabilized at the sheet center.
After cold rolling, the slowly cooled hot band develops a texture with an intensity four times higher than the cold rolled sample produced from the quenched hot band. Cold rolled samples from slowly cooled hot bands stabilize the maximum intensity of texture on the Brass orientation, while samples from quenched hot bands have a weak intensity and fraction of beta fiber. Moreover, cold rolled samples from hot bands from low strain rate show higher intensity of texture than hot bands rolled at high strain rates.
Later, these differences affect the driving force of Cube recrystallization during the solution heat treatment. The distribution of texture in solution heat treated samples has been assessed in detail. The optimal texture distribution through thickness resulting in best values of F-bending was obtained from hot bands hot rolled at high strain rates and quenched.

Symposium: Alloy Development and Characterization: Structural and Functional Materials

25118: Evaluation of the High Cycle Fatigue Behavior of Mg-Zn Alloy Modified with Yttrium and Calcium.

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Abstract: The increasing demand for lightweight materials in the automotive and aerospace industries has highlighted the potential of magnesium (Mg) alloys due to their high strength-to-weight ratio, recyclability, and dimensional stability. These properties make Mg alloys ideal for reducing vehicle weight. However, their hexagonal close-packed (HCP) crystal structure limits the number of slip systems available, leading to mechanical anisotropy and tension-compression yield asymmetry. These characteristics can affect their performance under dynamic loading conditions. While much research has focused on the fatigue behavior of common Mg alloy systems like Mg-Al-Zn and Mg-Al-Mn, there is growing interest in Mg-Zn alloys modified with rare earth elements (REs). Studies suggest that incorporating REs during the extrusion process can enhance fatigue resistance by refining the microstructure and reducing texture strength. However, further investigation is required to fully understand their performance under cyclic stresses.
This study examines the fatigue behavior of extruded Mg-Zn alloys modified with yttrium (Y), a rare-earth element, and calcium (Ca), an alkaline earth metal. The base alloy composition is Mg-1Zn (wt%), with two additional variants created by incorporating equal amounts of Ca and Y. The primary objective is to alloy these compositions with consistent proportions of elements and determine the optimal indirect extrusion conditions for each alloy to achieve a comparable grain size across all three compositions. This ensures uniformity in both alloying levels and grain size, enabling a precise evaluation of the specific effects of Y and Ca on fatigue behavior.
Microstructural analysis was conducted using optical and electron microscopy, electron backscatter diffraction, and synchrotron X-ray diffraction to study grain structure, texture, and phase formation. Mechanical and fatigue tests were performed to assess the influence of Y and Ca on alloy strength and cyclic performance.
The results show that both Ca and Y significantly enhance the fatigue resistance of Mg alloys by promoting weakening texture, and stabilizing precipitates. Among the alloys, the Ca-modified variant demonstrated the best fatigue performance, making it a strong candidate for lightweight,

high-performance applications in the automotive and aerospace sectors. This study provides crucial information for designing more efficient and safer structural components in demanding applications such as the automotive and aerospace industries.

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25120: Identification of nanoparticles in Al-Mn-Cu-X-based alloys
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Abstract: Precipitation-hardened alloys have been playing a vital role in practical applications. The design of new precipitation-hardened alloys requires knowledge of the microstructural characteristics encompassing atomic structure, chemical composition and geometrical parameters and their relationships with mechanical and other properties.
We have developed several new Al–Mn–Cu–X (X = Be, Sc, Zr, Y or V) alloys belonging to a new type of experimental precipitation-hardened aluminium alloys. An important task was to select an appropriate chemical composition and heat treatment procedures to control the formation and growth of different precipitates. This resulted in designing of a unique microstructure, mainly consisting of dual nanoprecipitates – icosahedral quasicrystalline and $L1_2$-Al_3X (X = Sc, Zr, Y or V) precipitates, which have a highly heat-resistant outer shell. Determination of nanoparticle properties in alloys plays an essential role in identifying mechanisms that contribute to the improvement of alloy properties. We present sample preparation and characterisation methods of nanoparticles in the as-cast state, after heat treatment and after deformation with friction stir processing. We used classic metallographic methods (grinding, polishing and deep etching), as well as ion etching with a cross-section polisher and analytical methods using high-resolution scanning electron microscopy (HR-SEM), transmission electron microscopy (TEM), transmission X-ray diffraction (2D-XRD) and atom probe tomography (APT).
The as-cast state did not contain any nanoprecipitates. During special heat treatment, icosahedral quasicrystalline and $L1_2$ precipitates were formed. It was revealed that quasicrystalline nanoparticles typically exceeded the size of 10 nm. Thus, much effort was directed to determine the distribution of these precipitates using HR-SEM, which allowed analysis of much larger areas than by TEM. On the other hand, the size of $L1_2$ precipitates was below 10 nm, and HR-SEM did not have sufficient resolution to identify those precipitates. Friction stir processing had a strong effect on microstructure. It caused dissolution and coarsening of precipitates and strong defragmentation of primary phases.

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25122: Incorporation of Ceramic Particles in an Aluminum Melt by Fluxing Agents: Aluminum Matrix Composites
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Abstract: The high-performance material properties of aluminum matrix composites (AMC) produced by ex-situ methods rely on the ceramic particles' wettability and interfacial strength with the matrix. The ceramic particles wettability improves as the metallic character of its bonding increases. Thus, the transition metal carbides of Group IV, particularly TiC, are a highly wettable ceramic phase when in direct contact with molten aluminum. The high wettability could ease the ceramic particles' incorporation rate and dispersion in the melt, promoting grain refinement and particle strengthening in the composite. To exploit the high wettability of the Al/TiC system, the inherent oxide films must be removed, as these oxide films work as a barrier, preventing direct contact between aluminum and TiC. By using fluxing agents capable of chemically dissolving these oxide film barriers, we could establish an oxide-free interface between the aluminum melt and the TiC particles, facilitating the intrinsic wetting behavior of the system.
When the ceramic particles are introduced into the melt, they must be stable without forming harmful interfacial reaction products, which could result in particle de-cohesion and loss of performance of the composite. Unfortunately, the high wettability of the carbides comes with a cost, as they are known for being less stable when in direct contact with the melt compared to the transition metal borides and nitrides, particularly at processing temperatures below 900°C. Thus, this results in the formation of aluminum carbide at the interface between TiC and aluminum, a brittle intermetallic phase that degrades the interfacial bond strength of the composite.
This study investigates the Al/TiC systems' wettability and stability when the oxide film barriers are chemically dissolved, and titanium is supplied directly at the interface by fluxing agents. Aiming to keep TiC stable at lower processing temperatures and finely dispersed during all steps of production into a high-strength composite filler wire.
To investigate the Al/TiC systems' wettability and stability, we have been conducting flux-assisted sessile drop experiments to narrow down the system of interest before casting master composites by molten salt-assisted stir-casting method. Then, the master composites have been added to a high-strength alloy and processed into a filler wire. The composite filler wire has been fusion welded by tungsten inert gas welding (TIG).
From the flux-assisted wetting experiments, instantaneous, complete wetting was observed when the fluxing agents chemically dissolved the oxide films. After characterizing the interface, aluminum carbide was observed in systems low in titanium. In contrast, the interface remained free from aluminum carbide when the fluxing agents directly supplied titanium at the interface at temperatures below 900°C.
The ceramic phase must be highly wettable by molten aluminum and stable during all production steps, particularly when the surface-to-volume ratio of the particles increases. Only when the nanosized ceramic particles are evenly distributed with strong interfacial bonding can they contribute to particle strengthening and improve the composites' performance.

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25126: Volumetric Energy Density Effects on Microstructure and Porosity in Scalmalloy Produced via Laser Powder Bed Fusion
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Abstract: The parameters chosen for a laser powder bed fusion (LPBF) alloy build can drastically affect the resulting microstructure. Local thermal histories and heat treatment of parts can affect the grain structure, precipitation, and porosity observed and thus properties. Scalmalloy is an alloy designed for production via LPBF displaying a bimodal microstructure,

with complex precipitation and porosity. This presentation will discuss the effects of the chosen volumetric energy density (VED) on the Scalmalloy microstructure to gain further insights into microstructure property relationships. Grain structure, composition, texture, precipitation, and porosity have been investigated over large areas at high resolution to give a holistic view of the microstructure. Further investigation into the observed porosity has been conducted using electron microscopy techniques and modelling of melt pools. Results show an increased equiaxed fine grain proportion with high VED and weak texture in coarse grained regions. High compositional homogeneity and microstructural stability is achieved, with two types of Al3(Sc,Zr) precipitation nucleating fine grains upon solidification and strengthening the material as a result of subsequent heat treatment. Keyhole porosity is observed near the surfaces of the builds, with lack of fusion porosity seen sporadically throughout. Modelling results agree well with observed porosity in the materials, and also provide further discussion regarding melt pool dynamics and the fine to coarse grain transition.

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25128: Design of low-modulus titanium alloys for additively manufactured biomedical implants using Material Property Optimiser

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Abstract: Alloys used in advanced engineering applications are becoming increasingly complex in terms of their compositions, processing methods and resulting microstructures. This complexity is essential to balance multiple, often conflicting, property requirements, such as strength, ductility, density and cost. Designing new alloys poses significant challenges, not only due to the vast and intricate design space but also because there is a pressing demand for the whole process to be faster and more cost-effective. In this context, materials modelling plays a crucial role in accelerating alloy development while reducing the need for time-consuming and expensive experiments. This presentation introduces the Material Property Optimiser (MPO), a powerful software tool developed to facilitate the design of multi-component alloys. It combines the property modelling engine of JMatPro® with a multi-objective optimisation method based on mesh-adaptive direct search. By exploiting JMatPro®'s reliable and consistent material property predictions and the optimisation algorithm's ability to efficiently explore the design space, the software can help identify trade-offs and pinpoint the most promising alloy compositions and processing routes.

The design of low-modulus titanium alloys for additively manufactured biomedical implants is used as an example of the alloy design process using JMatPro®-MPO. Titanium alloys are widely used in biomedical applications like orthopaedics and dental implants because of their high specific strength, biocompatibility and corrosion resistance. However, traditional titanium alloys, such as Ti-6Al-4V, have a higher modulus of elasticity than human bones, which can lead to issues like stress shielding and bone resorption. As such, the primary objective in designing these alloys is to lower the elastic modulus while maintaining essential properties such as strength, corrosion resistance, biocompatibility and suitability for additive manufacturing. Multi-dimensional composition-property relationships, referred to as "merit indices", are used to make estimates of the relevant mechanical, biological and manufacturing properties across a broad composition space. As such, the design process addresses all the critical stages from alloy formulation and component manufacturing to environmental performance.

The optimisation nature of the approach employed ensures the design targets to be reached at significantly reduced computational cost than the high-throughput computation methods. The quality of the optimisation outputs is closely related to the credibility of the merit indices used in the design criteria. JMatPro®-MPO provides users with the flexibility to define their own merit indices and therefore incorporate their own wisdom in the alloy design processes. This feature is significant, as it enables alloy design to extend beyond the current capabilities of JMatPro®.

Symposium: Alloy Development and Characterization: Structural and Functional Materials
25133: Effect of crystallographic texture on the anisotropic behavior during deep drawing of a Mg-Zn-Nd-Y-Zr alloy
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Abstract: After thermomechanical treatment of Mg alloys, e.g. rolling, and subsequent static annealing there is the stable development of texture components that persist after static recrystallization, i.e. Basal-type texture in conventional Mg alloys (e.g. AZ31) and the so-called TD-split texture in Mg-RE containing alloys (e.g. ZE10 alloy). This leads to a markedly difference on the work hardening rate (WHR), Lankford parameter (r-value), and ductility of the material with respect to the mechanical testing direction, e.g. uniaxial tension tests. This has profound implications on the anisotropic behavior of such alloys, which lead to undesirable defects during forming operations, e.g. earing behavior during deep drawing with concomitant inhomogeneous wall-thickness of the workpiece. Despite the huge efforts to understand the mechanical behavior of Mg alloys having off-basal textures, the topic dealing with the attenuation of planar anisotropy has not been deeply investigated. This is because most of the studies are aiming only to improve the formability neglecting this important issue. Thus, in this paper a highly formable and lean Mg-2Zn-0.2Y-0.2Nd-0.1Zr (wt. %) alloy is used and is thermomechanical processed in different way to promote different crystallographic texture components. In this regard, the effect different techniques such as cold rolling, conventional hot rolling and the use of equal channel angular pressing (ECAP) to process Mg sheets have been investigated. The deep drawing behavior was analyzed at two different temperatures, i.e. 150 and 200 °C, and using two deep drawing ratios, i.e. 1.7 and 2. It was observed a strong earing behavior in the conventional hot rolled sheets. This earing behavior was exacerbated by using ECAP. However, the cold rolling strategy showed the best results. In this case, an almost ear free cups were obtained. Additionally, uniaxial tests (using samples cut 0°, 30°, 60° and 90 from the rolling direction) were carried out at 200 °C to measure the r-value at 10 %. For comparison reasons a conventional AZ31 alloy, with a basal-type texture, was also tested. This has allowed to derive conclusions on the meaning of the normal and planar anisotropy in this hexagonal close-packed structured materials, which must be handled in a different way compared to cubic structured materials such as Al and steel.

Symposium: Computational Materials Design and Engineering
25201: Mechanical Characterization of Porous 3D-printed Polymer-Derived Ceramics

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Abstract: The mechanical characterization of bulk polymer-derived ceramics (PDCs) poses a significant challenge due to porosity introduced during pyrolysis, which complicates direct measurements of their material properties. Conventional approaches often fail to account for the voids created by evaporated resins, leading to inaccurate assessments of the bulk stiffness. To address this limitation, we propose a novel method to estimate the Young's modulus of bulk 3D-printed PDCs, enabling a more reliable understanding of their mechanical behavior. Hollow cylindrical specimens with varying wall thicknesses are manufactured through a liquid crystal display (LCD) three-dimensional (3D) printer. Micro computed tomography (CT) scanning is performed on these samples to reconstruct their porous structure, enabling the calculation of densities and porosities. Based on the reconstructed images, models meshed by cubic elements are created for each sample. Finite element analysis (FEA) is applied to simulate the elastic deformation of the cylindrical models under compression. A hypothetical bulk stiffness (E_{bs}) is assigned to the model, and the stiffness of the cylinders (E_{cs}) is acquired. In parallel, compression experiments are carried out on the 3D-printed cylindrical samples to obtain their stiffness (E_{ce}). Since the geometric models used in simulation and experiments are identical, the ratio of the true bulk Young's modulus (E_b) of this ceramic material to E_{ce} equals the ratio of E_{bs} to E_{cs}, thus E_b can be determined. Additionally, the average bulk Young's modulus of cylindrical specimens is calculated through experimental results based on the solid cross-sectional area, which represents a deviation of approximately 15% from the FEA-based result. This approach opens avenues to the acquisition of bulk material properties of porous materials including engineering ceramics and biological materials, and it offers valuable insights to guide the development of next-generation mechanical metamaterials.

Symposium: Computational Materials Design and Engineering
25198: Enhanced Tensile Test Method to Estimate Post-Necking Threshold Stress-Strain Response at Elevated Temperatures
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Abstract: Growing demand to reduce weight of the vehicles in the automotive industry have led to increase in the use of aluminum alloys for structural car body parts. Among these alloys, heat treatable AA7xxx series alloys are getting increased attention owing to their high specific strength. Hot forming and die quenching (HFDQ) procedure is attractive for manufacturing parts using these alloys since spring-back and distortion related issues can be reduced, while allowing for subsequent heat treatment. This necessitates the determination of flow behavior at elevated temperature regimes. However, previous researchers showed that the Considère criterion is reached at very low strains at temperature ranges necessary for HFDQ, facilitating difficulties in getting flow response for strain range which will be attained in the real forming operation. Positive strain-rate dependency is common in high temperature regimes for 7xxx aluminum alloys. As the neck is being formed, strain rate at the neck center increases, accompanied by an additional hardening effect. For materials with positive rate sensitivity, this phenomenon facilitates deformation away from the neck center. Therefore, severity of the of the neck does not increase as fast as it would have in a material without rate-sensitivity as the test continues. Using

3-D digital image correlation (DIC), instantaneous area at the neck center in a tensile test can be measured and used for obtaining average stress-strain response. This procedure was termed as area reduction method (ARM) by previous researchers. Being a local metric, local area measurement can be used to obtain reasonable effective stress-strain measurement even beyond Considère threshold up to some strain value. Due to stabilizing effect of positive rate sensitivity in a tensile test, strain range after Considère threshold at which effective stress-strain response can be ascertained, is increased. In the current study, a recently developed commercial 7xxx alloy was used for elevated temperature tensile tests. Tests were performed on Gleeble® thermomechanical simulator for its capability for reliable control of temperature and stroke. To get a representative response to HFDQ operation, specimens were kept at solution heat treatment temperature for a specified time, then quenched to the test temperature and tested immediately after quench using strain rates 0.01 s^{-1}, 0.1 s^{-1} and 1 s^{-1}. 3-D DIC was employed for strain measurements, both for extensometer and ARM strains. It is a common practice in the literature to perform tensile test using constant crosshead velocity, with the assumption that average strain rate stays constant. However, it was found that strain rate is not necessarily constant in a tensile test with such procedure. In the current study, trial runs with constant crosshead velocity were performed first and local strain rates at the neck location were tracked. Afterwards, tests were performed by adjusting the stroke control in the testing machine based on trial results. This approach allowed for getting quasi-constant effective strain rate around the neck, improving the test data to be representative for constant strain rate condition. Temperature, strain and strain rate dependent constitutive model was then developed.

Symposium: Computational Materials Design and Engineering

25156: AI-Enhanced Development of Elevated-Temperature Aluminum Alloys: From Generative Design to Experimental Validation

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Abstract: Aluminum (Al) alloys are valued for their high strength-to-weight ratios, machinability, and affordability. Automotive and aerospace structural and engine sectors require cost-effective Al alloys capable of withstanding 250–400°C. However, at elevated temperatures, phase coarsening reduces creep strength, leading to early failure. Accurate predictions of creep rupture life and the development of novel creep-resistant alloys are essential, but traditional alloy design methods are slow and expensive. The emergence of artificial intelligence (AI), powered by advanced computing and algorithms, when coupled with knowledge of physical metallurgy principles offers a promising solution for designing high-temperature Al alloys. This study presents a two-step AI-driven method. In the first step, a hybrid machine learning (ML)/CALPHAD framework analyzes alloy chemistry, processing routes, and thermodynamic properties under target conditions. ML models predict creep rupture life by combining time-temperature parametric models to assess and quantify the influence of input variables. The best-performing model is selected based on R^2 accuracy. In the second step, a generative high-throughput approach integrates a genetic algorithm (GA) with the ML model to explore a broader design space. A risk analysis identifies reliable candidate alloys for target applications. Proposed alloys are synthesized and tested to validate the approach, with experimental results closely matching target values. The newly developed alloy demonstrates excellent strength retention after prolonged exposure at 300°C and 30 MPa, with a significantly longer creep life compared to current Al-Si-modified creep-resistant alloys. Microstructural analysis reveals that a high-volume fraction of nanoscale, thermally stable dispersoids effectively inhibits coarsening and phase transformations. These dispersoids act as dislocation pins, creating obstacles to dislocation motion and grain boundary migration under high-temperature conditions. By combining ML, GA, and experimental validation, this method accelerates the discovery of high-temperature Al alloys and confirms its effectiveness on predict and design creep-resistant Al alloys.

Symposium: Computational Materials Design and Engineering

25193: Design of a Novel Cyclic Tension-Compression Test with In-Plane DIC Strain Measurement

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Abstract: Kinematic hardening data acquired from cyclic loading tests of automotive metals is critical for the accurate prediction of springback in forming simulations. The common method to acquire this data is to use in-plane tension-compression tests equipped with an anti-buckling device to restrict out-of-plane motion during compressive loading. Modern iterations of the test employ digital image correlation (DIC) of the specimen edge to measure the axial strain under the unverified assumption that the strain field is uniform across the sample width. Development of tension-compression tests has been empirically-focused and overly reliant upon correction methods for friction and biaxial stress, which involve further assumptions, and can introduce artefacts that are misidentified as kinematic hardening effects. A critical evaluation of the tension-compression test using virtual experiments is required to better understand the in-plane strain gradients, friction effects, magnitude of the through-thickness stress and the constraining effect of the anti-buckling fixture on the compressive R-value. The objective of the present study is to outline what geometric characteristics are important to an in-plane tension-compression geometry to allow for homogenous hardening during cyclic loading and during proportional compression tests. Design guidelines and recommendations for the sample geometry are developed from extensive finite-element simulations of a 6xxx-series aluminum alloy and the results compared to geometries in the literature. Furthermore, a novel design for an in-plane tension-compression test fixture that allows for in-plane digital image correlation is outlined and evaluated using virtual and physical experiments.

Symposium: Computational Materials Design and Engineering

25204: Effect of Boundary Conditions on the Sheared Edge Fracture Limits of MP780 Steels

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Abstract: The shearing process can create a work hardened region near the cut edge known as the shear affected zone (SAZ) which can lead to premature fracture during subsequent forming operations. The behavior of the cut edge during secondary edge stretching can also be influenced by the applied boundary conditions imposed during forming. The boundary condition influence on sheared edge formability can become more prominent in some hot rolled steels that exhibit centerline segregation at their mid-thickness which can be activated or suppressed depending upon the applied loading. In this study, in-plane bend, VDA V-bend, conical hole expansion, and hole tension tests were employed to study the effect of boundary conditions on the sheared edge formability of two multiphase (MP) steels having a nominal tensile strength of 780 MPa with different local ductilities and material defects. First, the work hardening in the SAZ was characterized using Vickers microhardness tests for the sheared holes. Digital image correlation (DIC) was used for full-field strain measurement during the secondary coupon tests to provide insight into the fracture strains and strain states. Additional tests were also performed with machined edge condition to measure the relative change in formability due to the shear cutting process.

Symposium: Computational Materials Design and Engineering

25172: The impact of solutes and precipitates on the strain hardening behaviour in Al-alloys

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Abstract: Understanding the influence of microstructure on the evolution of dislocations is fundamental for accurately simulating material behavior during plastic deformation. This study investigates the effects of solutes and precipitates on the strain hardening behavior of aluminum alloys. Compression tests are performed on the aluminum alloys 6016 and 6061 after various artificial aging treatments, as well as on two binary systems, AlSi and AlMg, which are solutionized to evaluate their fundamental microstructural properties. This approach assesses how changes in solute concentration and precipitation states affect dislocation dynamics, particularly focusing on dislocation generation and annihilation processes critical for work-hardening and dynamic recovery.
Measured flow curves are modeled using the thermo-kinetic software package MatCalc and an extended Kocks-Mecking approach to evaluate the dependency of model parameters on the material state. The study specifically examines the roles of silicon (Si) and magnesium (Mg) solutes on the dislocation behavior, emphasizing their impact on the mechanical response in aluminum. The findings are cross-referenced with state-ofthe-art constitutive modeling theories, offering enhanced insights into the interaction between microstructure and deformation behavior. This work contributes to a deeper understanding of how tailored microstructural engineering can improve formability and overall performance in aluminum alloys.

Symposium: Computational Materials Design and Engineering

25047: atomic modeling for the effect of single vacancy on thermal stabilities and mechanical behaviors as well as locally loading states for Ti matrixes

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Abstract: Atomic modeling within the formalism of classical mechanics is performed to investigate the thermal ability as well as mechanical properties of perfect and defective Ti matrixes, and the effects of Ti matrix anisotropy on tensile morphology. Potential energy, packing images, and atomic level stresses from the atomic-scale modeling reveals how temperature and heating rate affect the vacancy migration as well as potential barrier and the stress distribution on the atoms around the vacancy. By combining stress-strain curves with the atomic stress, the loading directions under unxaxial tension result in different mechanical behaviors and fracture morphologies. The Lode− Nadai values on the atoms in the modelled Ti

matrixes provide insights into the loading states of the atoms during tension. The atomic hydrostatic pressures are used to identify stresstransfer paths during the elasticity, plasticity, and fracture stages of the Ti matrixes.

Symposium: Computational Materials Design and Engineering

25072: Modeling Of Continuous Dynamic Recrystallization (CDRX): Application To Aluminum Alloys

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Abstract: Controlling microstructure presents a significant challenge in industry, especially during hot metal forming processes, as it directly impacts the durability and performance of metallic materials. To achieve this, one must understand and optimize the evolution of microstructure during thermomechanical processes, along with the mechanisms involved, which can be effectively guided by accurate simulations based on physics-based numerical models to predict and enhance material performance. In high stacking fault energy (SFE) materials hot worked under certain conditions, continuous dynamic recrystallization (CDRX) can be the dominant recrystallization mechanism. During CDRX, recrystallized grains are formed through progressive evolution of low-angle grain boundaries (LAGBs) into high-angle grain boundaries (HAGBs) by dislocation accumulation, annihilation and rearrangement.

In this context, hot compression tests were conducted on AA2139 Al alloy at temperatures between 350°C and 450°C, and strain rates between 0.01–1 s\(^{-1}\), for two main reasons: (i) to characterize CDRX phenomena, and (ii) to generate experimental data to identify material parameters for simulations. These simulations will be based on the pioneering Gourdet-Montheillet (GM) model for CDRX, taking into account the accumulation of dislocations, the generation of LAGBs, the increase in their misorientation, and their transformation into HAGBs.

The deformed microstructures were investigated using Electron Back-Scattered Diffraction (EBSD). Geometrically Necessary Dislocation (GND) density and Grain Average Kernel Average Misorientation (GAKAM) maps were calculated to explore CDRX mechanisms. It was found that CDRX grains located in the grain interior were formed through subgrain rotation (SGR), while those near grain boundaries were formed via strain-induced boundary migration (SIBM) combined with SGR around the original grain boundaries. Lower strain rates and higher temperatures promoted dynamic recovery, as indicated by the formation of larger subgrains and a reduction in both the fraction and specific length of LAGBs. Both the average disorientation angle of LAGBs and the fraction of LAGBs with disorientation angles between 10° and 15° increased with increasing strain and decreasing strain rate, indicating strong evidence of CDRX. This was limited at higher strain rates, where deformation time was insufficient for subgrain formation and their subsequent progressive rotation. The tendency of the experimental results of AA2139 aligned with the GM laws using the cited material parameters of commercial aluminum AA1200 cited within the original work of Gourdet and Montheillet. Once the material parameters will be identified for AA2139, the GM model should be able to predict its CDRX behavior.

Future work will expand the range of thermomechanical conditions to further explore the impact

of each condition on CDRX. Morever, the validated physical-based model will be implemented in a mean-field code and a full-field numerical framework dedicated to the prediction of CDRX in context of hot metal forming.

Symposium: Computational Materials Design and Engineering

25256: In-situ Simple Shear Tests of Single Grains for the Calibration of Crystal Plasticity Models

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Abstract: Knowledge of the constitutive behavior of single grains is crucial in crystal plasticity-driven modeling strategies, but experimental methodologies for the experimental characterization are scarce. Some of the challenges involve (i) material processing to produce single grains sufficiently large for mechanical testing, and (ii) experimental methods to probe the material to large strains beyond diffuse necking in conventional tensile tests. The present study proposes a hybrid experimental-numerical approach where the three-parameter extended Voce model is calibrated to experimental stress-strain curves obtained from *in-situ* simple shear tests of single grains. To this end, a suitable shear geometry was identified in virtual design using the finite-element solver LS-DYNA. The optimized sample geometry was extracted from AA6082 aluminum extrusions produced in the laboratory-scale extrusion press at Rio Tinto™ Aluminium in Saguenay (Quebec, Canada) and subjected to a heat treatment to produce large pancake-like grains. Samples were carefully selected to ensure that the gauge zone of the sample was aligned with a single grain. Samples were pulled in a 2 kN-capacity Deben mechanical loading stage incorporated in the KEYENCE microscope. Digital Image Correlation (DIC) was employed to track the strain evolution in the shear zone and synchronized with the load data to generate stress-strain curves of single grains. These experiments were modeled using crystal plasticity finite-element analysis for which the initial crystal orientation of the undeformed sample, identified from electron backscatter diffraction (EBSD), served as input. It is shown that using the experimental stress-strain curve as an optimization target is a suitable method for the reliable calibration of the constitutive law to large strains.

Symposium: Computational Materials Design and Engineering

25097: Finite element modeling for revealing the effects of machining on the metallurgical behavior of 6061-T6 aluminum alloy during dry machining.

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Abstract: The rapid advancements in industrial manufacturing demand efficient and sustainable technologies. High-speed dry machining (HSDM) has emerged as a critical process in aerospace, automotive, and electronics industries, recognized for its ability to handle complex thermal and mechanical loadings. These loadings induce metallurgical and physical behaviors, making a

comprehensive understanding of the associated metal-physical phenomena essential. In this work, a finite element (FE) model incorporating a user-defined subroutine was developed to predict metallurgical alterations, including dislocation density (DD) and grain size changes, under varying cutting conditions. Experiments were conducted to validate the FE model in terms of cutting forces, cutting temperature, and chip morphology. Results indicate that higher cutting speeds increase temperatures, promoting grain refinement near the machined surface and enhancing surface integrity. Conversely, lower cutting speeds result in higher dislocation densities and coarser grains, potentially reducing fatigue life and mechanical performance.
This research highlights the critical role of advanced modeling in optimizing HSDM processes for superior surface integrity, enhanced mechanical properties, and reduced environmental impact. Furthermore, the findings provide manufacturers with valuable insights to improve efficiency, quality, and eco-friendliness in modern production processes.

Symposium: Computational Materials Design and Engineering

25129: Microstructure-based modelling of hot deformation behaviour for as-cast Magnesium alloys

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Abstract: Cast magnesium alloys have gained significant popularity in recent years for their ability to maintain high strength at low weight, making them attractive for applications in automotive, aerospace, and other lightweight engineering sectors. Despite their advantages, these alloys suffer from poor formability at room temperature due to their hexagonal close-packed (HCP) crystal structure, which limits available slip systems. This limitation necessitates hot working processes to improve workability. At elevated temperatures, microstructural factors such as dislocation climb-controlled softening, second-phase particles, and dynamic recrystallisation play critical roles in influencing deformation behaviour and mechanical properties. Numerous empirical models have been developed to describe the hot working behaviour of as-cast magnesium alloys. However, these models often rely on extensive fitting parameters tailored to specific cases, lacking sufficient consideration of compositional and microstructural factors. Consequently, their predictive capability and applicability across a broader range of alloys remain limited.
This work presents our recent advancement in modeling the hot deformation behaviour of as-cast magnesium alloys by integrating thermophysical and microstructural data, such as phase fractions and composition-dependent material properties calculated using JMatPro®, into a comprehensive modelling framework. The softening behaviour is characterised through a dislocation climb-controlled creep mechanism, refined by a phase fraction-dependent back stress concept and dynamic recrystallisation. The approach is validated across a diverse range of as-cast magnesium alloys with varying compositions, temperatures and strain rates, demonstrating its robustness and adaptability.
Understanding the critical role of microstructure in hot working enables more accurate predictions of deformation behavior and supports the optimisation of processing conditions for improved material performance and integrity.

Symposium: Computational Materials Design and Engineering

25132: Investigations on the Cyclic Stress Strain Behavior of Thin Cladded Aluminum Sheets

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Abstract: Aluminum brazing clad sheets are extensively employed in automotive heat exchangers due to their favorable properties. To investigate their fatigue fracture behavior under application-relevant conditions using computational techniques such as the finite element method (FEM), it is crucial to develop a comprehensive understanding of the material's response to complex, cyclic thermomechanical loads. This requires detailed knowledge of the temperature-dependent mechanical properties of the material. Fatigue testing of thin sheet specimens (thickness below 1mm) is not covered by standard specifications, and poses a considerable experimental challenge. In this study, strain-controlled tensile fatigue experiments on micro-specimens are carried out. Strain control is established via real-time measurement of the engineering strain on the specimen surface via digital image correlation. This set-up yields reliable stress-strain curves reflecting the local properties of the material.

Based on these data, a hybrid mathematical model is developed to simulate the behavior of aluminum brazing clad sheets under thermomechanical cyclic loading, building upon established material modeling frameworks. Integration of the model with experimental data from tensile and fatigue tests highlights the presence of localized residual hardening effects, which are attributed to manufacturing processes. Accompanying SEM analyses support this hypothesis.

By calibrating the model parameters using the experimental results, the proposed model demonstrates high accuracy and computational efficiency, making it well-suited for the simulation of real-world components in engineering applications using computational methods. The proposed model balances complexity and practicality, featuring a sufficient number of parameters to accurately capture the temperature-induced variations in material behavior while remaining manageable for calibration using standard experimental tests. For efficient parameter estimation, efficient optimization techniques such as the Levenberg-Marquardt algorithm and the conjugate gradient method are employed, treating the problem as a nonlinear regression task. The results demonstrate that the proposed relatively simple model effectively replicates the temperature-dependent stress-strain relationship, even under conditions involving significant plastic deformation—a scenario frequently encountered in low-cycle fatigue of aluminum heat exchanger components. Furthermore, the mathematical modeling revealed that variability in the material properties, such as stress levels observed in standard strain-controlled fatigue tests, can be attributed to localized differences in the hardening of the material. This phenomenon is likely a consequence of the manufacturing process. Notably, this variability of local hardening is a characteristic feature of thin sheets and diminishes with increasing sheet thickness.

Symposium: Innovations in Manufacturing

25029: Microstructural Analysis of Dissimilar Fabrication in Wire-Arc Additive Manufacturing

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Abstract: In this study, a Cold Metal Transfer (CMT) was employed to fabricate two materials, copper (CuAl8) and steel (ER70S-6), using a Wire Arc Additive Manufacturing (WAAM) process. A cubic sample was produced using a 1 mm wire diameter, with the arc torch mounted on a six-axis robot operating at a constant speed of 10 mm/s, and the continuous fabrication process included a dwelling time of 120 seconds. Characterization of the sample revealed the formation of a steel dilution area in the CuAl8, with a Heat Affected Zone (HAZ) reaching a depth of 4 mm in the substrate, characterized by a notably finer grain size. Additionally, the joint area between CuAl8 and ER70S-6 was defect-free, and the microhardness in the steel was more uniform in the joint region, attributed to a lower cooling rate of the steel compared to that of copper.

Symposium: Innovations in Manufacturing
25142: Understanding the Effect of Metal Pouring Temperature on Pre-Solidified Grain (PSG) Formation in (Al, Zn, Mg)-Fe Dilute Eutectic Aluminum Alloy Castings
Mohammed Talha Aziz[1], Xiaochun Zeng[2], Gabriel Birsan[3], Kumar Sadayappan[3], Glenn Byczynski[4], Anthony Lombardi[4], Andre Phillion[2], Sumanth Shankar[2]
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Abstract: Pre-Solidified Grains (PSGs), in which grains begin to solidify in the shot sleeve of High Pressure Die Casting (HPDC) as opposed to the die itself, significantly affect the properties and performance of structural aluminum die castings. Control of PSGs has been documented in the literature for conventional die-casting alloys, where it was determined that higher metal pouring temperatures drastically reduce PSG formation. However, these effects are still to be evaluated in a newly developed (Al, Zn, Mg)-Fe casting alloy designed for high-strength applications. In this study, the effect of HPDC metal pouring temperature on PSG formation is investigated. Four pouring temperatures, 700°C, 715°C, 735°C, and 750°C were studied. Quantitative metallography and uniaxial tensile testing were performed to determine PSG content, cast quality and uniaxial tensile properties. The results show that as the metal pouring temperatures increased from 700°C to 750°C, the PSG content in the castings decreased from 10.1% to 1.00%. Moreover, with the reduction in PSGs, it was noted that there was less propensity of formation for gas porosities as well.

Symposium: Innovations in Manufacturing
25148: Extrusion of Particle-Reinforced AA2017 Aluminum Alloys Produced via High-Energy Ball Milling and Field-Assisted Sintering
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Abstract: Field-assisted sintering (FAST) is a widely used powder consolidation process known for its many advantages. However, it is primarily limited to producing flat shapes like discs due to the constraints of uniaxial compression and the need for uniform heat distribution. In contrast, performing extrusion with FAST is a newly developed technique that offers faster consolidation, the ability to produce extended geometries, and enhanced grain refinement under applied direct current and pressure. By integrating extrusion after FAST, the microstructure and mechanical properties of the composites can be significantly improved. Achieving the desired properties requires a high degree of reinforcement particle dispersion within the metal matrix and strong interfacial bonding. This study focuses on producing particle-reinforced AA2017 aluminum alloys using the powder metallurgy route involving high-energy ball milling (HEBM) and FAST, followed by the extrusion process in a spark plasma sintering device. AA2017-SiC_p composites with different amounts of SiC particles (5 to 15 vol%) were successfully fabricated. Sintered and extruded samples were subjected to heat treatment with a solution temperature at 500 °C for 2 h, and subsequent natural aging (T4) at room temperature for one week. The composite powders, sintered, and extruded samples were characterized to examine the effects of SiC_p content on the microstructural, mechanical, and tribological behaviors. Microstructural analyses were conducted using light microscopy (LM), scanning electron microscopy (SEM), and phase characterization via X-ray diffraction (XRD) to gain insights into the evolution of the composite material during the synthesis process. The LM and SEM results confirmed that a uniform distribution of SiC_p reinforcement and nearly spherical powder particles was obtained after 12 hours of milling time. Mechanical properties were evaluated through hardness measurements and tensile tests, demonstrating complete densification (100% relative density) after sintering and extrusion. The fine microstructure, uniform SiC dispersion, and strong interfacial bonding contributed to improved mechanical performance. The microhardness and ultimate tensile strength (UTS) increased with higher SiC content, with the maximum microhardness of 224 HV0.1 achieved for the AA2017 + 15 vol% SiC composite. The T4 heat treatment further improved hardness and tensile strength due to the homogenized distribution of precipitations in the aluminum matrix during the solution treatment. In addition, tribological behavior was assessed using a reciprocating wear test using different applied forces (5 and 20 N). The tribological properties of wear depth, wear volume, and coefficient of friction were determined, and the worn surfaces were evaluated using a 3D profilometer. The analysis showed that wear depth and volume increased with increasing SiC content. This study demonstrates that integrating FAST and extrusion significantly improves the microstructure and mechanical properties of AA2017-SiC_p composites, offering a novel approach to advanced material synthesis.

Symposium: Innovations in Manufacturing
25149: Deep Cryogenic Treatment of Shovel Teeth for Wear Resistance in GET's
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Abstract: The mining sector plays a crucial role in addressing the growing global energy demands. Wear of ground-engaging tools (GETs), such as shovel teeth, leads to significant downtime, increased maintenance costs, and reduced productivity of mining operations. This study highlighted the potential of deep cryogenic treatment (DCT) for improving the wear performance of mining tools, specifically, shovel teeth. DCT supplemented traditional heat-treatment processes to improve the mechanical properties of materials. Specimens extracted from

the skin of the in-service shovel teeth were subjected to two DCT procedures, targeting temperatures of -150°C and -180°C for a dwell time of 8 hours followed by a 250C tempering. The overall effect of DCT on microstructure and mechanical performance were evaluated using advanced characterization methods supplemented by finite element analysis. X-ray diffraction (XRD) revealed a significant reduction in residual stresses post DCT, which was further verified using finite element analysis (FEA). The FEA also provided insights into the distribution of residual stresses across different sections of the specimens during intermittent stages of the cryogenic treatment. Microstructure investigations demonstrated previous retained austenite to martensite transformation during to DCT, leading to a lower proportion of retained austenite in treated samples. It was suggested by some earlier studies that pushing out of carbon from the lattice might have happened during tempering, resulted in the precipitation of carbides. The increased martensite and carbide precipitation were reflected in the increased microhardness post DCT. Enhanced hardness translated to improved wear resistance which was measured as reduced mass loss in abrasive wear test. Wear testing of the post DCT vs. as-received specimens indicated a less dominant abrasive cracks, grooves, and ploughing of material from the center towards the edges of specimens. DCT was also found to have an increase in ductility with a marginal increase in strength of the treated specimens. However, DCT was found to have a combined effect on slightly decrease the impact energy of the specimens, presumably due to the increased martensite portion. This study also explored the effect of cryogenic treatment on the overlays applied to the substrate shovel teeth. Multi-pass overlay deposition often came with microcacks. Notably, a compressive strain was observed in XRD following the DCT, accompanied by a possible crack healing in the overlay matrix. The discontinuity in cracks at the carbide-matrix interface after DCT seemed to indicate partial healing, further validation was pending.

Symposium: Innovations in Manufacturing

25150: Deep Cryogenic Treatment of a High Manganese Steel for Ground Engaging Tools

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Abstract: High manganese steel has long been a material of choice for ground engaging tools (GETs) in oil sands mining, owing to its exceptional work hardening, toughness, and wear resistance. These properties are critical in harsh mining environments where materials are subjected to intense mechanical stress and abrasive wear. However, continuous improvements in material performance are essential for meeting the growing demands for durability and efficiency in such extreme conditions. This study explored the effects of deep cryogenic treatment (DCT) on mechanical properties and wear performance of a high manganese steel. The investigation employed a comprehensive suite of experimental techniques, including mechanical testing, G65 wear testing, and advanced microstructural characterization. Techniques such as X-ray diffraction (XRD), field emission scanning electron microscopy (FESEM), electron backscatter diffraction (EBSD), and dilatometry were used to examine the microstructural evolution, phase transformations, and thermal stability induced by DCT.
Mechanical testing demonstrated a complex behavior, including minor changes in hardness and wear resistance by G65 testing, but significant increase in impact toughness and ductility. Microstructural analysis was on-going, to reveal any alterations in carbide precipitation, grain

refinement, and grain boundary strengthening mechanisms. The EBSD analysis was expected to verify changes in grain orientation and dislocation density, while dilatometry to provide insights into phase stability and transformation behavior during cryogenic processing.
The G65 wear tests showed reduced material loss under abrasive conditions, confirming the potential of DCT to increase durability of mining equipment. By combining mechanical performance data with detailed microstructural insights, this research established a direct correlation between DCT and the enhanced mechanical properties of high manganese steel. The findings suggested that DCT was not only a practical but also an economically viable solution for extending the service life of GETs. Furthermore, the study provided a foundation for future research aimed at tailoring cryogenic treatment parameters for various applications within the mining and heavy industry sectors. This work highlighted the potential of DCT as an advanced material processing technique, paving the way for the development of high-performance steel components designed for extreme environments.

Symposium: Innovations in Manufacturing

25017: Additive Manufacturing Of Ti-6Al-4V Parts Via Fused Filament Fabrication (FFF)

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Abstract: Common equipment and operation of Additive Manufacturing (AM) of titanium is usually cost-intensive due to advanced machines. Extrusion Additive Manufacturing (EAM), for instance Fused Filament Fabrication (FFF), offers the fabrication of titanium components with complex geometries and a high level of detail at low costs. This can be achieved by the low waste of titanium powder and by using cost-effective, commercial FFF printers. These printers are fed with feedstocks containing titanium powder and thermoplastic polymers (binders), which enable the mixture to be shaped at moderate temperatures. After shaping, the binder must be removed by dissolving in water and subsequently pyrolyzing. A final sintering step densifies the metal and controls its structure and mechanical properties. With respect to the requirements of the printing process, we established and optimized the process chain to fabricate dense and defect-free Ti-6Al-4V parts via FFF. At first, new feedstock systems with various polymeric components were developed and subsequently characterized by using Capillary Rheology and Dynamic Mechanical Analysis (DMA). The second step included on the one hand the extrusion of flexible filaments and on the other hand the printing of green parts. A matter of interest were the printing parameters, such as the printing temperature or the infill pattern, and their influence on the properties of the final parts. Finally, the debinding behavior of the green parts in water and the sintering parameters (heating rate, temperature and time) were investigated and optimized.
After sintering, a density of more than 99.5 % of theory could be achieved. Tensile tests showed comparable mechanical properties to conventional manufacturing methods. In addition, the low contamination with oxygen and carbon validates the process chain. Furthermore, the knowledge gained about binder systems could be transferred to other materials such as CoCrMo or ZrO_2.

Symposium: Innovations in Manufacturing

25036: Laser Direct Energy Deposition of CoCrFeNiTi Equimolar High-Entropy Alloy

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Abstract: In metal additive manufacturing, the formation of a columnar microstructure along the build direction is common for many alloys. This phenomenon leads to anisotropic properties, which can significantly affect mechanical performance. While there are various post-processing methods available to refine the microstructure, these methods often increase manufacturing costs and duration. One potential alternative to avoid the need for post-processing is to change the alloy system to one that naturally forms a fine-grain microstructure during rapid solidification, without being influenced by the layer-by-layer heat treatment history inherent in the additive manufacturing process. High-entropy alloys, a relatively new class of materials, present a promising solution in this context. Considering their vast design space and the complex interactions of alloying elements, their behavior and properties are not yet fully understood. This study investigates the microstructure of the CoCrFeNiTi equimolar high-entropy alloy, which has been additively manufactured using laser direct energy deposition aiming to achieve an equiaxed microstructure. The as-deposited microstructures were examined using optical and scanning electron microscopy, while phase and elemental analyses were performed using Energy Dispersive Spectroscopy and X-ray diffraction. Mechanical properties were evaluated through Vickers micro-indentation hardness and tensile testing.

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25040: Printability and Green Mechanical Properties of Binder jet Additive Manufactured Co-Cr-Mo Parts
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Abstract: This paper investigates the optimization of the binder jetting process using gas-atomized Co-Cr-Mo (F75) powder. Various parameters including particle size distribution (PSD), binder saturation, and recoating speed were systematically examined to understand their effects on green part density and flexural strength. Results demonstrated that increasing binder saturation significantly enhanced green density up to 56% and flexural strength up to 14 MPa. While increasing recoating speed negatively affected green density down to 47%, it had minimal influence on flexural strength, with a maximum variation of 10 MPa for all printing conditions. For the MIM-cut powder with finer PSD, the best printing condition was a binder saturation level of 100% and a recoat speed of 80 mm/s. However, for the coarser PSD of LPBF-cut powder, the best printing condition was a binder saturation level of 80% and a recoat speed of 80 mm/s. This is because exceeding optimal binder saturation values may compromise accuracy and lead to excessive binder consumption and prolonged debinding times. Broader PSDs contributed to higher green densities and flexural strength.

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25041: Influence of temperature and print orientation on anisotropy sintering in binder jet stainless steels
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Abstract: Binder jetting shows great promise for high-throughput mass production of metal parts with complex geometries. However, primitive lines formed during the process produce anisotropic sintering shrinkage, complicating the design of new parts. In this study, the effect of temperature (between 1000 °C and 1400 °C) on the microstructure and activation energy for sintering two stainless steels (316L and 17-4 PH) is evaluated. Shrinkages along the three major orientations with respect to the powder bed are considered to link sintering kinetics to the material's anisotropic behavior. The effect of particle size distribution on the anisotropic shrinkage factor is also discussed. In both materials, the anisotropic shrinkage factor increases with the amount of δ-ferrite observed in the microstructure and the green density. The maximum shrinkage occurs along the build direction due to the formation of primitive lines, while the minimum shrinkage occurs along the recoating direction.

Symposium: Innovations in Manufacturing

25206: Refractory Materials Used in Liquid Aluminum and Steel Processing for Assuring Cast Metal Quality.

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Abstract: Refractories are defined by ASTM C71 as "non-metallic materials having those chemical and physical properties that make them applicable for structures, or components of systems that are exposed to environments above 1000 ^{0}F (811K; 538 ^{0}C)". Their applications within the metallurgical industry include their use in the production of aluminum and steel semi-finished products, where their role in assuring the quality of the final metal product plays an intrinsic part in metal extraction, refining, and casting. For instance, their use as containing vessels for holding these liquid metals during their refining is essential. Refractory porous plugs, located in the base of typical ladles used within the steel industry, inject (inert) argon to stir a melt. The argon bubbles formed help degas the liquid steel, and remove products of deoxidation, such as clusters of alumina particles, from the melt by attachment to their bubbles surfaces as they rise though the melt. Similarly, it is common practice to degas liquid aluminium of dissolved hydrogen, prior to casting, again using rising bubbles of argon. The gas is typically introduced into the melt using a refractory injection tube (carbon) in combination with a rapidly rotating impellor, to create extremely fine bubbles of argon (e.g. ABF, SNIFF, in-line degassers, etc.). These bubbles equilibrate with dissolved hydrogen to degas the molten aluminum. Similarly, small inclusions are removed by passing the liquid aluminum through CCF's (Ceramic Foam Filters). In both cases, the sizes of inclusions and bubble sizes are important variables which must be optimised. For liquid steel, many inclusion particles less than ~60 microns cannot presently be removed by means of flotation by the action of rising bubble plumes of argon, while for liquid aluminum, the opposite holds true, in that these melts are conveniently degassed, but they are thereby flooded with very fine microbubbles of argon, that obscure LiMCA (Liquid Metal Cleanliness Analyzer) sensor readings of particulate concentrations within a melt about to be cast into DC (Direct Chill Cast) ingots, after having been filtered of hard inclusions using CFF's.
At the McGill Metals Processing Centre, we have been working on the task of creating sized microbubbles of gas in ladle shrouds to overcome current deficiencies in standard steel casting operations. We have been using sized orifices and spinning gas injection rotors in a low

temperature liquid metal, Cerrolow 136, to determine the size range distributions of gas bubbles and entrained particles that can be removed by these new approaches. The generation of these sized bubbles is affected by various parameters including: the type and characteristics of refractory materials used for gas delivery through a nozzle or orifice, liquid metal density and viscosity, surface tension and wetting angle, and inlet gas velocity and flowrate, and gas density. The present work addresses the types and characteristics of refractory materials used in aluminum and steel industries, particularly for melt refining.

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25018: A layer-by-layer FEM curing model for binder jetting of 316L

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Abstract: Binder jetting is faster than laser-based AM technologies, which enables the required throughput for the mass production of metal components. However, binder jetting requires several post-processing steps, such as curing and de-binding, which increase production costs. This study aims to establish an in-process curing method to reduce the production time of binder jetting printed parts using heat sources. Three different models based on FEM were developed to thermally simulate in-process curing during binder jetting. In the first model, the heat source moves incrementally over the powder bed. The second model integrates the heat input over each deposited powder layer, reducing computational time. In the third model, a lumped approach is employed, allowing for the grouping of several layers, thereby improving computational efficiency. The three models are compared with experimental measurements, their accuracy and computation times are also evaluated.

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25260: Linking Hydraulic Turbine Steel Microstructures to their Fatigue Properties: Current Progress and Future Prospects at Hydro Quebec

Daniel Paquet[1], Jean-Benoît Lévesque[1], Pierre-Antony Deschênes[1], Laurent Tôn-Thât[1], Vladimir Timoshevskii[1]

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Abstract: In the context of aging assets and the increasing demand for clean energy production, Hydro Quebec recognizes the critical need for improved decision-making in the fabrication, use, and repair of hydraulic turbines. Fatigue damage mechanisms in hydraulic turbine steels are complex and dependent on their underlying microstructure. However, current turbine design methodologies do not account for the micro-mechanisms responsible for fatigue damage. Hydro Quebec is actively developing numerical tools, including high-fidelity simulations and artificial intelligence models, to establish the link between steel microstructures and their fatigue properties. This presentation will provide an overview of the progress made in developing these tools and offer insights into their potential future applications in enhancing hydraulic turbine efficiency and fatigue life.

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25266: Die Wear Behaviours of Al-Fe and Al-Ni Alloys

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Abstract: Modern aluminum castings for emerging automotive and transport purposes require properties that differ from traditional cast alloys. The aluminum transition metal system has shown promise regarding high castability, high electrical and thermal conductivity, and reasonable mechanical properties. In addition to hot tear susceptibility, tendency to die soldering is also an important parameter to assess castability. The current research examined the die soldering tendency of Al alloys with transition metal additions of Fe and Ni. Pure Al has a high die soldering tendency due to the low Fe content. Aluminum-iron alloys have significantly reduced die soldering due to the low concentration gradient. Aluminum-nickel alloys have comparable or more severe die soldering tendency than pure Al. Development of Al-Fe and Al-Ni alloys will enable high electrical and thermal conductivity alloys with high castability that can be used with multiple production processes for low cost manufacturing.

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25053: Texture Evolution in Rotational Vibration-Assisted Incremental Sheet Forming of Aluminium AA6082 and Magnesium AZ31 Alloys

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Abstract: Incremental Sheet Forming (ISF) has emerged as a promising technique for the flexible manufacturing of complex geometries, offering advantages such as cost efficiency and material adaptability. Rotational Vibration-Assisted Incremental Sheet Forming (RV-ISF) builds upon conventional ISF by incorporating vibrations, significantly enhancing material formability, particularly for hard-to-form alloys. Most research on ISF has concentrated on process parameters, forming limits, and tool design to further improve forming limits. However, the material deformation mechanisms responsible for the improved formability with RV-ISF are not well understood. Analysis of the crystallographic texture and stored energy of the formed materials offers valuable insights into these mechanisms, providing a deeper understanding of how materials behave during the ISF and RV-ISF processes.

In this study, the crystallographic texture evolution in two alloys AA6082 and AZ31 was investigated with electron backscattered diffraction (EBSD). For AA6082 alloy, texture analysis highlighted distinct deformation modes through the sheet thickness during ISF. The shear-related brass texture was observed near the tool-contact surface, while typical rolling textures dominated the mid-thickness layer.

For AZ31 magnesium alloy, the effect of tooling type (standard tool and novel rosette tool with vibration-assisted ISF) was compared under two different rotational speeds (3000 rpm and 6000 rpm). EBSD analysis revealed significant differences in grain size and texture evolution across the sheet thickness. Near the tool-contact surface, finer grains formed due to dynamic recrystallization, while the mid-thickness and bottom layers retained deformed grains with distinct texture characteristics.

These findings advance the current understanding of the ISF process by linking texture evolution

to deformation mechanisms in both aluminium and magnesium materials. It reveals the complex deformation patterns in alloys during ISF, offering valuable insights into material flow behaviour that can guide the development of future ISF techniques for manufacturing complex geometries in challenging materials.

Symposium: Innovations in Manufacturing

25199: Synchrotron Characterization and Corrosion Analysis of Additively Manufactured Titanium-based Alloys for Biomedical Applications

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Abstract: Additive manufacturing (AM) has transformed manufacturing, as it is ideal for complex geometry products, new alloy designs, and gradient alloy designs, such as different bulk and surface properties. For example, for biomedical applications, it is possible to alloy previously impossible elements such as copper (Cu) for antibacterial properties into biomedical lightweight alloys or their surface. Titanium (Ti)-based alloys have been a material of interest in biomedical, aerospace and automobile industries owing to their excellent combination of mechanical properties, biocompatibility, and corrosion resistance. The comprehension of microstructure-related corrosion behavior of additively manufactured Ti-based alloys is extremely important for their successful application as biomedical implants or devices. Because of the large difference in standard potential between Ti and Cu, microgalvanic effects such as those resulting in selective corrosion or in increased hydrogen pickup are of interest for Cu-functionalized biomedical Ti alloys. The antibacterial effect of Cu is caused by its corrosion, which results in the release of Cu ions and reactive oxygen species, destroying the cell membrane of bacteria. The rate of corrosion of Cu incorporated in Cu-enhanced biomedical Ti alloys is hence of great interest for their application and can be tuned by AM settings. Here, we report the corrosion and microstructure of two Cu-enhanced Ti-based alloys characterized by synchrotron techniques such as synchrotron X-ray diffraction, X-ray absorption spectroscopy and X-ray fluorescence imaging. The results and insight of this study help to optimize the design and development of optimal AM methods for Cu-enhanced biomedical lightweight alloys.

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25213: The influence of elevated Fe and Zn impurities on the rapid solidification behaviour of AA6061 processed using single track laser surface melt trials

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Abstract: Increased adoption of recycled aluminum (Al) alloys in the automotive sector can provide several economic and environmental benefits through vehicle lightweighting, decreased fuel consumption, and reduction in greenhouse gas emissions. A major challenge in the adoption of secondary Al for a broader range of products is the accumulation of impurity elements, as increased scrap use can result in the compositional drift of alloy streams, leading to degraded mechanical and electrochemical properties. The objective of the current study is to demonstrate the use of rapid solidification processing (RSP) to increase the potential adoption of recycled Al through the formation of non-equilibrium and metastable phases, refinement of microstructural features, and increased solubility of certain elements. Cast ingots of an Al alloy 6061 (AA6061) were produced with iron (Fe) and zinc (Zn) addition in amounts ranging from 0 to 1 wt% to simulate recycling impurities. Thermodynamic simulations were used to predict the crack susceptibility of each alloy composition. Laser surface melting (LSM) trials were performed on plates cut from each ingot to generate rapidly solidified microstructures. The simulation predictions and microstructure results suggest that alloy impurity composition does have an influence on the cracking behaviour observed in the resolidified melt pools, with Fe addition having a positive effect on the observed cracking behaviour, while Zn tended to increase the crack susceptibility, regardless of Fe content. The results suggest that the adoption of RSP techniques like additive manufacturing can optimize impurity control in recycled Al alloys, advancing its use for automotive applications.

Symposium: Innovations in Manufacturing

25216: Inherent damping to enhance Vibration Fatigue Performance of Titanium Coupons by Encapsulating Powder During Additive Manufacture

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Abstract: In this presentation we will discuss how laser powder bed fusion additive manufacturing (AM) can be used to create titanium structures with an inherent capability to damp vibrations, and whether this can be used to increase the fatigue life of structures under vibration loading. To achieve this, pockets of un-melted powder (the feedstock) are encapsulated inside samples. Under vibration testing the movement of the powder damps the vibration and significantly reduces the strain in the samples. We will show that as-built structures show considerable promise for damping vibrations, with quality factors an order of magnitude lower than solid specimens (demonstrating much greater damping). Unfortunately, the residual stresses induced by the AM process make it impossible to deploy these structures without further processing. Indeed, several of the as-built specimens cracked while they were awaiting testing, i.e., under zero external loading. When the recommended post AM heat treatment (800 °C for 4 hours, designed to both relieve the residual stresses and improve the mechanical properties) is applied to the structures, the damping effect is entirely removed. This appears to be due to a very mild sintering of the powder, which despite making no significant difference to the powder morphology when observed by SEM, seems to prevent the movement of the powder within the pockets. We will demonstrate that the damping can be maintained by altering the post processing steps to relieve the residual stress without sintering the powder. However, this removes the opportunity for microstructure refinement induced by the recommended heat treatment, and in particular, the decay of martensitic structures. When testing the material under conventional uniaxial fatigue conditions, our results show a significant drop in the fatigue life expected at a given stress when the AM titanium is subjected to a lower temperature heat treatment than the recommended. Thus, there are two objectives with competing methods to achieve them: damping the vibration (better achieved by avoiding high temperature heat treatments) and maximising the

fatigue resistance (better achieved by utilising high temperature heat treatments). We will use experimental data to evaluate whether the reduction in strain is enough to offset the reduction in fatigue life for a given stress, and thus produce a longer lasting material than current practice.

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25057: Martensite Decomposition of Ti-6Al-2Sn-4Zr-6Mo for Improved Mechanical Properties

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Abstract: Ti-6Al-2Sn-4Zr-6Mo is classified as a β-rich (α+β)-titanium alloy and can, therefore, exhibit α- as well as β-phase. In addition, and depending on the heat treatment temperature, in Ti-6Al-2Sn-4Zr-6Mo either the α'-martensite or the α''-martensite (both metastable, non-equilibrium phases) can form during rapid cooling. At present, the alloy is primarily used as a fan disk material at higher strength levels in some newer and larger aircraft engines (at temperatures up to 400 °C) and is typically applied with bimodal microstructures as the metastable martensite might undergo further phase transformations during service. First additive manufacturing studies have recently been carried out on Ti-6Al-2Sn-4Zr-6Mo. Multi-track experiments (PBF-LB/M) performed in our group have shown that martensitic transformations occur during additive manufacturing of Ti-6Al-2Sn-4Zr-6Mo so that martensite decomposition has to be considered during post processing. Therefore, in the present feasibility study, a heat treatment strategy including martensite formation and decomposition has been carried out on conventionally produced material first and afterwards at samples coming from multi-track experiments.
For conventionally produced Ti-6Al-2Sn-4Zr-6Mo, in the first heat-treatment step, an α_p/α''-microstructure with an α_p volume fraction of approx. 13% to allow enhanced fatigue properties has been produced by annealing the alloy at 925 °C for two hours followed by water quenching. Afterwards a martensite decomposition study has been performed by ageing the alloy between 500 °C and 700 °C at holding times between 5 minutes and 240 hours. The resulting microstructure and phase composition have been analysed by optical and scanning electron microscopy as well as by X-Ray diffraction. Hardness, tensile and fatigue tests have been carried out to study the mechanical properties. Finally, long-term exposure at elevated temperature (up to 450 °C) were performed to study the microstructure stability at service temperature. The results obtained show that martensite decomposition can lead to reasonable mechanical properties.
In a second step, martensite decomposition has been carried out on the multi-track samples as well to study the microstructure and properties evolution during post-processing.

Symposium: Innovations in Manufacturing

25061: Metallurgical Challenges in Sustainable Titanium Additive Manufacturing

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Abstract: There is a strong focus in the research community to develop additive manufacturing (AM) processes to produce high-performance titanium components, especially for aerospace industries. Conventional manufacturing of these components requires energy-intensive rolling or forging to meet the stringent property specifications, and the wrought billets subsequently require extensive machining with only a small amount of material eventually being used on the aircraft. High-deposition-rate AM processes, like wire-arc AM (WAAM), are less-energy-intensive alternatives that heavily reduce material wastage through manufacture of near-net-shape parts that require only minimal surface machining, which would result in significant CO_2-emission reductions. However, these processes use virgin-alloy powder or wire feedstock that have associated production costs and contribute to CO_2 emissions. AM processes can be made more sustainable and environmentally friendly by utilising recycled titanium swarf from machining as feedstock. In this work, the metallurgical challenges associated with two novel Ti-6Al-4V AM processes incorporating recycled swarf were investigated. Both processes use a 'skin and core' strategy, whereby WAAM is used to print the part outer layer (skin) using virgin feedstock and the interior (core) is then infilled with recycled swarf. The metallurgical results are primarily focused around establishing the effect of key alloy contaminants (oxygen and nitrogen) in the context of AM and their influence on microstructure-property relationships.

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25221: Lifting Magnesium into Challenging Applications – by Ultraceramic® PEO Protection

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Abstract: Required component weight reduction often competes against wear and corrosion issues when it comes to lightweight metals. While Aluminum and its alloys are widely used in different industrial applications, e.g., aerospace, automotive and machinery, further weight reduction of components can be achieved by using Magnesium alloys. However, high corrosion tendency of Mg and its alloys extremely limits the application range. An appropriate environmentally friendly surface technique to prevent corrosion on lightweight metals is the PEO process (plasma-electrolytical oxidation), which converts the lightweight surface to ceramic-like oxides, leading to high corrosion and wear protection. In this talk we will refute reservations against PEO shortcomings by unveiling high-demand applications through our surface technology. Further on, we will present very recent research results, where 3D-printed WE43 samples, especially those with a complex geometry, are protected with our Ultraceramic® surface, giving those surfaces a high corrosion and wear resistance. The corrosion properties are characterized by means of electrochemical measurements and a long-term immersion test. A Pin-On-Disc tribometer test was used to analyze the wear properties of the surfaces, whereas the microstructure and the morphology of the surfaces as well as the corrosion phenomena were analyzed with the help of SEM / EDX.

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25225: Advancing Light Metal Castings: A Study on Core Shooting of Eco-Friendly Salt

Materials Without Binding Agents

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Abstract: In metal casting, cores are used to realize undercuts in casting components. They are usually made from a sand-binder mixture. Cores with high strengths are particularly necessary for filigree geometries like cooling channels, which are realized in sand casting by increasing the binder content. However, removing the cores from the casting without leaving any residue mechanically in an economically viable manner is an unresolved challenge when using inorganic binders. This currently limits the complexity of cavities that can be created in thin-walled aluminum components. The overarching research project aims to develop a new process chain in aluminum gravity casting in which casting cores are produced from an environmentally friendly salt using the core shooting process. The process chain involves fluidizing moist salt powder using compressed air and shooting it into a mold. The molding material is hardened by crystallization to form a dimensionally stable and temperature-resistant core. The crystallization and thus the solidification is adjusted purely via the amount of moisture added to the salt powder and the drying conditions. After casting, the porous, water-soluble molding material can be removed from the component mechanically or by partial dissolution and completely recovered. Thanks to the binder-free material system, no harmful emissions occur before or during the molding process. At the same time, the exposure of production workers to respirable silicate dust and the dumping of sand mixed with a binder that is hazardous to the environment can be completely avoided. In this study, suitable salt raw material mixtures are identified for the production of high-performance components. The investigations include different powder size distributions and purity grades of the base materials potassium chloride (KCl) and sodium chloride (NaCl) due to their high availability and environmental safety. The materials are compared in terms of their process suitability, efficiency, and sustainability.
The properties that are particularly relevant for processing are analyzed and compared with those of sand cores bound by a water glass binder: the grain morphologies, the powder size distribution, the bulk and tapped density as well as the Hausner factor derived thereof, and the thermophysical properties. Selected material compositions are processed in core shooting tests: The salt powder is wetted and shot into a mold for producing test specimens in the shape of bending bars using the LUT-1 core shooting test rig (Multiserw-Morek*, Brzeźnica,* Poland). The solidification via crystallization in the mold is solely achieved by adding distilled water, ionized water, or brine to the dry salt powder prior to core shooting and drying the molding material via a flow of heated compressed air. The test specimens are analyzed for density, bending strength, hot distortion, and surface quality and compared to the conventional sand material. Casting tests show that better surface qualities and comparable strengths can be achieved with this environmentally friendly material.

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25226: Microstructural Evolution in Support-Free Low Overhangs of IN625 and IN718 Alloys Under Heat Treatment

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Abstract: This study investigates the microstructural and microhardness evolution heat treatment (HT) of support-free overhangs with angles below 15° for IN625 and IN718 nickel-based superalloys. These alloys are strengthened by solid solution strengthening in IN625 and γ'' precipitation hardening in IN718, respectively. In the as-built (AB) condition, IN625 displayed a hardness gradient, with values decreasing from 322 ± 17 HV in the bulk to 278 ± 18 HV in the downskin. This gradient is attributed to cell boundary and dislocation strengthening, with the bulk region exhibiting fine cellular structures and a higher dislocation density, while the downskin region displayed coarser solidification structures and a lower dislocation density. Following HT, the hardness gradient reversed, with reduced bulk hardness (252 ± 15 HV) attributed to recrystallisation, whereas the increased downskin hardness (271 ± 10 HV) was linked to a transition from cell boundary strengthening to Orowan dispersion strengthening. AB IN718 exhibited a significant hardness disparity between the bulk (380 ± 9 HV) and the downskin (315 ± 5 HV), which was attributed to the presence of finer cellular structures in the bulk compared to the coarser structures in the downskin. Heat treatment successfully eliminated this discrepancy, resulting in uniform microhardness values of 482 ± 3 HV in the bulk and 478 ± 4 HV in the downskin. This homogenisation was driven by γ'' precipitation, which exhibited comparable characteristics in both regions.

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25227: Enabling Complex 3D Structures in Investment Casting: An Exploration of Slurry-Based Additive Manufacturing of Ceramic Casting Molds for Medical Technology

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Abstract: Investment casting is used for producing high-performance metal parts in particular for use in medical and aerospace technology. In the investment casting process, metals are processed into highly complex components with high precision and surface quality. Conventional investment casting shells are produced by coating lost models layer by layer. Once the desired shell thickness has been attained through 5-20 cycles of dipping in ceramic suspension, sanding, and drying, the model is subsequently melted away, and the mold is fired. The production of the molds for injection molding of the wax models, as well as the iterative dipping and drying process, is associated with high costs and lead times. It is not possible to reprocess the shells, so the mold shells are disposed of after casting. The applicability of the slurry-based binder jetting process for the direct additive manufacturing of casting shells is currently being investigated. In binder jetting technology, layers of powder are deposited and selectively bound by liquid binder droplets ejected by inkjet printheads. In contrast to the conventional binder jetting process, slurry-based 3D printing technology processes fine powders dispensed in a liquid to achieve high-density green parts and high surface qualities. The utilization of this mold production process in investment casting may enable the transition to an environmentally friendly, time and resource-efficient process chain for thin-walled, high-performance metallic components of unprecedented complexity.
In this study, a novel slurry material based on an aluminum oxide capillary suspension is qualified for processing in slurry-based 3D printing. Suitable process parameters are identified for crack-free processing in 3D printing, and an appropriate sintering process is determined. The thermal and mechanical properties of additively manufactured green bodies and sintered bodies are analyzed. The mold properties relevant for use in metal casting are determined at the test specimen level, and the feasibility of highly complex structures, as required for medical

technology applications, is investigated. For this purpose, structures with different wall thicknesses and complex interior structures are 3D printed and cast with metal melt. The study finds that this process, due to the lack of need for support structures, can enable even more complex structures than those possible with laser beam melting illustrating the exceptional potential of this innovative approach for use in medical technology.
The results are discussed with regard to the new possibilities of the increased design freedom and individualization that arise from this flexible manufacturing method for utilization in medical technology applications, and the challenges of future process logistics against the background of patient-specific implants based on MRI scans.

Symposium: Innovations in Manufacturing

25066: Enhancing the Tribological Performance of Tool steels through Layered AlTiCrN PVD Coating: Application to Woodcutting Tools

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Abstract: Tribological performance has become a contemporary subject of great interest, especially in the woodworking industry, due to its significant impact on the cost of wood products. Therefore, the desire to remain economically competitive birthed the exploration of innovative physical vapour deposition (PVD) coatings as a promising alternative for tribological performance enhancement. This study investigates the tribological performances of a bilayer (AlTiCrN I) and two trilayers (AlTiCrN II and III) AlTiCrN-based cathodic arc evaporated PVD coatings deposited on AISI A8 tool steel. The wear resistance and adhesion strength of the coatings were assessed using the dry sand rubber wheel test and scratch test, respectively, while the hardness and elastic modulus were measured via nanoindentation testing. Microstructural analysis of the coated samples was performed using scanning electron microscopy, energy-dispersive X-ray, and X-ray diffraction techniques, while the surface roughness was evaluated using a stylus profilometer. The results revealed that the AlTiCrN III coating exhibited superior tribological performance, having a wear rate 29 % and 14 % lower than that of AlTiCrN I and II coatings, respectively. This superior performance is attributed to the combined effects of enhanced hardness (up to 27 GPa), improved adhesion strength (critical load reaching 19.2 N), greater coating thickness (up to 4.9 µm), and lower surface roughness (average roughness, R_a = 1.62 µm). These findings highlight the potential of innovative layered ceramic PVD coatings for achieving enhanced tribological performance in woodcutting tools.

Symposium: Innovations in Manufacturing

25231: Shock Induced Mechanical behavior of additively manufactured Ti-5Al-5Mo-5V-3Cr Alloy

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Abstract: Metal Additive Manufacturing (AM) has revolutionized the production of metallic materials, enabling the fabrication of complex geometries with high precision. Among AM methods, Laser Powder Bed Fusion (LPBF) has gained significant attention for its ability to produce high-performance components with excellent dimensional accuracy. Titanium alloys are particularly valued in industries such as aerospace and biomedical due to their exceptional strength-to-weight ratio and corrosion resistance. Among these, Ti-6Al-4V (Ti64) stands as the most widely used titanium alloy, known for its versatile mechanical properties and manufacturability. However, Ti5553, a metastable β-titanium alloy, offers advantages over Ti64, including superior strength, toughness, and resistance to high-cycle fatigue, making it a promising candidate for critical applications. The dynamic mechanical properties of Ti5553, particularly under high strain rate loading conditions, are crucial for understanding its performance in demanding environments. A Split Hopkinson Pressure Bar (SHPB) apparatus was utilized to evaluate the dynamic properties of AM-Ti5553 over a strain rate range of 1000–1200 s^{-1}. Dynamic stress-strain curves indicated that AM-Ti5553 alloy is strain rate sensitive. Phase analysis and microstructural investigation were performed using X-ray diffraction, optical microscopy, scanning electron microscopy (SEM), and electron backscatter diffraction (EBSD). The as-printed samples consisted of a body-centered cubic β phase. Under dynamic compression, stress-induced martensitic transformation (SIMT) was observed, enhancing the strength of the alloy. An increased level of strain with rising strain rates was observed in the deformed samples.

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25233: Dynamic Deformation of Laser Powder Bed Fused Ti-5553 Alloy at Elevated Temperature

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Abstract: Ti-5Al-5Mo-5V-3Cr (Ti-5553), a metastable β titanium alloy, has gained significant attention in aerospace applications due to its exceptional mechanical properties and heat treatability. This study investigates the dynamic mechanical behavior and microstructural evolution of Ti-5553 produced via Laser Powder Bed Fusion (LPBF), focusing on its response under high strain rate conditions at room and elevated temperatures. While the quasi-static deformation of Ti-5553 has been widely studied, research on its dynamic deformation behavior remains limited, particularly for LPBF-made components, which have not been previously explored. The findings advance knowledge on LPBF-induced material behavior, supporting the development of lightweight, high-performance titanium alloys capable of meeting stringent aerospace performance requirements under extreme conditions, thereby enhancing efficiency and sustainability. Dynamic compressive testing was conducted using a Split Hopkinson Pressure Bar (SHPB) system at strain rates below 10^3 s^{-1} at different temperatures. Preliminary results demonstrate that increasing strain rates elevate stress and strain at room temperature, while elevated temperature reduces strength and hardness, accompanied by increased ductility. Microstructural analysis using optical, scanning electron, and electron backscattered microscopy revealed grain refinement, increased dislocation density, and texture transition with strain rate. Under higher strain rate deformation, adiabatic shear bands (ASBs) were observed, a phenomenon that is not present in quasi-static deformation conditions.

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25234: Feasibility Study of Manufacturing a Closed Face Impeller Using Laser Powder Bed

Fusion

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Abstract: **Feasibility Study of Manufacturing a Closed Face Impeller Using Laser Powder Bed Fusion** Yahya Aghayar[1†] and Mohsen Mohammadi[1]
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Abstract
This study focuses on the design, production, and comprehensive evaluation of a 316L stainless steel closed face impeller manufactured using Laser Powder Bed Fusion (LPBF). The impeller was designed to meet performance and structural requirements, then fabricated using LPBF technology, which offers precise control over complex geometries. To enhance the material properties and address potential manufacturing defects, the component underwent Hot Isostatic Pressing (HIP) in accordance with ASTM standards. The microstructural analysis revealed that the HIP process effectively eliminated all porosities, yielding a highly homogeneous microstructure composed of equiaxed grains with distinct twinning features. This improvement in microstructure integrity directly influenced the mechanical properties, with significant enhancements observed in ductility. Notably, the elongation at failure for HIP-treated samples increased by approximately 80% compared to as-built specimens, highlighting the critical role of post-processing in improving material performance. The study also investigated the fatigue behavior of the impeller under rotating bending conditions. Results demonstrated a substantial increase in the fatigue life of HIP-treated samples, with the number of cycles to failure significantly surpassing that of the as-built components. This enhancement is attributed to the removal of porosities and the homogenized microstructure achieved through HIP, which mitigates stress concentration sites and improves the overall fatigue resistance of the material. These findings underscore the effectiveness of combining LPBF with HIP to optimize the microstructure, mechanical properties, and fatigue performance of additively manufactured components. This approach holds promise for advancing the use of LPBF-fabricated parts in high-performance applications, such as those in aerospace and energy industries, where reliability and durability are paramount
Keywords: Closed impeller; Laser Powder Bed Fusion, microstructure, Hot Isostatic Pressing, Rotating bending fatigue.

Symposium: Innovations in Manufacturing

25236: Ballistic and Dynamic Performance of Additively Manufactured Hybrid Armour Plates

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Abstract: Precipitation-hardened (PH) monolithic M350 maraging steel (M350-MS) exhibits high hardness and impact strength, making it desirable for defense applications. However, its susceptibility to cracking under dynamic loads presents a significant challenge. To address this

problem, a hybrid armour plate which combined the advantageous properties of M350-MS and the ductility of $Al_{0.5}CoCrFeNi_{1.5}$ high-entropy alloy (HEA) was developed. Hybrid armour plates comprising layers of M350-MS and $Al_{0.5}CoCrFeNi_{1.5}$ HEA, with varying layer thickness ratios, were additively manufactured using laser-based directed energy deposition technique (L-DED). Cylindrical specimens from hybrid plates with a 1:1 thickness ratio were subjected to dynamic compression testing, while the hybrid plates themselves were subjected to ballistic testing to evaluate their V_{50} ballistic limits (V_{50} BL). The mechanical and microstructural responses of the hybrid plates were compared with those of monolithic M350-MS and HEA in both as-built (AB) and heat-treated (HT) states. The results demonstrated that the HEA layer significantly enhanced the energy absorption capability and strain-hardening behaviour of the plate. In addition, increasing the thickness of the M350-MS layer improved V_{50} BL values in both AB and HT states. Notably, HT hybrid plates exhibited superior resistance to cracking and material fracture during ballistic impact compared to HT monolithic M350-MS, which fractured catastrophically. These findings highlight the potential use of hybrid material designs as a good option for producing high-performance metallic armour plates for defense applications.

Symposium: Innovations in Manufacturing

25237: Microstructure and Solidification Characteristics of 316L Stainless Steel using Laser Powder Bed Fusion (LPBF)

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Abstract: *La*ser Powder Bed Fusion (LPBF) has become a prominent and transformative technology within the field of additive manufacturing (AM), particularly gaining significant traction in the marine and defense sectors. This method is valued for its ability to fabricate complex parts and metallic components with remarkable precision. LPBF is distinguished by its highly localized melting, steep thermal gradients, and rapid solidification rates, which together give rise to non-equilibrium hierarchical microstructures. These unique material characteristics set LPBF apart from traditional manufacturing techniques, enabling the production of high-performance, tailored components. As this technology continues to evolve, it presents new opportunities for innovation, allowing for the creation of materials with optimized properties to meet the rigorous demands of advanced industries. The compatibility of traditional metallic alloys, such as 316L stainless steel, with AM processes is essential for industrial applications. Achieving this requires precise optimization of process parameters to control microstructures at various scales, enabling the production of high-performance components. In this study, a tailored design approach was applied to LPBF-manufactured 316L components. The results revealed that, beyond adjusting energy input parameters such as laser power and scan speed, altering scan strategies at a constant energy input significantly impacted part quality. High-density components were achieved, with the smallest grain and cell sizes observed in the bidirectional scan strategy, while the largest grain sizes were associated with stripe scan strategies. Furthermore, by combining computational frameworks with empirical observations, a relationship between energy density and grain size has been established for LPBF-316L, identifying optimal scanning strategies. The study also investigated the correlation between microstructural features and material properties, particularly mechanical and electrochemical performance, by fine-tuning key LPBF process parameters.

Symposium: Innovations in Manufacturing

25238: Additive manufacturing of aluminum alloys with high-quality surface finish

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Abstract: Selective Laser Melting (SLM)-based additive manufacturing (AM) has emerged as a key technology for fabricating aluminum (Al) alloys with complex geometries and superior mechanical properties. Among these, AlSi10Mg has gained significant attention due to its lightweight and high-performance characteristics, making it ideal for aerospace and automotive applications. Surface roughness, a crucial factor in determining the functionality and longevity of AM components, significantly impacts mechanical performance, fatigue resistance, and corrosion behavior. High surface roughness, characterized by prominent peaks and valleys, often acts as stress concentrators and promotes localized corrosion, thereby limiting the structural integrity of components. This study investigates the effect of SLM processing parameters on the surface quality of AlSi10Mg alloy, focusing on the application of contour passes with varying laser power. Surface roughness was evaluated through key metrics such as Ra, Rq, and Rz, providing a comprehensive assessment of the surface profile. Results demonstrated that applying a contour pass led to substantial reductions in Ra and Rq values, indicating a smoother surface. However, the improvement in Rz was less pronounced, suggesting persistent surface irregularities. Microstructural analysis revealed a strong correlation between refined microstructures and reduced surface roughness in samples where contour passes were applied. Finer grain structures, achieved through optimized laser parameters, were associated with enhanced surface finishes. These findings underline the critical role of parameter optimization in reducing surface roughness and improving the overall quality of SLM-fabricated components. This research highlights the importance of surface roughness control in ensuring the performance and reliability of AM-fabricated Al components. By addressing roughness through parameter adjustment, SLM can be further refined to meet the stringent demands of high-performance applications, paving the way for broader adoption of aluminum alloys in additive manufacturing.Selective Laser Melting (SLM)-based additive manufacturing (AM) has emerged as a key technology for fabricating aluminum (Al) alloys with complex geometries and superior mechanical properties. Among these, AlSi10Mg has gained significant attention due to its lightweight and high-performance characteristics, making it ideal for aerospace and automotive applications. Surface roughness, a crucial factor in determining the functionality and longevity of AM components, significantly impacts mechanical performance, fatigue resistance, and corrosion behavior. High surface roughness, characterized by prominent peaks and valleys, often acts as stress concentrators and promotes localized corrosion, thereby limiting the structural integrity of components. This study investigates the effect of SLM processing parameters on the surface quality of AlSi10Mg alloy, focusing on the application of contour passes with varying laser power. Surface roughness was evaluated through key metrics such as Ra, Rq, and Rz, providing a comprehensive assessment of the surface profile. Results demonstrated that applying a contour pass led to substantial reductions in Ra and Rq values, indicating a smoother surface. However, the improvement in Rz was less pronounced, suggesting persistent surface irregularities. Microstructural analysis revealed a strong correlation between refined microstructures and reduced surface roughness in samples where contour passes were applied. Finer grain structures, achieved through optimized laser parameters, were associated with enhanced surface finishes. These findings underline the critical role of parameter optimization in reducing surface roughness and improving the overall quality of SLM-fabricated components. This research highlights the importance of surface roughness control in ensuring the performance and reliability of AM-fabricated Al components. By addressing roughness through parameter adjustment, SLM can be further refined to meet the stringent demands of high-performance applications, paving the way for broader adoption of aluminum alloys in additive manufacturing.

Symposium: Innovations in Manufacturing
25181: Laser Powder Bed Fusion (LPBF) and microstructure of alloy AlSi3.5Mg2.5
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Abstract: Aluminum alloys utilized in laser powder bed fusion (LPBF) processes are primarily based on the Al-Si system due to the high susceptibility of Al alloys to cracking under the rapid cooling rates characteristic of LPBF. Silicon is incorporated to modulate melt viscosity and mitigate crack formation. Among these alloys, AlSi10Mg is the most commonly used in LPBF. Current research focuses on enhancing the mechanical properties of these alloys by incorporating rare earth elements, such as scandium and zirconium, albeit with increased costs. This study investigates a novel aluminum alloy, AlSi3.5Mg2.5 (commercially known as Custalloy), characterized by a Mg-Si content exceeding 1.85 wt.% Mg_2Si. The alloy specimens were fabricated using a DMG MORI LASERTEC 30 SLM system at varying build plate temperatures to explore the effects of in-situ aging. Test samples were produced for parameter optimization and analyzed for porosity using optical microscopy. Additionally, the microstructure of the samples was examined in both the as-built (AB) and direct-aged (DA) conditions using optical microscopy, scanning electron microscopy (SEM), Transmission Electron Microscopy (TEM) and differential scanning calorimetry (DSC). The alloy is analyzed by the means of CALPHAD method.
Keywords: selective laser melting; laser powder bed fusion; aluminum; aging behaviour

Symposium: Innovations in Manufacturing
25242: Printability, mechanical properties and corrosion resistance of WE43 magnesium alloy porous scaffolds processed by laser-powder bed fusion
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Abstract: Magnesium (Mg) alloys, renowned for their high strength-to-weight ratio, biocompatibility, and recyclability, have garnered significant attention for applications in various industries such as aerospace, automotive, and biomedical engineering. Advanced manufacturing through additive manufacturing (AM; or 3D-printing) can enhance the potential for implementation of Mg alloys in these industries through increased weight reduction (e.g., consolidation of parts, porous structures), customized design (e.g., patient-specific components), and material efficiency (e.g., reduced waste) among other means. However, the successful application of Mg alloys in AM presents unique challenges due to their high reactivity, poor processability, and susceptibility to oxidation during fabrication, which directly impacts the final properties of printed components. Such challenges in processability are often enhanced when fabricating complex geometries. In this regard, this research investigates the printability,

mechanical integrity and corrosion properties of 3D-printed WE43 Mg alloy triply period minimal surface (TPMS) and strut-based lattice structures. Along with their high potential for light-weighting, such porous structures are beneficial for biomedical applications (i.e., bone replacement), given their ability to support defected tissues, as well as facilitate the diffusion of nutrients and oxygen to cells. Overcoming the foreseen challenges associated with these structures will be a significant step towards enhancing commercial implementation of AM-fabricated WE43 Mg alloy components.

Various TPMS structures and strut-based lattices were designed and fabricated using laser-powder bed fusion (L-PBF). As the most commonly used metal AM technique, L-PBF enables high resolution and accuracy, along with refined microstructures. Process optimization was first performed to achieve high-quality prints with minimal (<0.05) porosity. The influence of structure geometry on alloy microstructure, mechanical performance and corrosion resistance was then investigated. Scanning electron microscopy (SEM) was carried out both prior to and following bulk corrosion testing by hydrogen evolution measurements, which together with potentiodynamic polarization (PDP) and novel acoustic emission (AE) measurements, effectively enabled a quantification of corrosion rate for WE43, while depicting the underlying corrosion mechanisms at localized regions. Moreover, mechanical properties were evaluated through compression testing followed by SEM fractography to characterize the failure modes of the various structures.

The results reveal the effect of pore size, strut thickness, and scaffold geometry on corrosion rate, which could be linked to distinct differences in surface area and resulting microstructure for the different structures. Overall, enhanced corrosion resistance was demonstrated by the TPMS structures, while strut-based lattices had predominantly higher compressive strengths, despite a strong dependence on strut orientation to loading direction. In contrast, the TPMS structures possessed mostly lower strength and higher ductility, with fracture surfaces demonstrating failure primarily by bending. The results of this study illustrate the potential for L-PBF to fabricate high quality WE43 Mg alloy porous structures, with enhanced versatility enabled by tailoring material properties through component geometry.

Symposium: Innovations in Manufacturing

25071: Additive Manufacturing of Ti-6Al-4V Alloy Premixed with TiO2 Nanoparticles Using Directed Energy Deposition

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Abstract: Additive manufacturing of metals offers innovative solutions to the problems faced during traditional fabrication methods, particularly in producing metal platforms for removable partial dentures. However, the presence of dendritic grain structure in 3D-printed metal microstructures limits its application in the denture field. This study explores the 3D printing of Ti-6Al-4V powders mixed with ~1 vol% TiO_2 nanoparticles by directed energy deposition technique. Ti-6Al-4V metal powders and TiO_2 nanoparticles were uniformly mixed using a ball-mill. Cubic samples were printed using the BeAM Modulo 250 V1.0 DED metal 3D printer, and their microstructural changes were analyzed with optical and scanning electron microscopes. Mechanical properties were studied using Vicker micro-indentation hardness and tensile testing. The results show that incorporating TiO_2 nanoparticles resulted in an equiaxed grain structure in the build direction, indicating a significant enhancement in the mechanical properties of the

coupons. This improvement potentially eliminates the need for post-processing heat treatment and hot isostatic pressing.

Symposium: Innovations in Manufacturing

25246: Sintering Behavior and Microstructural Evolution of Binder Jet-Printed Monel 400 Components

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Abstract: This research explores the use of Monel 400 powders, produced through gas atomization, in binder jetting (BJ) additive manufacturing to develop high-density components. The study aims to gain a comprehensive understanding of the sintering behavior of Monel 400, with an emphasis on both the powder and BJ-printed parts. Differential scanning calorimetry (DSC) was employed to analyze the thermal behavior of the gas-atomized Monel 400 powders and its BJ-printed components after debinding and sintering stages. The BJ process was utilized to fabricate Monel 400 parts, which are subsequently subjected to debinding and sintering under controlled atmospheres, including argon and pure hydrogen. The microstructural evolution following the sintering process was investigated using advanced characterization techniques such as laser confocal microscopy and scanning electron microscopy (SEM). These analyses provided detailed insights into pores structure, grain boundaries, and phase distributions within the BJ-fabricated part.

Density measurements were also conducted using the Archimedes method and confocal microscopy to evaluate the impact of sintering conditions on the densification of the printed parts. The findings from this research offer valuable insights into optimizing sintering parameters, improving density, and minimizing defects in binder jet-printed Monel 400 components.

Symposium: Innovations in Manufacturing

25249: Solidification modeling of an additively manufactured aluminum alloy

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Abstract: Additive manufacturing (AM) is revolutionizing modern fabrication by enabling the production of complex and customized geometries that are otherwise impossible or prohibitively expensive to fabricate using traditional methods. Among AM techniques, laser powder bed fusion (LPBF) stands out as a highly precise process that utilizes a powerful laser to selectively melt and solidify metal powders. LPBF is particularly effective for creating high-performance components with intricate details and excellent mechanical properties. Aluminum, a widely used material in LPBF, is prized for its lightweight nature, high strength-to-weight ratio, corrosion resistance, and exceptional thermal and electrical conductivity. These attributes make aluminum indispensable in demanding applications such as aerospace structures, automotive components, and electronic housings. In this study, AlSi10Mg aluminum alloy is specifically modeled to capture its behavior during the LPBF process. This study focuses on modeling the LPBF process,

emphasizing the dynamic behavior of the melt pools during material melting and solidification. A computational framework is developed using a phase-field approach, where the Allen-Cahn equation is coupled with the heat diffusion equation to simulate the evolution of the melt pools. The model is implemented in the Multi-physics FEniCS platform using the finite element method (FEM). To address the complexities of LPBF, the powder bed is represented as a homogenized continuum medium, with the geometry divided into two domains: (i) the powder layer and (ii) the substrate. The simulation captures critical phenomena, including phase transitions, material melting, solidification, and associated distortions. The proposed model provides a robust tool for understanding the thermal and phase evolution in LPBF, contributing to optimizing process parameters and enhancing the quality of additively manufactured components.

Symposium: Innovations in Manufacturing
25250: Crack Propagation in Additively Manufactured 316L Stainless Steels
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Abstract: Additive manufacturing (AM) has transformed the way advanced materials are designed and produced, enabling the creation of highly complex geometries and tailored material properties that are challenging to achieve with conventional manufacturing techniques. Among the diverse AM methods, Laser Powder Bed Fusion (LPBF) has emerged as a leading technology, known for its ability to fabricate intricate components with customizable microstructures and precise compositions. This study investigates the fracture behavior and crack propagation mechanisms of 316L stainless steel manufactured via LPBF, aiming to improve its mechanical performance for critical applications in the aerospace and automotive sectors. The research addresses a significant knowledge gap by focusing on the fracture toughness and crack growth characteristics of LPBF-fabricated 316L stainless steel in comparison to its conventionally wrought counterparts. The experimental approach involves Mode I fracture tests conducted on fatigue pre-cracked notched specimens to simulate real-world loading conditions. Digital image correlation (DIC) is employed during testing to perform high-resolution strain analysis and monitor crack initiation and growth with exceptional precision. This experimental setup provides detailed insights into the fracture properties and mechanical behavior of LPBF components. In addition to experimental testing, advanced numerical simulations are performed using the finite element software ABAQUS to model crack propagation under realistic loading scenarios. The numerical models account for the anisotropic mechanical properties and microstructural characteristics unique to LPBF components. The numerical models are rigorously validated against experimental results, demonstrating a high degree of accuracy and reliability in predicting crack growth behavior. The combined experimental and computational approach not only enhances the understanding of fracture toughness and crack propagation in LPBF-manufactured components but also offers valuable insights for optimizing LPBF process parameters and material properties.

Symposium: Innovations in Manufacturing
25081: Influence of High Pressure Torsion Extrusion on the Microstructure and the

Fatigue Behaviour of the Magnesium Alloy ZK60

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Abstract: The magnesium alloy ZK60 shows a good strength to weight ratio as well as biocompatibility and is thus used in lightweight construction and in biomedical applications. One way to further strengthen the alloy and be able to adapt the mechanical properties to different applications is the modification of the microstructure. The severe plastic deformation (SPD) method High Pressure Torsion Extrusion (HPTE) has been shown to increase the mechanical strength of bulk structural materials significantly due to substantial microstructure refinement. In the present study, specimens of the magnesium alloy ZK60 are subjected to HPTE processing at two different temperatures. The resulting microstructures are investigated and compared to the initial state showing that HPTE reduces the grain size of ZK60 significantly.
Hardness and tensile tests show that the reduction of the grain size due to HPTE increases the hardness and tensile strength of the material. In the next step the fatigue properties of the HPTE-processed states are compared to those of the initial state in cyclic three point bending tests. The fatigue strength of the HPTE-processed specimens surpasses the fatigue strength of the initial state. The results show that the application of HPTE leads to an improved mechanical performance of the ZK60 alloy.

Symposium: Innovations in Manufacturing

25085: Processing and characterization of AlSi10Mg and AlSi10MgZr reinforcement structures for mobility systems produced by direct energy deposition with laser beam and powder

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Abstract: Aluminum alloys are widely used in automotive engineering due to their low density and simultaneously good mechanical properties. A hybrid manufacturing process based on additively manufactured surface structures on thin-walled tubular frame parts is to be used to reduce vehicle weight while improving crash tolerance. Direct Energy Deposition (DED) with laser beam and powder is very well suited to building these structures integrated into conventional production chains. Design of experiments are used to develop DED process parameters and test build-up strategies for the two aluminum alloys AlSi10Mg and AlSi10MgZr. The specimen setup for three-point bending specimens is carried out on 1.5 mm thick Al substrates in order to determine and compare the energy absorption of the reinforced structures. Three different load scenarios are compared: substrate without reinforcement, substrate with reinforcement on the tensile side of the specimen and the reinforcement structure on the compressive side. The additional zirconium content in the second alloy system is intended to increase the toughness of the reinforcements. In addition, a heat treatment of the reinforced structure was carried out to test the influence of subsequent temperature increases in the manufacturing process on the reinforcement. Initial results with the AlSi10Mg system already show that reinforcement structures on the tensile side increase energy absorption by 2.4% due to plastic deformation compared to the substrate material alone and by 75.8% with the

reinforcement structure in the compression direction.

Symposium: Innovations in Manufacturing

25095: Electron beam weld modelling for near-β Ti alloy

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Abstract: **Electron beam weld modelling for near-β Ti-alloy Jiaxi Zhang[a], Anastasia Vasileiou[a], Xenofon Gogouvitis[b], Michael Preuss[ac], Mike Smith[a]**
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The longer service life and lighter weight are two main driven forces and challenges for aerospace industries to explore more designs, materials and manufacturing technologies. As a representative of light-weight and high strength materials, Ti-alloy plays an important role in critical load-carrying components in air crafts. Compared to traditional α+β alloy, near-β Ti-alloy has two key advantages, higher yield strength and better corrosion resistance and thereby becomes increasingly prevalent. Moreover, electron beam welding (EBW), as an advanced joining technology with high energy density beam can achieve material joining by one pass, which has marked superiorities on efficiency and distortion control compared with traditional multi-pass welding. The combination between above material and manufacturing provides us a great opportunity to improve the performance of structural components with lower costs.
In this project, EBW process and material modelling is conducted to achieve following aims. 1） The prediction of residual stress and distortion, as two typical negative effects induced by welding. Although there is some research have been done to investigate the weldability of near-β Ti-alloy, there is no any published residual stresses characterization for near-β Ti-alloy. 2) The micro-constituent prediction for optimization of heat treatment. Yield strength of near-β Ti-alloy would decrease markedly due to α precipitate being dissolved during welding. The subsequent post-weld heat treatment is vital to regulate material properties. Particularly, significant variation of properties also causes a great challenge to residual stress prediction in turn.
The following two experiments are conducted to support the modelling work. Dilatometry testing are used to characterize solid state phase transformation (SSPT) behavior and volumetric effects induced by SSPT. Moreover, a yield strength model based on temperature history are constructed by a series of tensile testing at different temperatures.
This work hopes to reveal some special properties of near-β Ti alloy in terms of weld metallurgy and what need to be careful and satisfied in modelling works for accurate prediction of residual stress, distortion and microstructures, which could promote the better welding application of near-β Ti-alloy.

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25100: A Novel Approach to Bubble Generation Using Refractory Porous Devices for Melt Refining

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Abstract: This study introduces a novel design for generating small bubbles using a rotating porous device submerged in liquid metal or water at low gas flow rates. A block generating microbubbles was designed to rotate at varying speeds and gas injection rates to evaluate its performance. The results demonstrate that this approach can effectively produce controlled sizes of microbubbles at lower gas flow rates with significant improvement of melt cleanliness. This is possible without causing surface vortex formation with consequent entrainment of any oxides, dross or slags.

Symposium: Innovations in Manufacturing

25005: Hot-stamping of AA7075 friction stir tailor welded blanks used in structural automotive applications

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Abstract: In this study, four tailor-welded blanks (TWB) of AA7075 were friction stir welded (FSW) and hot-stamped at a solution heat treatment temperature of 460 °C for obtaining an automotive structural component which is the B-pillar. The studied part is characterised by relatively complex geometry and the adopted thicknesses are relatively high (2.0 mm to 2.8 mm sub-parts). A prior crash simulation test demonstrated the benefits of using a TWB instead of a one-thickness blank. Before the experimental study, the hot-stamping FE simulations showed very satisfying thinning and plastic deformation levels. The experimental tests led to obtaining four defect-free TWB B-pillars with an aesthetic final shape. The obtained mechanical yield strength values after forming were slightly lower than the ones recommended by the industry. However, the post-forming assessment helped us define potential routes for improving the mechanical properties to meet the manufacturers' requirements.

Symposium: Innovations in Manufacturing

25015: Three-dimensional Mathematical Modelling of the Solidification of Aluminum Alloys Strip Produced via the Horizontal Single Belt Casting (HSBC) Pilot-Scale Process

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Abstract: The Horizontal Single Belt Casting (HSBC) process has been developed and optimized in the last 26 years, as an alternative to traditional casting processes, to produce thin strips (3-15 mm thick) of various Advanced Hight Strength Steels, as well as some light metal alloys, i.e., commercial aluminum alloys. The process has been applied at the pilot-scale, to successfully produce aluminum and steel alloys sheets, 200-250 mm wide. Recently, isothermal mathematical predictions showed an improvement in the process and flow stability during pilot-scale casting, by changing the “free fall” distance from 6 to 3 mm. In the present work, the Computational Fluid Dynamics (CFD) software ANSYS-Fluent v. 19.0 was used to generate a 3D transient solidification model, to study the effect of the “free fall” distance on the solidification behaviour of commercial aluminum alloys (AA2024, AA5182 and AA6111,

AA7068) during the production of a 250 mm strip. The model was used to test different belt materials, superheats and belt speed to assess the best combination of parameters to promote an optimal solidification and flow behaviour for the three different alloys for pilot-scale and industrial HSBC applications. Predicted heat fluxes, cooling rates and temperature contours are presented for the AA2024, AA51812, AA6111 and AA7068 alloys.

Symposium: Innovations in Manufacturing

25121: The effect of partial recrystallization on the static and fatigue performances of aluminum EN AW6082 forged automotive components in neutral and corroded status.

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Abstract: Aluminum alloy forgings (i.e., EN AW 6082-T6) are characterized by high strength and low weight, which determine their large use in structural automotive components. A critical issue in this context is the recrystallization phenomenon, frequently observed in these products related to their different production stages (e.g. billet extrusion, hot forging, solubilization treatment). Partial recrystallization, often occurring in localized areas of component, is expected to reduce the tensile and fatigue strength and impact corrosion resistance. The available literature on this topic is limited and widespread, especially when related to full scale industrial products. Firstly, the present research studied the corrosion behaviour of both recrystallized and non-recrystallized samples collected at the surface of EN AW 6082-T6 forged components. Different standardized corrosion tests (i.e., PV 1113, ISO 11846, and VW 96380) were applied and the most representative of real field exposure conditions was selected. Tensile and fatigue tests were performed on samples in 4 different conditions: recrystallized and non-recrystallized specimens, both in the as forged state and after corrosion. The results revealed that the recrystallization phenomenon led to a reduction in tensile strength, but the mechanical properties became comparable after corrosion test due to an improvement of corrosion resistance compared to the non-recrystallized samples. The impact of recrystallization on fatigue performance was more complex to evaluate, with different conclusions depending on the stress levels applied.

Symposium: Innovations in Manufacturing

25200: Linking die design, texture development and mechanical properties of directly extruded flat products

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Abstract: Anisotropic mechanical properties are known to limit the application range of extruded products, as traditional extrusion processes result in direction-dependent material flow, thus creating a strong crystallographic orientation. Additive manufacturing of dies provides an opportunity to alter material flow based on an adjusted die design and, consequently, influence the material properties. This study explores the modification of texture and its impact on the mechanical properties of two magnesium alloys (AZ31 and ZX10) and an aluminum alloy

(AA6082) based on changes in die design (material flow, strain path). The findings reveal that texture change is linked to the strain path and can be controlled through die design. These insights are crucial for optimizing die geometry and enable a more systematic development of texture and mechanical properties during the extrusion process.

Symposium: Innovations in Manufacturing

25131: On the Mechanical Performance of TiC-Reinforced CX Stainless Steel Fabricated by Laser Powder Bed Fusion

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Abstract: The laser powder bed fusion (LPBF) process, characterized by high thermal gradients and repeated cycles of melting and solidification, typically results in non-uniform, textured columnar microstructures in CX stainless steel (CX SS). This leads to non-uniform mechanical properties across different locations and orientations of the as-printed components. To address this issue, incorporating ceramic particles as grain refining agents into the feedstock powder has been proposed as a strategy to enhance the mechanical performance of additively manufactured components. This study investigates the effect of titanium carbide (TiC) reinforcements (0–2 wt.%) on the microstructure and mechanical properties of LPBF-fabricated CX SS. Microstructural characterization revealed that the addition of TiC disrupted the columnar structure, promoting the formation of a refined and equiaxed grain structure in the as-printed components. Notably, the CX SS reinforced with 2 wt.% TiC exhibited superior grain refinement and a significant reduction in martensite lath size. Additionally, in-situ nano-sized TiC particles (~50 nm) were formed alongside microscale particles in the TiC-reinforced microstructure. Among the studied compositions, the 2 wt.% TiC-reinforced CX SS showed an optimal combination of high strength and ductility. Post-printing solutionizing and aging treatments further enhanced the mechanical performance of all compositions, attributed to the precipitation of nano-sized β-NiAl phases. The 2 wt.% TiC-reinforced alloy achieved the highest hardness and tensile strength following these heat treatments. These findings underscore the potential of TiC reinforcement to tailor the microstructure and improve the mechanical properties of LPBF-fabricated CX SS, offering a promising approach to enhance the performance of additively manufactured components in demanding applications.

Symposium: Joining and Multi-Material Design

25143: The effect of the heat treatment on the mechanical properties of linear friction welded WE43 cast alloy

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Abstract: This research investigates the development of linear friction welding (LFW), a solid-state joining process, to weld cast WE43 magnesium alloy. The study aims to analyze the effects of heat treatment—both pre-weld and post-weld—on the joined material compared to the base material. Microstructural characterization was performed to correlate mechanical properties with the T6 condition (solution treatment, quenching, and aging) at different welding stages. The results show that the yield strength is higher when heat treatment is applied either before or after welding compared to as-cast welding. Conversely, the ultimate tensile strength and elongation decrease with pre- or post-weld heat treatment compared to as-cast and T6-welded base materials. overall base material with T6 has the best properties. Microstructural evaluation reveals that dynamic recrystallization occurs in all cases, but abnormal grain growth is observed in post-weld heat-treated samples. Future work will involve applying LFW on wrought WE43 alloy. These findings have significant implications for the aerospace sector, where lightweight materials are critical to achieving net-zero carbon emissions in aviation.

Symposium: Joining and Multi-Material Design

25202: Influence of c-fibers on processing, microstructure and compressive strength of AZX913 magnesium foams

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Abstract: The principle of lightweight construction, which calls for the optimization of the choice of material at the specific place of use, can also be applied to the shape of the material. Therefore, depending on their structure, metal foams can combine high mechanical properties at low density. Foam structures made of magnesium alloys have been a subject of intensive research over the last decade. The use of magnesium as a structural material in lightweight construction has significant potential due to its high specific strength and low density. In addition, the combination of low density of the base material with the porous shape of a cellular material scales the effect of weight reduction. This enables a considerable weight reduction in large-volume components. The development of hybrid materials, such as aluminum or magnesium alloys reinforced with nanoparticles or fibers, aims to show advantages in mechanical properties. In this work, the influence of carbon fibers on the properties of an AZX913 magnesium foam produced by the melt foaming method is analyzed and discussed. The Alporas process or melt foaming method is a batch casting process in which a solid porous metallic foam structure is produced from a melt. Magnesium metal is melted in a crucible and foamed using a powder blowing agent that is stirred into the melt. After quenching, the pore structure of the foam is determined by the escaping gas. Important process parameters that influence the foaming process are related to the properties of the melt and the handling of the stirring processes. For example, the viscosity of the melt is an adjustable parameter that changes the shape of the growing pore structure. Common practice with magnesium melt is to increase the viscosity of the melt by adding calcium and foaming with $CaCO_3$ as a blowing agent. After a holding time, the crucibles are quenched in water to freeze the resulting pore structure. In addition to the magnesium metal foam hybrids with different amounts of carbon fibers, AZX foam without fibers is produced as a reference. In the analysis the different magnesium foams are compared in terms of macroscopic pore structure, density and compressive strength. Typical metallurgical characterization with optical and scanning electron microscopy will give insights into microstructure and the influence of fibers on grain size level. In addition to the microscopic examination, the non-destructive analysis of the compression test samples by Ct-scans were performed.

Symposium: Joining and Multi-Material Design

25171: Sustainable Multi-Material Design: Development of Eco-Leather for High-Performance Applications

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Abstract: The selective combination of materials in multi-material design enables optimized performance and weight efficiency by using each material where it is most effective. However, achieving sustainability in such designs requires addressing challenges in material compatibility, joining methods, and end-of-life recyclability. Animal leather, a widely traded material with a global market exceeding $80 billion annually, presents significant sustainability challenges due to its dependence on animal agriculture and variable properties arising from biological factors. Despite advances in vegetable-based and alternative leathers, uniformity and large-scale production remain elusive.
In response to these challenges, the CTT Group has developed an innovative process to produce eco-leather—a sustainable, high-performance material that is 100% bio-sourced and/or biodegradable, depending on the chosen composition. This process integrates unvulcanized rubber with bio-based thermoplastics and other additives, adapted for extrusion into uniform membranes laminated onto textiles. The resulting material achieves properties equivalent to, and in some cases exceeding, those of animal leather, particularly in demanding applications such as the automotive industry.
This contribution explores the design, material pairing, and manufacturing process behind eco-leather, highlighting its ability to meet stringent performance requirements (flexibility, breathability, protection) while offering customization (colors, flexibility levels) in a single production step. Additionally, the study addresses the implications for sustainable multi-material design, focusing on recyclability and integration into a circular economy. This breakthrough underscores the potential for innovative material combinations to advance both performance and sustainability in multi-material design.

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25050: Impact of various parameters in the rotary friction welding process on the fatigue behaviour of hybrid steel and aluminium joints

Laura Huber, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Bayern, Germany

Abstract: Due to the emphasis on efficiency and reduction of CO2 emissions in the automotive industry, the potential for lightweight materials has become increasingly important. Moreover, safety-relevant components such as gear wheels and brake discs cannot be replaced with lightweight materials like aluminium alloys because of their high strength requirements. In most cases this high strength is only necessary in certain parts of the component, while other parts could be substituted with lighter materials. The joining of light and heavy materials can be achieved through rotary friction welding (RFW). RFW is predominantly used in the industry for similar material connections, such as steel-to-steel joints, where connections are formed because of high speed and pressures. Since the melting point is not reached during the process, it is

possible to weld dissimilar alloys with significant differences in their chemical, thermal, and physical properties. This capability is currently the focus of ongoing research and has not yet been widely adopted in the industry.
During the RFW process of dissimilar materials, the significant influence of high temperature and time leads to the formation of intermetallic phases. In the aluminium-iron system, the orthorhombic η and monoclinic θ phases are primarily formed. However, with the addition of silicon, a broader range of intermetallic phases, such as α and β, can develop, while the addition of manganese results in a more complex system. These intermetallic phases are crucial for achieving high joint quality due to their hardness and strength. They also possess low fracture toughness. In literature intermetallic phases are reported to be necessary for high joint quality. However, excessive formation beyond a certain threshold adversely affects tensile strength.
In contrast to tensile strength, the fatigue behaviour of aluminium-steel joints is hardly reported. While some studies have explored the fatigue properties of dissimilar aluminium alloys, there is a lack of research on aluminium-steel joints. This is particularly relevant in applications such as hybrid brake discs or hybrid gear wheels, where fatigue plays a critical role and requires further investigations. To address this, parameters in the RFW, such as friction time and forging pressure, are studied in joints between steel and a precipitation-hardened aluminium alloy from the 6xxx series, notable for its higher silicon and manganese content. The focus is on understanding how different intermetallic phases formed during the process affect the fatigue behaviour of these joints. Finally, the influence of these parameters in RFW and the resulting intermetallic phases will be examined in relation to their influence on fatigue characteristics.

Symposium: Joining and Multi-Material Design

25259: Development Of A Predictive Model Of The Mechanical Properties And Tool Wear In Bobbin Tool Friction Stir Welding(BT-SFW)

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Abstract: Over the past two decades, friction stir welding (FSW) has received significant attention as a welding technique due to its energy efficiency and reduced environmental impact. However, welding tool wear is a major problem associated with this technique. Tool wear negatively affects the welded joint by causing surface degradation, which increases manufacturing costs and degrades product quality. Therefore, it is essential to accurately predict tool wear to improve product quality and ensure the reliability of corrective decisions such as tool replacement. In this study, we aim to firstly propose a welding tool wear prediction model based on the process operating parameters. Secondly, a finite element model to predict the mechanical properties of welded joints will be proposed in this study using ABAQUS software. The modified Johnson-Cook model integrating the Hall-Petch equation will be used to better consider certain metallurgical parameters in the constitutive law.
Au cours des deux dernières décennies, le soudage par friction-malaxage (FSW) a fait l'objet d'une attention particulière en tant que technique de soudage en raison de son efficacité énergétique et de son impact réduit sur l'environnement. Toutefois, l'usure de l'outil de soudage constitue un problème majeur associé à cette technique. L'usure de l'outil affecte négativement le joint soudé en provoquant la dégradation de surface, ce qui augmente les coûts de fabrication et dégrade la qualité du produit. Il est donc essentiel de prédire avec précision l'usure de l'outil pour améliorer la qualité du produit et garantir la fiabilité des décisions correctives telles que son remplacement. Dans cette étude, nous visons, dans un premier temps, à proposer un modèle de

prédiction de dégradation des outils de soudage basé sur les paramètres opératoires du processus. Dans un deuxième temps, un modèle d'éléments finis permettant de prédire les propriétés mécaniques des joints soudés sera proposé dans cette étude à l'aide du logiciel ABAQUS. Le modèle Johnson-Cook modifié intégrant l'équation de Hall-Petch sera utilisé pour mieux prendre en compte certains paramètres métallurgiques dans la loi constitutive.

Symposium: Joining and Multi-Material Design

25241: Microstructure Evolution In Laser Direct-Energy Deposition (L-DED) of Grade 91 Steel

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Abstract:
This study combines experimental characterization, thermal cycle models, and phase transformation kinetics calculations to investigate the mechanism for microstructure evolution across the height in an L-DED of Grade 91 steel. A high preheat temperature significantly prolonged the thermal histories during the cooling and resulted in a longer time to allow the δ-to-γ transformation to complete. It is found that the microstructure of the last layer consists of δ-ferrite/martensite, with δ-ferrite accounting for ~60\% of the area fraction.
The layers below, for instance the third to the last layer, however, show significantly smaller fractions of δ-ferrite, and shows the martensite being tempered. In the layers further below, for instance, the fifth to last layer, the amount of δ-ferrite is stabilized to a level similar to that of the third last layer. However, the martensite is further tempered, evidenced by more carbide precipitates. A thermal model is developed to investigate the thermal history of each layer and correlate with the CCT diagram. Based on the thermal model, the third to last layer is heated by subsequent layers to a peak temperature above the A3 temperature. Therefore, the δ dissolution has happened, and less δ-ferrite is observed on cooling. The fifth to last layer is also reheated multiple times to allow the tempering and precipitation of carbides. To further validate these findings, EBSD characterization are performed to analyze the microstructures in these three layers through misorientation analysis and prior austenite grain reconstructions. This confirms the reaustenitization in the third to last layer, and tempering of martensite tempering in the fifth to last layer. The diffusion-based kinetic calculations are validated to provide a deeper mechanistic understanding of the microstructure evolution.

Symposium: Joining and Multi-Material Design

25184: Young's modulus and thermal expansion of a sustainable magnesium composite containing recycled C-fibres

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Abstract: Carbon fiber reinforced magnesium composites are potential candidates for structural applications in aerospace, automotive, and other structural sectors. These composites combine the lightweight, high specific strength and corrosion resistance of magnesium alloys with superior strength and stiffness of carbon fibers (CF). As a result, these composites have high specific strength, high specific modulus as well as low coefficient of thermal expansion (CTE). The incorporation of carbon fibers into the magnesium matrix significantly improves the thermal and mechanical properties and thereby overall material performance, making them suitable candidates for advanced engineering applications where both strength and dimensional stability under different temperature conditions are required. A key aspect of this study is the incorporation of recycled C-fibers (rCF), which are not only cost-effective but also an environmentally sustainable alternative to virgin CF. These recycled CF maintain the properties of virgin CF and promote sustainability in material production because the C-fibres obtained by pyrolysis from CFRP only have a very small CO_2-footprint compared to virgin C-fibres. This study investigates the thermal expansion behavior and determination of Young's modulus of AZ91 based rCF-composites, which are important properties to ensure structural integrity of the material. The composite material was fabricated using a stir casting technique, in which recycled CF were added to molten AZ91 magnesium alloy. The molten mixture was then stirred using a high shear dispersion device to ensure uniform distribution of fibers in the alloy, which was followed by solidification and hot extrusion to obtain the final product. The study focusses on varying rCF content and rCF length and evaluates the impact on thermal and mechanical behavior of the composite. The CTE of the composites was determined through dilatometry experiments and the Young's modulus was measured using impulse excitation technique. The findings indicate that increasing the rCF content had positive impact on CTE and Youngs's modulus.

Symposium: Joining and Multi-Material Design

25078: Improving Microstructure and Mechanical Performance of EH36 Marine Steels through FCAW Parameter Optimization

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Abstract: This study investigates the impact of flux-cored arc welding (FCAW) on the microstructure and mechanical properties of EH36 shipbuilding steel, a critical material for marine applications. The research aims to determine whether the welded joints comply with classification rules and regulations for ship hull construction. Two welding procedures, Test 01 and Test 02, were employed on TMCP-EH36 steel using FCAW with a butt-weld configuration, each with specific parameters for heat input and weld position. Comprehensive microstructural analysis was performed using Optical Microscopy (OM), Scanning Electron Microscopy (SEM), and Electron Backscatter Diffraction (EBSD) to observe phase and grain structures. Mechanical properties were evaluated through Vickers hardness, tensile, bending, and Charpy impact tests. The welded samples, including those subjected to high and low heat input variations, demonstrated robust mechanical integrity, consistently meeting classification standards for hardness, tensile strength, and bending performance. This investigation provides valuable insights into optimizing welding parameters to enhance the durability and performance of EH36 steel in harsh marine environments, contributing to improved safety and longevity in shipbuilding.

Symposium: Joining and Multi-Material Design

25082: Material Bonded Metal-FRP-Joints by Continuous Hybrid Profile Pultrusion

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Abstract: Lightweight design of complex structures is crucial for saving energy and, finally, CO_2 emissions in transportation. For that reason, beside the mainly metallic primary structures (chassis), e.g. in the automotive industry, fiber reinforced plastics (FRP) are used for secondary structures in rising amounts to match the requirements of the e-mobility. In order to realize effective FRP lightweight design in load-bearing structural components, a cooperation between Fraunhofer IWU and Leibniz IPF has developed hybrid profile components that can be produced in large volumes in future using a modified, continuous pultrusion process. The profiles consist of an FRP base structure and a metallic core, which increases the ductility of the resulting component. Furthermore, metal inserts are partially placed at the surface to integrate additional functionalities into the component structure, e.g. sliding properties.

In order to achieve a high bond strength between metal and FRP, pre-coated metal coils are fed into the pultrusion process. A special two-stage cross-linking powder coating developed at the IPF was used for the metal coating, which has a latent reactive adhesive function when cured. This powder coating was originally developed for material-bonded metal-plastic joints produced with thermoplastics via injection molding at temperatures above 200 °C. By adding dendrimers to the powder coating, the powder coating has been adapted to bond with the epoxy matrix of the FRP during the pultrusion process, which took place at temperatures between 150 and 190 °C. In the boundary layer between the pre-coated metal and FRP, covalent bonds were formed through interfacial reactions, which resulted in a material bond between the two components. In this way, a very high bond strength was achieved. The integration of the bond formation directly into the pultrusion process also resulted in savings in additional process steps, energy, cleaning and pre-treatment chemicals and waste water. This was due to the elimination of subsequent bonding processes and the complex pre-treatment processes required for this and ultimately increased efficiency in the manufacture of metal-FRP composites.

Symposium: Joining and Multi-Material Design

25089: Combinatorial development of Al-based alloys using DED technology

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Abstract: The use of additive manufacturing technologies has greatly expanded the capabilities of metallurgical research for the development of new high-performance alloys. In particular, laser additive manufacturing (LAM) and direct energy deposition (DED) technologies provide a powerful combinatorial approach for the rapid evaluation of alloy compositions. However, many well-established alloys, such as aluminium alloys, still require further optimisation of their AM processing compared to traditional casting methods. In this work, we present and discuss a systematic combinatorial framework designed for combinatorial screening of metallic alloys via laser DED. Rapid development of metal alloys is achieved through high-throughput screening, which integrates combinatorial strategies and efficient evaluation to improve alloy properties. The material feeding system uses powder as the source, allowing in-situ powder mixing to produce on-demand compositions. First, the methodology of alloy screening and its optimisation

are presented. Then, the effects of DED process parameters on manufacturing defects such as pores or cracks have been investigated. In addition, crack-free and high-density samples were further evaluated by microstructural, structural and hardness tests, allowing the mapping of binary to multicomponent systems for Al-Mn-Fe-Zr alloys.

Symposium: Joining and Multi-Material Design

25093: From Base Alloy to Welded Joint: Understanding Microstructural Evolution and Mechanical Responses in Electron Beam Welded Near-β Titanium Alloys

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Abstract: To meet the aerospace industry's demand for materials with exceptional strength-to-weight ratio, high toughness, and excellent workability, near-beta titanium alloys have been developed as potential alternatives or supplements to conventional titanium alloys (e.g. Ti-6Al-4V). Electron Beam Welding (EBW), characterized by its high energy density, rapid welding speed, low heat input, and high precision, has become the ideal choice for welding Ti-alloy. However, the welding process also induces complex thermal cycles that can cause microstructural evolution and alter local mechanical properties. In this study, both parent and welded samples were characterized, and the effects of heat treatment parameters on the microstructural modifications and resulting mechanical responses in EB-welded near-β Ti-alloy specimens were also investigated. Microstructural evolution of both parent and EB-welded specimens with different heat treatment temperatures was characterized using Optical Microscopy (OM), Scanning Electron Microscopy (SEM), while Electron Backscatter Diffraction (EBSD) provided insights into grain orientation relationships as well as phase distributions. In addition, Energy Dispersive X-ray Spectroscopy (EDX) was employed to examine the compositional changes from the base area to fusion zone (FZ). Micro-hardness measurements across the FZ, heat-affected zone (HAZ) and base area were conducted to establish correlations between microstructural modifications and mechanical responses.
The results revealed that the parental samples under the specific heat treatment routes exhibit a typical bi-modal microstructure; whereas significant microstructural changes were found in the welded samples with formation of coarse prior β columnar grains in the FZ and refined equiaxed grains in the HAZ, which ultimately shapes the hardness distribution in such specimens. Moreover, EDX analysis confirmed the compositional evolution and the gradual dissolution of α phase.
A comprehensive understanding of the effects of EBW process and heat treatment parameters, as well as microstructure-property relationships, helps establish a framework for optimizing processing conditions, ultimately contributing to the enhanced performance and reliability of EB-welded near-β Ti-alloy components in demanding aerospace applications.

Symposium: Joining and Multi-Material Design

25270: Alloy Design for Metal Additive Manufacturing: A Microstructural Perspective

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Abstract: This presentation explores the critical role of advanced transmission electron microscopy (TEM) in driving innovation in metal additive manufacturing (AM) through microstructural characterization and alloy design. Leveraging TEM techniques, we provide insights into solidification behavior, phase distribution, and nanoscale features that directly influence mechanical performance and heat treatment responses in AM alloys.
Key studies on AlSi10Mg alloys have elucidated the effects of solidification cell structures, build orientation, and post-processing heat treatments on mechanical properties and deformation mechanisms. Investigations into maraging steels revealed microstructural evolution during heat treatments, highlighting phase transformations critical for optimizing strength and toughness in AM components. For nickel-aluminum bronze (NAB), TEM identified a unique nano-precipitate formed during AM, providing new perspectives on hierarchical microstructure development compared to conventional cast alloys.
Research on Ti-6Al-4V demonstrated the potential of hybrid grades with optimized oxygen content, achieving a balance between cost efficiency and mechanical integrity while improving fatigue resistance and tensile strength. Additionally, collaborative work on A205 aluminum alloys with ceramic additives, such as TiB_2, has shown significant improvements in microstructural refinement, crack resistance, and overall material performance, addressing common challenges in AM aluminum alloys.
These findings underscore the transformative impact of TEM in AM research, facilitating a deeper understanding of microstructure-property relationships and enabling data-driven optimization of alloy design, heat treatment strategies, and mechanical performance for industrial applications.

Symposium: Materials and Processes for Closed-Loop Circularity in Transport Applications
25137: Friction extrusion: a solid-state materials processing for recycling and upcycling aluminum alloy chips

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Abstract: Aluminium (Al) is a circular material that can be recycled repeatedly without losing its original properties. Currently, melting the feedstock represents an energy-intensive process in the recycling process, posing a significant energy barrier to economically recycling the metal waste. In this regard, eliminating the melting process in the metal recycling would be beneficial for future sustainable recycling technologies. Additionally, remelting Al scrap also presents several challenges, such as material loss, the presence of Al oxide (Al_2O_3) on its surface and the accumulation of deleterious impurities. Solid-state materials processing is considered as an alternative route for recycling Al scraps due to its remarkable ability to overcome the challenges occurring in melting processes. Friction extrusion (FE) is a friction-based processing that emerges as one of the promising technologies for recycling and upcycling Al chips. FE is a solid-state material process that utilises a non-consumable die to produce fully consolidated extrudates in various shapes, such as wire, rods and hollow structure. During the FE process, the die rotates relative to the feedstock, while an extrusion force is applied to press the die against the feedstock. Friction between the die and the feedstock introduces severe plastic deformation and generates frictional heat, softening and consolidating the materials. No external pre-heating is

required during the process, making it an energy-efficient process. FE can process feedstocks directly from a variety of feedstock materials, including solid billet, powder or machining waste. The ability to process the machining waste, such as machining chips, positions the FE process as a promising energy-efficient technology for recycling and upcycling materials into highly engineered materials.
In this study, machining chips of AA6082 alloy are recycled and upcycled using the FE process to produce thin wires with an extrusion ratio about 1000. The effect of the extrusion parameters and additional reinforcing particles on the microstructure and mechanical properties of the extruded wire will be discussed.

Symposium: Materials and Processes for Closed-Loop Circularity in Transport Applications
25157: A Comparative Analysis of Traditional and Advanced Methods in Evaluating Anti-Corrosion Performance of Sacrificial and Barrier Coatings
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Abstract: Using protective coatings is a promising approach for extending the lifespan of metallic structures and components in transport applications, ensuring asset integrity while contributing to improved material efficiency and reduced environmental impact. The diversity of corrosive environments requires tailored protective coatings suitable for specific conditions. Accurate selection and interpretation of analytical methods are crucial for identifying optimal coatings that enhance durability and minimize resource loss. This study presents a comparative analysis of traditional and advanced techniques to evaluate the anti-corrosion performance of sacrificial and barrier coatings under diverse environmental conditions. The performance of pure epoxy, zinc-rich epoxy, and cold galvanizing coatings was assessed using salt spray tests, electrochemical impedance spectroscopy (EIS), and potentiodynamic polarization methods. These coatings were evaluated for their protective capabilities in both atmospheric and immersion conditions. The distinct protective performance of each coating against atmospheric corrosion was assessed using traditional standard methods. Additionally, the electrochemical responses of these coatings in immersion conditions were systematically studied, and a detailed discussion on interpreting the electrochemical responses is provided. Zinc-rich epoxy and cold galvanizing coatings offer a superior anti-corrosion performance against atmospheric corrosion, while the pure epoxy coating excelled in immersion conditions. These findings highlight the importance of selecting appropriate protective strategies aligned with specific environmental challenges to maintain asset integrity in transport applications.

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25054: End of Life Vehicle Content and Surface Condition Effects on A365-T7 Alloy Corrosion
Amal Abraham, McMaster University, Hamilton, ON

Abstract: Automotive light-weighting with aluminum alloys requires efficient recycling and reuse at the end of its service life to offset its high initial production energy. The objective of this work is to determine how End of Life Vehicles (EOL) content affects the corrosion susceptibility of A365-T7 alloy. High-vacuum high pressure die casting (HVHPDC) produced alloys with 0%

and 75% EOL content, which were examined in as-received and ground surface conditions. Cyclic Potentiodynamic Polarization (CPDP) and Galvanostatic testing revealed that the 75% EOL alloy demonstrates higher corrosion susceptibility compared to the 0% EOL alloy in both as-cast and ground surfaces. Ground surfaces exhibited greater corrosion sensitivity than as-cast surfaces. Comprehensive microstructural analysis employed Light Optical Microscopy (LOM), Scanning Electron Microscopy (SEM), and Transmission Electron Microscopy (TEM) with Focused Ion Beam (FIB) milling to identify microstructural factors controlling corrosion mechanisms.

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25218: Deformation characteristics of Al alloys with significant volume fractions of intermetallic phases
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Abstract: By 2050, the availability of aluminum scrap in Europe is projected to double, driven by increasing end-of-life material flows. While advancements in sorting technologies, such as X-ray transmission evolve and improve in remelting the management of impurities and the accumulation of alloying elements remain critical challenges. Iron accumulates during recycling and predominantly forms primary intermetallic phases due to its low solubility in aluminum, often stated as negatively impacting alloy properties and hindering their reuse in high-performance applications. Additionally, alloying elements such as manganese and chromium contribute to the formation of primary phases but can also increase dispersoid concentrations, both of which affect formability Therefore, this study focuses on addressing these challenges by designing aluminum alloys optimized for high secondary content, with an emphasis on applications in the transport sector. Modified compositions, including Al-Mg, Al-Mg-Si and novel crossover alloys, were evaluated for their precipitation-dislocation interactions. Advanced characterization techniques, including electron microscopy, EBSD, and high energy X-ray diffraction, were employed to investigate the role of intermetallic phases and dispersoids in deformation mechanisms.
Potential design approaches must also consider robust bendability, a key attribute for automotive sheet applications. The findings reveal that intermetallic morphologies enable improved ductility and work hardening, even with elevated iron content. At high strains microstructural features that control dynamic recovery as elements in solid solution and dispersoid distributions gain increased importance.
By advancing the understanding of microstructural effects associated with recycled materials, this work supports the transition toward more sustainable and high-performance aluminum alloys for transport applications, addressing both mechanical performance demands and environmental sustainability goals.

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25220: Insights into the high strength and ductility behavior of cluster-hardened Al-Mg-Zn-Cu crossover alloys
Philip Aster, Montanuniversität Leoben, Leoben, Steiermark, Austria

Abstract: Crossover alloys, particularly those composed of Al-Mg-Zn, represent an innovative class within commercial aluminum alloy series, distinguished by their remarkable combination of high strength and ductility, alongside unique properties achieved through the crossover alloying concept. This principle, which aims to expand the property profile and improve sustainability, has become a focal point in aluminum alloy research. Cluster hardening, i.e. the formation of clusters instead of classical metastable hardening phases, depicts a promising approach for strengthening with a reduced loss of ductility in aluminum alloys. In this context, the effect of a typical pre-aging- and an unusual long-term aging treatment on the mechanical properties and forming behavior of a novel Al-Mg-Zn-Cu alloy (5xxx/7xxx crossover alloys) is investigated. Aging is performed at temperatures which promote the formation of clusters instead of typically larger, metastable hardening phases. In the tensile test, the cluster-hardened alloys show pronounced strain-hardening properties, which we evaluate by structural analysis using atom probe tomography (APT). The results show a pronounced aging response in combination with improved ductility compared to a conventional aging regime.

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25224: In-situ STEM investigation of solidification and primary phase formation in-view of high Fe content Al alloys
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Abstract: Recycling of Al alloys is gaining evermore importance with the increasing use of Al alloys as structural alloys in the automotive industry, accelerated also by the rise of electric vehicles. Fe is one of the main contamination elements introduced by increased recycling rates, it is critical for eventually forming brittle primary phases and is therefore often strictly limited by alloy limits. Nowadays transmission electron microscopes are capable of a broad range of in-situ experiment capabilities also including possibilities for investigation of solidification.
In our in-situ scanning transmission electron microscope experiments we utilize a simple but time-efficient sample preparation for specimens determined for melting and solidification on a commercial MEMS-based chip heating system. We show that rapid solidification conditions but also comparatively slow cooling experiments are feasible, present results and possibilities of analytic investigation of formed phases. In-view of high-Fe content Al alloys we will highlight strategies for investigation of primary phase formation and the in-situ observation of primary phase formation in a high Fe, Al-Fe-Si alloy.

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25064: Introducing post-consumer-scrap into primary foundry alloys for high-pressure-die-casting structural automotive applications
Alicia Vallejo Olivares, Hydro, Sunndalsøra, Møre og Romsdal, Norway

Abstract: High-pressure-diecasting (HPDC) is one of the preferred manufacturing processes for aluminium parts in the automotive industry, due to its cost-efficiency, productivity, and flexibility to cast diverse shapes. Recent developments in the HPDC technology move towards larger, thinner, and more complex castings with structural demands, which limit the use of secondary aluminium due to the strict purity requirements in most of the produced alloys for

such applications. At the same time, environmental regulations and corporate goals push for increased circularity and substantial cuts in the CO_2 footprint of new vehicles. Therefore, it is crucial to understand the opportunities and challenges of taking post-consumer scrap (PCS) from automotive waste (twitch scrap) back into the loop by blending it into the primary foundry alloys used for the new car components cast by HPDC. This study compares the properties of several variants of an AlSi10MnMg alloy shaped by HPDC. Half of the alloys were prepared by mixing primary Al with PCS before casting, and the rest used alloying elements to replicate similar compositions as the alloys with recycled content. Three aspects of adding 30% or 50% PCS were evaluated: the chemical composition of the alloy, the melt cleanliness (inclusion content), and the mechanical properties of the cast. The properties were also compared with the reference of the commercial AlSi10MnMg without recycled content.
The results show that adding 30 wt% or 50 wt% twitch scrap can lead to Fe and Cu concentrations above the alloy specifications. Still, although the Fe concentrations tripled compared to the alloy maximum limits (<0.13wt%), this did not significantly affect the mechanical properties. A slight decrease in ductility was observed for the samples where the scrap was mixed into the HPDC furnace, which is attributed to the heavy content of inclusions measured. Thus, the process of adding the scrap directly into the HPDC furnace followed by fluxing with Ar gas was not enough to ensure the melt cleanliness. The melt cleanliness could be improved by filtration, salt-fluxing, and/or a thermal de-coating pre-treatment of the scrap.
In conclusion, given that the required melt cleanliness is achieved by appropriate melt treatment, the results are promising and showcase the need to expand the Fe specifications for more recycling-friendly-alloys (RFAs), with no expected consequence for the alloy's mechanical performance. Designing RFAs and processes that take back twitch back into HPDC alloys will have a major impact on increasing the sustainability and circularity of the aluminium products in the automotive sector.

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25178: Sustainability in Aluminum Recycling Through Fe and Mn Removal

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Abstract: In order for aluminum to be infinitely recyclable and a true closed-loop material, there must exist financially viable methods of removing undesirable elements. While aluminum purification is possible via a number of methods such as zone refining none are currently financially feasible compared to material dilution. This necessity for an ongoing supply of aluminum prime prevents aluminum recycling from being a closed loop system and increases the carbon footprint of recycled aluminum. This presentation will present a method of removing Fe and Mn via precipitation that has the potential to be low cost and require few process controls. During the development of this process many unsuccessful reaction paths were attempted, some that failed due to thermodynamic considerations, and some that were impractical due to other considerations. As part of this presentation these will be discussed, including the use of Mg, Y, Ce, Ca, Sr, V and Ti and La, and unsuccessful efforts to trigger similar precipitation reactions to remove silicon from the melt.
This presentation will discuss the practical requirements of such a precipitation reaction, and the technical methods used to evaluate the feasibility of the reactions involved. Alternate separation methods for future evaluation will be discussed briefly.

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25119: Recycled aluminum foils for the powder metallurgical production of particle-reinforced aluminum matrix composites

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Abstract: Aluminum matrix composites (AMCs) reinforced with finely dispersed ceramic particles offer higher stiffness and strength than conventional aluminum alloys. This reinforcing effect mainly depends on the amount, size, and distribution of these ceramic particles. Using the powder-based production route, High-energy ball milling (HEBM) is an effective method for incorporating hard particles into a ductile matrix alloy powder. However, the high production costs of AMCs, partly due to expensive starting powders, often limit their use in applications. This study explores a cost-reduction approach using recycled aluminum grit derived from foil chips as matrix material, combined with sub-micrometer-sized SiC reinforcement particles in the HEBM process. The composite powders were subsequently consolidated into 20 mm rods through indirect powder extrusion. Using the design of experiments (DoE) methodology, the effects of key milling parameters – including time, atmosphere, amount of process control agent (PCA) and rotor speed – on the microstructure and the mechanical properties of the extruded AMC were investigated. The recycled aluminum grit corresponds to an alloy of the 8xxx series with 1.10 wt.% Fe and 0.15 wt.% Si. SiC powder with an average particle size of 0.7 µm and a volume fraction between 5 and 20 percent was used as the reinforcing component in the milling experiments. The HEBM was conducted in a Simoloyer CM08 using steel balls, with a total powder amount of 800 g. For AMC with 10 vol.% SiC, a significant increase in ultimate tensile strength and yield strength can be shown by simultaneous loss of elongation. The maximum values of the ultimate tensile strength (UTS=382 MPa), yield strength (YS=291 MPa), and elongation to break (e_b=14.3%) were received by a six-hour milled trial. Surprisingly was that a medium milling time of 3.5 hours leads to a maximum elongation to break up to 18%, which is untypical for increasing milling time. The regression of the DoE shows a significant influence of the milling time on the mechanical properties. The performance of these recyclate-based AMCs was evaluated in comparison to an AMC produced from a high-quality powder of the alloy AA6082. This high-quality AMC material, also containing 10 vol.% SiC and produced under similar conditions, exhibited lower mechanical properties after extrusion (UTS = 319 MPa, YS = 243 MPa, and eb = 14.1%) compared to the best results presented here. The results demonstrate great potential for using inexpensive starting materials as matrix materials to produce particle-reinforced AMCs.

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25130: Effect of Dual Rate Cooling Homogenisation on Recycling Friendly Alloys

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Abstract: Previous work on optimizing lean Al-Mg-Si alloys (EN-AW6060 and EN-AW6063) for extrudability has pointed to three factors that are especially important. (1) Mg/Si ratio close to 1, giving the best combination of strength and extrudability, (2) use of a dual rate ageing process which gives higher strength, making it possible to use leaner alloys, (3) adding a slightly more Mn than what is required for the β to α transformation. Low pressure casting (LPC) has enabled a further optimization of extrudability. Extrusion ingots casted using LPC has a narrower and leaner inverse segregation zone (ISZ) due to a lower metallostatic pressure during casting than other DC casting methods. The leaner ISZ allows for homogenization at higher temperatures for such billets. The higher homogenization temperature as well as a dual rate cooling (DRC) after homogenization reduces the amount of Mn and Fe in solid solution, further increasing extrudability. The CO2-footprint of producing primary aluminium ingots is much greater than the CO2-footprint of producing ingots from post-consumer scrap, and to meet with CO2 emission targets more post-consumer scrap must be used. When adding more post-consumer scrap in aluminium alloys, the concentration of some impurity elements inevitably rises. To enable an increase of scrap content in our alloys, and the use of less pure scrap, the limits of impurity elements content in the alloys should be revisited to allow for more recycling friendly alloys (RFAs).
The aim of this work was to explore the effect of dual rate cooling homogenization on 6060 and 6063 RFAs with a higher Fe and Mn content than primary based alloys. The influence of the dual rate cooling homogenization practice compared to the standard homogenization was investigated with respect to extrudability and tensile properties. The effect of increasing Fe and Mn levels on extrudability and tensile properties was also investigated. One finds that DRC can compensate for higher extrusion pressures from elevated Fe- and Mn-contents, while maintaining the mechanical properties.

Symposium: Materials for Clean Energy Transition - Hydrogen, Magnets, and Batteries

25147: Microstructure-Property Analysis in NdFeB Permanent Magnets by Cold Spray Deposition

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Abstract: In recent years, the demand for high-performance Neodymium-Iron-Boron (NdFeB) permanent magnets has increased rapidly due to emerging industries like electric vehicles and wind turbines. To achieve higher efficiency and lower energy losses, ongoing efforts are being made to optimize the designs of motors and generators. Conventional manufacturing methods like sintering and hot-deforming are limited by equipment and material brittleness, making them unsuitable for complex shapes, driving the need for more flexible alternatives. Cold spray (CS) uses compressed gas to accelerate powder to supersonic speeds, forming coatings through plastic deformation, offering flexibility in shape design and reduced material loss. Compared to traditional thermal spray or laser additive manufacturing, CS is a solid-state process with minimal thermal impact, reducing oxidation and thermal residual stresses. Previous work has verified the viability of producing NdFeB bulk magnets with the CS technique, using aluminum powder as the binder to enhance the bonding between NdFeB particles. However, the magnetic

performance, especially the coercivity of the NdFeB-Al cold spray deposited coating shows decrease compared with as-received NdFeB powder, while the microstructure of cold spray deposited NdFeB remains unexplored. This study aims to reveal the microstructure evolution of cold spray deposited NdFeB-Al system, using characterization methods like XRD, SEM, EDS, EPMA, EBSD, to sufficiently explore this material and build the microstructure-property relationships. By analyzing the phase transformation and grain size evolution, we managed to explain the reason for the coercivity reduction of cold spray deposited NdFeB. Understanding these mechanisms provides crucial insights for optimizing cold spray parameters to enhance the magnetic properties of NdFeB-Al magnets, making them suitable for flexible shape designs and high-performance applications.

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25153: Magnetic Properties and Microstructure of NdFeB Permanent Magnets Fabricated by Spark Plasma Sintering

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Abstract: NdFeB permanent magnets exhibit the highest maximum energy product among all permanent magnets and are suitable for clean energy applications, e.g., manufacturing electric vehicles and wind turbines. Conventional magnet fabricating techniques such as sintering and hot deformation frequently encounter problems like undesired grain growth and phase instability, hence deteriorating the performance of the magnets. In view of these problems, spark plasma sintering (SPS) has recently emerged as an alternative processing technique to achieve rapid densification and better microstructure, due to its short holding times and lower sintering temperatures. This study investigates the magnetic and structural characteristics of NdFeB magnets fabricated by SPS in a temperature range of 650-850 °C and under different pressures of 50 and 70 MPa. The starting material was strip-cast and jet-milled NdFeB powder with an average particle size of 38 µm. The analysis of the $Nd_2Fe_{14}B$ magnetic phase by X-ray diffraction (XRD) revealed that samples sintered at lower temperatures exhibited higher coercivity (H_{cj} up to 793 kA/m) and maximum energy product (BH_{max}~41 kJ/m^3). Higher temperatures and pressures impair the performance due to the formation of the α-Fe phase.

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25155: Improving the Hydrogenation Kinetics and Thermodynamics of the γ-Mg17Al12 Intermetallic Alloy with Trace Y and Er Additions

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Abstract: Magnesium (Mg) is a promising candidate for solid-state hydrogen storage, forming the bimolecular magnesium hydride (MgH_2) in a hydrogenation reaction. Compared to other storage methods, MgH_2 has a relatively high gravimetric potential, high stability, high abundance (low cost) and low toxicity. The hydrogenation and dehydrogenation conditions of pure Mg, on the other hand are not ideal, given the extended de/hydrogenation times and the high temperature required to desorb hydrogen from Mg due to its high stability. Thus, the problem involves

modifying both the kinetic and thermodynamic properties of MgH_2. Moreover, current hydrogen storage technologies are energy intensive, requiring high pressures and low temperatures, and can potentially be unsafe due to flammability and punctures to the storage containers. The desired conditions are hard to obtain without compromising the storage properties of MgH_2, such as the stability of the hydride, the storage capacity, and operating conditions (such as temperature and pressure). They need to be perfectly balanced for this technology to be adopted on a wide scale. Previously, attempts were made to alloy Mg with destabilizing agents to lower the hydrogen desorption with other alkali, transition and rare-earth metals. However, one or more of the storage properties remain significantly affected, for instance, the high cost of rare-earth metals and the introduced irreversible hydrogenation of Mg and additive metal solid solutions. While magnesium-aluminum (Mg-Al) alloy systems are known to be promising candidates for solid-state hydrogen storage systems, very little investigation has been conducted into the microstructural or nanostructural changes of the alloy with trace element additions. We propose a Mg-Al alloy with trace Er and Y additions to enhance both the kinetic and thermodynamic properties of the MgH_2. The cast alloy is further ball-milled to reduce particle sizes and introduce mechanical deformations. The formation of the γ-$Mg_{17}Al_{12}$ and β-Mg_2Al_3 phases, as well as the graphite reinforcement, will serve as thermodynamic destabilizers, and the trace rare-earth element additions which form dispersoids and precipitates will be used to accelerate the kinetics of dehydrogenation.

Symposium: Materials for Clean Energy Transition - Hydrogen, Magnets, and Batteries

25203: Assessing the Relationship Between Graphitic Cathode Morphologies and Performance and Mechanism in Aluminium-ion Batteries

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Abstract: Aluminum-ion batteries (AIBs) have gained interest in the field of energy storage due to the high abundance, safety, low cost, high theoretical specific and volumetric capacities of aluminum metal. Specifically, the use of graphitic cathodes, when employed with an ionic liquid electrolyte, is preferred due to favorable high average discharge voltage (up to 2.0 V), long cycling (up to 7500 cycles), and high capacities (up to 200 mAh g^{-1}). A systematic process to engineer these favorable features does not exist despite significant variations in performance and mechanistic metrics of AIBs reported in over 50 studies. It was hypothesized that these variations arise because of the variable morphology of the graphitic cathode used. To investigate the reason behind these variations, over 30 studies that employ an undoped graphitic cathode employing the $AlCl_3$/EMIMCl (molar ratio = 1.3), along with three in-house graphitic cathodes, were statistically analyzed. There were three main takeaways. First, graphite morphology does not influence the oxidation and reduction peaks measured using cyclic voltammetry. Second, the specific discharge capacity is not correlated with the morphology of the graphite used. Third, higher crystallinity is correlated with an increase in average charge and discharge voltage, while a higher surface area is correlated with a reduction in these two metrics. Beyond these insights, several gaps in this field of research were identified. First, the lack of correlation between morphology and performance suggests that some unaccounted variables, such as the chemical properties of the cathode, influence these metrics. Second, inconsistent testing conditions across studies call for standard testing conditions to make reliable comparisons. Therefore, recommendations for best practices for testing are made. Overall, this study provides insights and direction on engineering cathodes to advance research in AIBs using graphitic cathodes.

Symposium: Materials for Clean Energy Transition - Hydrogen, Magnets, and Batteries

25035: Study on the Microstructure, Mechanical Properties and Fracture Characteristics of Friction Stir Welded 2098-T85 Al-Li Alloy Joints for Consideration in Aircraft Cryogenic H2 Storage

Priti Wanjara[1], Sheida Sarafan[1], Satish Kumar Tumulu[2], Javad Gholipour Baradari[1], Natesa MacRae[3], Mathieu Brochu[2]
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Abstract: This research study was aimed at assessing friction stir welded aluminum-lithium (Al-Li) alloy 2098-T85 for use in the design and construction of liquid hydrogen storage tanks for airborne applications, as part of the broader Low Emission Aviation Program (LEAP) of the National Research Council of Canada. The research involved the application of friction stir welding (FSW), a solid-state joining technology, to manufacture defect-free joints in Al-Li 2098-T85 alloy using an optimal set of welding parameters. After FSW, two different post weld heat treatments (PWHT) were investigated, namely natural ageing and artificial ageing, to improve the mechanical properties of the joint. The microstructural evolution across the joints was characterized using microscopy and microhardness mapping. The plastic deformation and heat produced during the FSW process resulted in grain structure changes and hardness/strength loss (due to over-ageing and/or dissolution of the strengthening precipitates) within the three zones identified in the welds – (1) the stir zone (SZ) at the center, (2) a thermomechanically affected zone (TMAZ) and (3) heat affected zone (HAZ) on either side of the SZ. Through the application of PWHT, the room temperature hardness of the welds recovered, though most effectively via prolonged artificial ageing at 155 °C for 96 hours compared to natural ageing at room temperature for 120 days. The tensile mechanical response at room and cryogenic temperatures showed that artificial ageing for 96 hours is effective in maximizing the strength, but at the expense of ductility. At room temperature, the artificially aged welds exhibited a joint efficiency (the ratio of weld strength to base material strength) of 90-99%, relative to 75-82% for naturally aged welds. Under cryogenic condition, the strength and ductility of both the artificially and naturally aged welds improved. Fractographic analysis of the welds after room temperature tensile testing showed ductile-intergranular failure through the weld microstructure, whilst the specimens tested at the cryogenic temperature (77 K) exhibited small dimples and a predominant ductile fracture mode; this is in contrast to the Al-Li 2098-T85 base material that showed fibrous fracture associated with the elongated grain structure and the presence of dimples around second phase particles.

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25165: Directed Energy Deposition of Defect-Free NdFeB Permanent Magnets

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Abstract: NdFeB permanent magnets are critically important in electric vehicles, power systems, and electronic devices due to their exceptional magnetic properties. Traditional fabrication methods, such as sintering and polymer bonding, limit design flexibility due to the

brittleness of NdFeB, which often requires additional post-processing to achieve specific geometries. Additive manufacturing (AM), particularly laser-based techniques, offers an alternative by enabling 3D geometries through layer-by-layer deposition. However, AM-fabricated NdFeB magnets often show reduced magnetic performance and critical defects compared to sintered products. Challenges such as surface flaws, internal defects, and process parameter optimization limits AM's advancement. Moreover, repeated thermal exposure during AM can disrupt the microstructure and magnetic alignment, leading to further performance degradation. Addressing these challenges demands a comprehensive understanding of how process parameters influence material behavior. This study investigates the potential of laser-powder directed energy deposition to fabricate defect-free, high-performance NdFeB permanent magnets by optimizing process parameters and applying in-situ modifications.

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25038: Microstructural Evolution and Mechanical Properties of 2219 Aluminum Alloy Fabricated by Electron Beam Additive Manufacturing for Aircraft Cryogenic H2 Storage
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Abstract: As part of the Low Emission Aviation Program (LEAP) of the National Research Council of Canada, this research study involved developing electron beam additive manufacturing (EBAM) of aluminum alloy (AA) 2219 for use in the design and construction of lightweight liquid hydrogen storage tanks for airborne applications. In this process, ER2319 wire – having the same chemical composition as the AA2219 – was introduced into a stable molten pool created by a defocused electron beam operated in a high vacuum environment. High quality deposits – crack-free, without lack-of-fusion defects and having very low porosity (<0.5%) – were built using a set of robust processing conditions. In the as-built microstructure, inner- and inter-layer zones were discernible. The inner-layer zones consisted of slightly elongated alpha-aluminum (α-Al) grains that were oriented in the direction of the maximum thermal gradient. This is in contrast to the inter-layer zones where small equiaxed α-Al grains were present as a result of local remelting of the previously deposited material. A copious amount of the theta (q) eutectic phase, Al_2Cu, was distributed as a continuous network along the α-Al grain boundaries, and as coarse globular particles within the α-Al grains. Rod-like second phase particles, with a composition close to the Al_7Cu_2(Fe,Mn) intermetallic phase, were occasionally noticed attached to the edge of the θ-Al_2Cu phase at triple junction grain boundaries. The hardness and tensile properties of the as-built material exceeded the specifications of the wrought equivalent AA2219 composition in the annealed (O) condition. For high strength service, the AA2219 fabricated by EBAM was precipitation hardened with a T62 temper that involved solution treatment at 535°C for 1 hour followed by rapid quenching in water and then artificial ageing at 170°C for 6 hours. The T62 temper was effective in dissolving most of the eutectic θ-Al_2Cu phase particles at the grain boundaries and interiors, as well as precipitating the strengthening θ'-Al_2Cu phase, which was detected/differentiated by a differential scanning calorimetry (DSC) analysis. Thus, the resulting T62 microstructure consisted of α-Al grains and fine second phase particles, θ'-Al_2Cu, θ-Al_2Cu, and the Al_7Cu_2(Fe,Mn) intermetallic phase (that remained unchanged from the as-built condition). The tensile mechanical response of the T62 material at room and cryogenic (77 K) temperatures was isotropic and showed promising properties with a suitable balance between

high strength and good ductility. Fractographic analysis of the as-built and T62 materials after room temperature tensile testing showed that failure occurred in a ductile manner through microvoid initiation, growth and coalescence, which was influenced by the characteristics of the grain structure and second phase particles in the microstructure.

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25207: Formation of ordered L10-FeNi phase through carbon and phosphorus additions in Fe-Ni alloy

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Abstract: Chemically ordered tetrataenite $L1_0$-FeNi phase exhibits magnetic properties close to the NdFeB magnets and is a promising alternative to rare earth permanent magnets. However, massively synthesizing this material to fabricate bulk magnets is challenging due to the low atomic mobility associated with the chemical ordering at a relatively low temperature. It has been shown that adding secondary elements to the Fe-Ni system can influence the lattice structure and thus facilitate the formation of the tetrataenite phase. In this work, two elements (C and P) were added to Fe-Ni alloy to investigate their effects on the formation of the ordered phase. Ingots with compositions $Fe_{(60-x)}Ni_{(40-x)}P_{2x}$ and $Fe_{(60-x-y)}Ni_{(40-x-y)}P_{2x}C_{2y}$ (x = 0-8 at. %, y = 0-2 at. %) were fabricated using arc melting. The impact of phosphorus and carbon additions on the phase stability, microstructure, grain growth, domain wall pinning, magnetization, and coercivity is discussed. This work offers a guidance on researching further secondary element additions and processing strategies that can aid in accelerating the chemical ordering in FeNi-based bulk magnetic materials.

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25208: Heat treatment of Fe-Ni-P-Si alloys to maximize ordered L10-FeNi phase

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Abstract: The high theoretical energy density together with a low cost-to-performance ratio makes ordered $L1_0$-FeNi a strong candidate for rare earth-free permanent magnets. However, techniques that can accelerate the atom diffusion around the order-disorder transition temperature of ~320 °C and that can also be realized in large scale in a reasonable timeframe are still not available. This work intends to combine the local elemental segregation and grain refinement induced by alloying Fe-Ni with P and Si to enhance the $L1_0$ phase formation. The as-cast $Fe_{(60-x-y)}Ni_{(40-x-y)}P_{2x}Si_{2y}$ (x = 0-8 at. %, y = 0-2 at. %) alloys are also subject to heat treatment in a magnetic field to assist the formation of the ordered $L1_0$-FeNi phase. Crystallographic texture characterization and XRD analysis show that the phase distribution, dendrite growth, and thermal stability of the $L1_0$-ordered phase all vary with the alloying addition and the heat treatment temperature, indicating a promising strategy for fabricating FeNi-based rare-earth free magnets.

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25209: Solid electrolyte interface of the chevrel molybdenum sulfide cathodes in aluminum ion batteries – investigation and modification by alkali chlorides

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Abstract: Global need for electrical energy storage is rapidly rising, and lithium-ion batteries (LIBs) alone cannot satisfy this demand. Instead, a supplementary battery chemistry is needed. Aluminum-ion batteries (AIBs) are one of the most promising alternatives, as aluminum metal is highly abundant, inexpensive, and highly charge density (2980 mAh g^{-1} and 8046 mAh cm^{-3}). However, current conventional AIBs use graphite cathodes, which store charge by $AlCl_4^-$ intercalation. This process is stoichiometrically limited by the available electrolyte, resulting in very low overall cell charge densities. By contrast, transition metal sulfides (TMSs) are a promising alternative class of cathode materials, as they store charge by either Al^{3+} intercalation or Al_2S_3 formation, both of which are not limited by the electrolyte mass. Furthermore, TMSs are advantageous due to their stability, safety, and high charge capacity. Most TMS electrodes have achieved only low current densities, due to the slow migration of aluminum through the cathode lattice. However, chevrel molybdenum sulfide is predicted to avoid this limitation. Large channels exist between octahedral molybdenum clusters in chevrel Mo_6S_8 enabling rapid aluminum transport, as shown in density functional theory simulations. However, experimental investigations of the system have demonstrated the same limitations as other TMS cathodes, as high charge storage densities have only been achieved at charge densities below 50 mA g^{-1} and for fewer than 100 cycles.

This investigation elucidates the role of the solid electrolyte interface (SEI) in this discrepancy, utilizing both in situ electrochemical and structural characterization. Furthermore, this study investigates the use of alkali chloride electrolyte additives to improve the long-term performance of chevrel molybdenum sulfide cathodes at higher current densities. This investigation brings the field towards utilizing the full potential of the aluminum batteries, and thus towards a sustainable post-lithium future.

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25049: Precipitation Formation and Li Loss During the Membrane Separation of Li from Spent-LIB Acid Leachate

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Abstract: The importance of lithium-ion batteries (LIBs) has increased, as the challenges of global warming and climate change have become increasingly urgent. The rising demand for LIBs has increased the demand for lithium (Li). Because the enhancement of mining activity is not ideal for a sustainable environment, it is essential to develop technologies for efficient

recycling of lithium from used batteries. The goal of lithium recycling is challenging, with an 80 % recycling rate before 2031 set by the European Union. Conventionally, the recovered black mass is first processed by acid treatment, and critical metals such as Co and Ni are then separated by the solvent extraction method, with Li being the last recovered element through the precipitation method. However, this method sometimes has the issue of a low Li recovery rate. Alternatively, we intend to selectively recover Li in the earlier stage, being prioritized over other metals, by filtering black mass leachate through the nanofiltration membrane. In this process, Li is allowed to pass through the membrane, whereas the other metals are not. However, the membrane also allows hydrogen and sulfate ions to pass through. This property of the membrane, in turn, results in an increase in local pH and pH-driven secondary precipitation at the surface of the membrane. Secondary precipitation may affect the stable performance of the nanofiltration membrane and may incorporate Li, resulting in Li loss. However, the mechanism of secondary precipitation remains largely unknown. In this study, we investigate if the formation process of pH-driven secondary precipitation can be simulated by applying anion-exchanging resin to eliminate sulfate ions from black mass leachates. Two types of solutions were used for the experiments: one containing a large number of impurities, such as aluminum and iron, and the other containing a small amount of these impurities. Our analysis results suggested that Li-bearing sulfates with more complicated chemical compositions involving Al and other metals are the main precipitates formed during the membrane separation process. These precipitates often contain a large amount of water, and it is considered that the resulting concentration of the solution promotes the formation of precipitates. These precipitated species accumulate on the surface of the membrane and hinder filtering. In addition, our results demonstrated that over 20% of Li was incorporated into these precipitates in the high-impurity solution. Based on current observations, sulfate ions are the primary cause of precipitation. Our results reveal that the key to suppressing the precipitation of these sulfate species and incorporated Li amount is to maintain the solution pH during nanomembrane separation and to remove as much as possible of impurities that form precipitates with sulfate, such as Al, before acid leaching.

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25211: Microstructure and Magnetic Properties of High-silicon Non-oriented Electrical Steel Sheets Fabricated through Hot Dipping and Diffusion Annealing
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Abstract: High-silicon electrical steels (6.5 wt% Si) exhibit superior magnetic properties compared to conventional electrical steels containing ~3.2 wt% or less Si. However, electrical steel sheets with Si content higher than ~3.5 wt% are difficult to produce using the conventional hot rolling-cold rolling-annealing procedure, due to the pool ductility of the intermetallic phases formed in the steel. Chemical vapor deposition (CVD) has been used to produce 6.5 wt% Si electrical steel through the diffusion of Si into thin electrical steel sheets with lower Si contents. However, this method is costly and requires complex equipment, which has limited applications. In this work, a hot-dipping-plus-diffusion-annealing route was developed to produce 6.5 wt% Si non-oriented electrical steel using cold rolled, 3.5 wt% Si steel sheets as the base material. The

process involved dipping the cold rolled steel sheets into an Al-8 wt% Si melt to form Al-Si coatings, followed by annealing to diffuse the coated Al and Si into the steel sheets. It was demonstrated that a near homogeneous distribution of about 6.5 wt% Si in the steel sheets can be achieved through appropriate diffusion annealing. The magnetic properties were evaluated using a single sheet tester, and the total core loss is close to that of 6.5 wt% Si steel produced via the CVD method.

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25056: Comparative Study Of Metals Extraction Efficiencies Of NMC And LFP Cathode Materials From Lithium-Ion Batteries By Sulfuric Acid

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Abstract: The ever-growing demand for electric vehicles has considerably increased the consumption of mineral resources to support the production of lithium-ion batteries (LIBs). The recovery of valuable materials from spent batteries represents a sustainable source of minerals while playing a significant role from both ecological and economic points of view. Among the leading technologies for LIBs used in vehicles, lithium nickel manganese cobalt oxide battery (NMC) and lithium iron phosphate battery (LFP) are the two dominant types. The NMC have been the most commonly used LIBs due to their high energy density conferred by their components. Meanwhile, LFP batteries are expected to dominate the electric vehicles market thanks to their lower cost, long lifespan and safety management. While most hydrometallurgical LIBs recycling plants are able to treat both types of batteries, the venue of LFP may affect the process efficiency and profitability. In this respect, comparing the extraction efficiencies of NMC and LFP leaching is important to mitigate the impact of the current market changes on the recycling process. In this study, a hydrometallurgical approach was developed to extract metals from NMC and LFP cathode materials through sulfuric acid leaching, both individually and mixed with the aim to compare the two different recycling conditions. In order to define the range of best operating conditions for extracting metals from spent batteries by sulfuric acid (H_2SO_4) leaching, parametric studies were performed. Then, the effect of H_2SO_4 concentration, addition of H_2O_2 and solid-liquid (S/L) ratio on the leaching efficiency of metals from single leaching of NMC and LFP materials, and a mixture of them was studied. Results shown that there was an interaction between NMC and LFP that affected the the efficiency of metal recovery when extractions were done with mixtures of NMC and LFP. In the case of leaching single NMC, the leaching efficiency of Mn, Ni, Co and Li was around 0%, 47%, 43% and 98% respectively and it increased by adding H_2O_2 up to 100% for all metals under conditions of S/L of 0.1 g/mL, concentration of H_2SO_4 2 M, concentration of H_2O_2 0.68 M, temperature of 75°C, and leaching time of 82 min. For single LFP, 100% of leaching efficiency for Fe, P, and Li was obtained under the same conditions without adding H_2O_2. In the case of leaching a mixture of cathodes, the leaching efficiency of Mn, Ni, and Co from NMC increased up to around 86% and the leaching efficiency of Fe and P from LFP was around 98% for a mass ratio NMC/LFP of 1 and the same conditions that single materials. This improvement is attributed to the electron transfer and synergistic redox reactions between NMC and LFP in the sulfuric acid system. The characterization of the leach residue revealed that it is possible to recover orthorhombic $FePO_4$, a valuable by-product with potential for reusing in the manufacturing of LIBs.

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25217: Mitigating Hydrogen Embrittlement in Vintage Pipeline Steels: The Role of Surface Oxides and Microstructural Variations in Achieving a Hydrogen-Based Energy Transition

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Abstract: Hydrogen plays a pivotal role in achieving net-zero energy targets, with strategic initiatives aiming to repurpose existing national gas networks for hydrogen distribution. However, this transition is critically challenged by hydrogen embrittlement (HE), which compromises the mechanical integrity of pipeline steels in hydrogen rich environments. Despite extensive research, the behaviour of pipelines under real world conditions remains poorly understood, presenting significant risks to adopting hydrogen as a mainstream energy carrier. This study examines the influence of surface conditions and microstructural variations through the wall thickness on hydrogen uptake in vintage pipeline steels, representative of those used in current gas transmission infrastructure. The microstructure of these steels, predominantly hot-rolled and seam-welded, is characterised by an anisotropic banded ferrite-pearlite arrangement, with tighter bands concentrated at the wall's mid-thickness. Hydrogen embrittlement susceptibility in such materials is strongly influenced by chemical composition, microstructural features, and residual stresses, necessitating a comprehensive understanding of these factors for effective mitigation strategies.
Surface oxides have been observed to impede hydrogen uptake and diffusion by increasing the energy barrier for hydrogen physisorption. However, current literature primarily focuses on polished samples, leaving a critical gap in understanding the role of naturally occurring oxide films. The most common iron oxide phases; wüstite (FeO), hematite (Fe_2O_3), and magnetite (Fe_3O_4differ significantly in structure and properties, yet their impact on hydrogen uptake and embrittlement remains underexplored. This study addresses this gap by characterising oxide films on vintage pipeline steels both before and after hydrogen exposure, leveraging advanced surface analysis techniques.These findings provide new insights into the mechanisms governing hydrogen uptake and HE in aging pipeline materials. By combining surface condition and microstructural analyses, this research contributes to the development of robust strategies to mitigate HE risks, thereby enabling the safe and effective use of hydrogen in existing gas networks. These outcomes support the broader objectives of transitioning to a hydrogen-based energy system, aligning with global decarbonisation goals and fostering the development of a sustainable hydrogen economy.

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25002: Cost reduction of metal hydrides for hydrogen storage

Jacques Huot, UQTR, Trois-Rivières, QC

Abstract: Metal hydrides are attractive materials for a large range of hydrogen storage

applications. However, a few characteristics have to be improved in order to make them more commercially suitable. In this talk we will review a few ways to reduce the cost of conventional and new metal hydrides. First, we will show that the addition of a secondary phase to alloys such as TiFe or Body Centered Cubic alloys makes the first hydrogenation much easier under mild conditions. Second, we will demonstrate that various mechanical deformation techniques such as Cold Rolling (CR) and Ball Milling (BM) could enhance the hydrogenation kinetics and regenerate an alloy that has been passivated by air exposure. Different examples of these techniques on a wide range of metal hydrides (Mg-based, LaNi5, TiFe, BCC alloys and High Entropy Alloys (HEA) will be shown.

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25230: Global Patent Filing Trends in Lithium-ion Battery Recycling

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Abstract: Patents are playing an increasingly important role in today's business world. A patent portfolio can enable a company to secure a monopoly within the market, which can provide a commercial advantage over competitors. At the same time, possessing a patent portfolio increases the value of a company's intangible assets. As electric vehicles grow in popularity and the automotive sector shifts towards electrification, the amount of lithium-ion battery waste being generated is increasing in kind. Companies and research institutions worldwide are racing to develop, and ultimately commercialize, processes and technologies for recycling lithium-ion battery waste, in order to recover and re-use the valuable materials contained therein. These new processes and technologies are routinely patented soon after they are developed, as a step toward monetization. Analysis of this patent filing data can provide a unique, combinatorial picture of both research and commercial activities within the field. The present study looks at patent filing trends in the field of lithium-ion battery recycling over the decade spanning 2013 to 2023, the most recent year for which complete patent publication data is available. The data shows a non-linear, near-exponential growth in annual patent filings over the decade. From 2013 to 2020, the share of patents filed by Chinese entities increased steadily from 21 to 82 percent, after which this share decreased steadily to 65 percent as U.S, European, Korean and Japanese entities increased their patent filings. A majority of the patents filed by Chinese entities were filed in China only, while patents filed by entities outside China were filed more internationally and in multiple jurisdictions, providing an interesting indicator as to anticipated commercial activity by those entities in those different global markets. In all countries, the share of patents filed by research institutions fluctuated between only 6% and 13% over the decade and followed no trend, confirming that corporate entities were responsible for the majority of filings.

On a technological level, the vast majority of patents pertain solely to hydrometallurgical processing, while patents for less conventional approaches such as pyrometallurgical and electrometallurgical processes began to increase from 2019 onwards, reflecting a general expansion and broadening of research interests in the field of lithium-ion battery recycling in recent years.

A more granular analysis of the above data and findings, as well as recommended patent filing strategies for researchers in view of the current patent landscape portrayed by the data, will be provided.

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25067: Analysis of microstructure and fracture characteristics of X65 Line Pipe Steels from Pilot vs. Production trials in air and gaseous hydrogen environment

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Abstract: This study compares the microstructure and fracture characteristics of a pilot-scale skelp variant with an actual pre-production X65 pipe material with similar chemical composition. The differences in TMCP practices resulted in a more refined final microstructure for the pilot-rolled plate, although some coarse elongated grains were observed at mid-thickness. The pilot plate exhibited a more irregular ferrite microstructure with a higher fraction of LAGBs and dislocation substructure. Furthermore, both materials were exposed to a pressurized pure hydrogen environment at the ambinet and a higher temperature, followed by thermal desorption analysis. The mechanical properties of specimens before and after gaseouse hydrogen charging were evaluated. A comparison and quantification of the fracture surfaces from mechanical testing were conducted for both as-received and hydrogen-charged specimens.

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25091: Non-Thermal Plasma vs. Hydrogen Gas: A Comparative Study of Iron Oxide Reduction for Metal Fuel Applications

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Abstract: Hydrogen direct reduction (HyDR) of iron oxides has emerged as a promising technology for sustainable metal-fuel cycles, offering a low-carbon alternative to industry-dominant carbon-based processes. Though, achieving complete reduction of iron oxides requires elevated temperatures. Non-thermal hydrogen plasma presents significant thermodynamic and kinetic advantages over molecular hydrogen, potentially enhancing reduction efficiency. This study investigates the morphological and kinetic behavior of micron-scale iron oxide particles reduced under hydrogen gas and non-thermal plasma conditions. Using thermogravimetric analysis (TGA) at temperatures ranging from 500–900°C, reduction rates of spherical and non-spherical particles were measured for gaseous hydrogen, and compared to rates achieved with an inductively-coupled plasma (ICP) at temperatures in the range of 250–900°C. Complementary techniques, including Brunauer-Emmett-Teller (BET) analysis, X-ray diffraction (XRD), particle size analysis (PSA) measurements, and scanning electron microscopy (SEM), were employed to characterize the structural changes induced by each process, offering critical insights into their viability for metal-fuel applications.

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25187: Designing of light-weight tank for advanced hydrogen storage materials.

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Abstract: The future applications using hydrogen require adequate infrastructure: pipelines, tanks, reactors, tubes, etc. Some of these devices will instead be made of steel because of its mechanical properties. However, steels are very susceptible to hydrogen embrittlement, and they have a significant weight. Thus, aluminum alloys have been considered for the manufacture of different parts and more particularly hydrogen storage tanks and bottles. The storage of hydrogen in these bottles is generally at a lower pressure than in steel bottles but they have the advantage of being much lighter. A recent technology for storing hydrogen in solid materials (carbon-based or metal hydrides) makes it possible to store hydrogen at low pressure and more densely than with high pressure cylinders made of steel. In this study we designed a hydrogen storage tank for room temperature metal hydrides. We used the examples of LaNi5 hydride and FeTi hydride. Thermal transfer simulations were performed to study the exothermic absorption reaction of the hydrogen and to determine an adequate thermal design allowing to evacuate the heat and foster the speed of the charging. The results showed that a tank with fins greatly improves the heat transfer and in the case of FeTi at 40 bars the absorption is advanced at 68% only in 500 s in comparison to 42% for a tank without fins. Mechanical simulations were performed in order to assure the tank resistance at higher pressures. An innovative manufacturing process was developed using friction-stir welding with custom designed tools adapted for aluminium alloys in order to enhance the mechanical resistance of the welded zones.

Symposium: Materials for Clean Energy Transition - Hydrogen, Magnets, and Batteries
25105: Exploring the equivalence of hydrogen uptake from electrochemical and gaseous charging in pipeline steels for clean energy applications
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Abstract: Hydrogen embrittlement significantly affects the integrity of pipeline steels, and this phenomenon is largely influenced by the steel's hydrogen uptake and retention capacity. To better understand hydrogen uptake under various gaseous charging conditions for different developed microstructures, extensive testing is necessary. And for steel testing to be more accessible, it is essential to establish an equivalence between the readily available electrochemical methods and the more technically involved gaseous charging. This study investigates the hydrogen uptake in pipeline steels subjected to gaseous and electrochemical charging methods. Using electrochemical hydrogen permeation in 0.1 M NaOH electrolyte, the equivalent hydrogen fugacity for various electrochemical conditions was determined and validated via thermal desorption analysis. The results show that equivalent hydrogen content can be determined for both methods based on the hydrogen activity on the steel surface. Furthermore, the addition of recombination poisons (e.g., As_2O_3) allowed for higher hydrogen fugacity at lower absolute overpotentials. Without recombination poison, at a fixed H_2 gas pressure of 10.34

MPa comparable hydrogen concentration was obtained at an overpotential of -0.7 V. This result offers a practical benchmark for the evaluation of gaseous charging of pipeline steels by electrochemical charging.

Symposium: Materials for Clean Energy Transition - Hydrogen, Magnets, and Batteries

25107: Effect of Elemental Substitution and Doping on Mechanical Properties of NASICON Electrolytes in Solid-State Lithium-Ion Batteries

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Abstract: Solid electrolytes (SEs) with sodium superionic conductor (NASICON) structures, have shown considerable promise in solid-state lithium-ion batteries. However, the brittle nature of ceramic LATP presents a major challenge. This study investigates the mechanical properties of three different NASICONs: $Li_{1+x}Al_xTi_{2-x}(PO_4)_3$ (LATP), $Li_{1+x}Al_xGe_{2-x}(PO_4)_3$ (LAGP), and $Li_{1+x+y}Al_xTi_{2-x}Si_yP_{3-y}O_{12}$ (LATSP), focusing on the effects of elemental substitution and doping, and relates these properties to battery performance. Fracture toughness, elastic modulus, and strain rate sensitivity of three NASICONs were examined by nanoindentation method. The results follow the strength-ductility trade-off: LATP has the highest fracture toughness but the lowest elastic modulus and hardness, while LAGP exhibits the opposite trend. These differences stem from bond strength and packing density variations among the materials. All three NASICONs demonstrate strain-rate-dependent crack propagation, suggesting faster charging/discharging may accelerate failure in SSLBs.
Battery cyclic testing further shows LATP-based batteries achieve the longest lifespan, while LAGP-based ones fail faster, consistent with their mechanical properties. This study highlights the critical role of fracture toughness in resisting brittle failure and optimizing battery performance.
These findings provide valuable guidance for designing NASICON solid electrolytes with improved mechanical resilience and enhanced cyclic performance in SSLBs.

Symposium: Materials for Clean Energy Transition - Hydrogen, Magnets, and Batteries

25110: Degeneration and Regeneration of Lithium Iron Phosphate: Waste or Wealth?

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Abstract: Lithium iron phosphate (LFP) batteries have gained widespread application due to their low cost and minimal environmental impact, stemming from the absence of dependence on nickel and cobalt. Coupled with their exceptional safety performance and outstanding cycle stability, LFP batteries have been gradually increasing their market share and are progressively replacing ternary lithium batteries. However, after a certain period of use or several charging-discharging cycles, LFP batteries experience performance degeneration. This degeneration is attributed to lithium loss rather than crystal collapse or structural destruction. Consequently, restoring the electrochemical performance of LFP batteries through lithium supplementation

demonstrates significant potential, highlighting the feasibility of direct regeneration. Direct regeneration differs from conventional hydrometallurgical recycling of spent LFP batteries. With a shorter process flow, direct regeneration shows promising application prospects. Additionally, the economic benefits of recycling LFP batteries through conventional metallurgical methods are relatively low, making direct regeneration a more rational approach. This study provides a comprehensive review of recent advancements in LFP regeneration research. It classifies regeneration methods into four categories: solid-phase methods, liquid-phase methods, electrochemical methods, and other techniques. The feasibility, advantages, and disadvantages of these methods are assessed. Based on the concept of wealth and waste, the paper discusses the degeneration and regeneration processes of LFP, analyzing the dual attributes of waste and wealth in spent LFP batteries. Furthermore, it elucidates the relationship and transformation mechanism between these two aspects.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling

25136: Enhancing Magnesium Extraction from Mine Tailings via Ultrasound and Fluorite Activation

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Abstract: The increasing global demand for critical minerals, particularly magnesium, has highlighted the urgent need for innovative and sustainable extraction methods. Magnesium, recognized as one of Canada's 31 critical minerals, is vital for advanced manufacturing and clean technologies, including the production of lightweight aluminum alloys for the transportation, fertilizers, animal feed, and various consumer goods. As a key enabler of the transition to a low-carbon economy, magnesium's role in reducing greenhouse gas emissions and promoting sustainable development cannot be overstated. Recovering magnesium from mine tailings presents an economically viable and environmentally sustainable solution to address both resource scarcity and waste valorization challenges. This research focuses on an integrated approach to magnesium extraction from serpentine mine tailings, combining ultrasound-assisted leaching with the addition of fluorite as a process enhancer. Serpentine, a magnesium-rich silicate mineral, is known for its stable layered structure, which poses significant challenges for efficient magnesium extraction. The addition of fluorite disrupts this structure by forming strong Si-F bonds with silicon atoms in the tetrahedral silica layer, leading to structural deformation and exposure of reactive magnesium sites. Ultrasound technology complements this mechanism by generating intense cavitation effects, including shockwaves, microjets, and localized high-pressure zones. These effects create micropores on the serpentine surface, enhance solution diffusion, and accelerate the dissolution of magnesium. This novel combination of techniques significantly reduces acid consumption, leaching time, and energy requirements, making the process more cost-effective and environmentally sustainable compared to conventional methods. Comprehensive analyses were conducted on serpentine tailings sourced from various locations to evaluate the efficiency and scalability of this approach. Characterization techniques included particle size distribution (PSD), X-ray diffraction (XRD), X-ray fluorescence (XRF), inductively coupled plasma mass spectrometry (ICP-MS), scanning electron microscopy (SEM), and advanced surface characterization methods. These analyses confirmed the structural modifications achieved through fluorite addition and the enhanced dissolution rates facilitated by ultrasound treatment. Furthermore, the study investigated the influence of key process parameters such as time, temperature, acid concentration, solid/liquid ratio, and ultrasound

intensity on magnesium recovery rates, providing valuable insights into optimization strategies. This study demonstrates that integrating ultrasound and fluorite activation effectively addresses the challenges posed by serpentine's stable structure, providing a sustainable and energy-efficient pathway for magnesium extraction.
The findings of this research not only demonstrate the technical feasibility of this integrated method but also align with Canada's Critical Minerals Strategy, which aims to establish a resilient supply chain for essential materials needed in clean energy technologies. By transforming mine tailings into a valuable resource, this approach supports the principles of circular economy and contributes to reducing the environmental footprint of mining operations. The improved magnesium recovery process is poised to play a crucial role in the development of advanced materials, lightweight alloys, and other clean technologies essential for achieving global climate targets.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling

25016: ENHANCED SCANDIUM RECOVERY FROM A CANADIAN ORE SAMPLE

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Abstract: This study focuses on optimizing scandium (Sc) recovery from ore samples obtained from a Canadian project featuring an alkali igneous intrusive complex enriched with scandium and rare earth elements (REEs). The primary objective is to reduce scandium concentrate mass through gangue rejection, using advanced concentration and separation methods. Key objectives include the application of Dense Media Separation (DMS) to reduce gangue minerals, by 50–60%, achieving a 15–20% reduction in concentrate weight, and enhancing scandium grade. Magnetic separation tests, including Low-Intensity Magnetic Separation (LIMS) and Wet High-Intensity Magnetic Separation (WHIMS), have demonstrated high scandium recoveries of up to 97% and gangue rejection. Additional flotation tests have further refined the concentrate by removing remaining gangue minerals. Ongoing work focuses on refining flotation techniques and processing finer sample sizes to further elevate scandium grade and minimize non-target minerals. The recovery of titanium (Ti) and zirconium (Zr) as valuable by-products also adds economic value and is considered in the flowsheet development. These findings support sustainable resource development through optimized processing and recovery, positioning this project as a strategic source of scandium.

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25197: A Combined Experimental and Modeling Approach for Separation of Neighboring Heavy and Light Rare Earth Elements (Samarium, Europium, Gadolinium, Terbium, and Dysprosium) Using Chelation-assisted Electrodialysis

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Abstract: Chelation-assisted electrodialysis is emerging as a sustainable and energy-efficient alternative to traditional separation methods for rare earth elements (REEs). Developing rapid, cost-effective, and low-energy separation processes is critical for advancing REE recovery technologies. This study combines experimental and modeling approaches to efficiently separate heavy and light REEs, including samarium, europium, gadolinium, terbium, and dysprosium. A dual-cation exchange membrane electrodialysis cell is employed, utilizing ethylenediaminetetraacetic acid disodium salt (Na_2EDTA) as a chelating agent to enhance selectivity by forming stable rare earth chelates. To optimize the process, a robust mathematical model is developed, integrating three critical elements: feed solution equilibrium, membrane-solution interactions, and ion migration dynamics through the cation-exchange membrane. The model leverages thermodynamic equilibrium constants for solution behavior, the Extended Nernst-Planck equation for transport dynamics, and includes considerations for overpotential and resistance within the solution and membranes. Key operational parameters—rinsing solution concentration, applied voltage, pH, and EDTA concentration—are systematically evaluated. Process performance is assessed in terms of kinetics, recovery efficiency, product purity, and specific energy consumption. This comprehensive approach demonstrates the potential of chelation-assisted electrodialysis to revolutionize rare earth separation with reduced environmental impact, paving the way for scalable and greener REE recovery processes.

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25144: The Impact of an Adequate Selection of Flotation Intervals in Kinect Tests for Scaling-Up Industrial Circuits

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Abstract: Flotation continues being one of the most versatile separation techniques in mineral processing. The robust design and sizing of industrial flotation circuits strongly depends on laboratory tests; more specifically, batch flotation kinetics. Although significant efforts have been made to standardize flotation tests for the estimation of rate constants (k) and maximum achievable recoveries (R_∞), the robust definition of the flotation intervals in the experimental designs has received limited attention in kinetic characterizations. Measured recovery rates are strongly dependent on the set of flotation intervals in kinetic studies. These intervals have been typically chosen to obtain enough datapoints at the beginning and at the end of the tests, with the aim of estimating the k - R_∞ pairs. This rule is reasonable if sustained increasing trends at long times and fast recovery rates at short times are measurable. Otherwise, the flotation tests may artificially unbalance the relative presence of fast and slow-floating minerals, also affecting the scale-up results for circuit design. This work proves that the arbitrary selection of flotation intervals in kinetic characterization biases the scale-up results, leading to significant uncertainties in circuit sizing. Flotation tests with 14 concentrates per experiment are analysed. The flotation intervals of these tests are chosen such that they guarantee sufficient datapoints to estimate the time-recovery curvature from the beginning of the experiment to reach steady recoveries. The k - R_∞ stability is analysed comparing the estimated k - R_∞ pairs after removing 7 datapoints at a time with that pair obtained from the entire kinetic responses (14 datapoints). From all combinations of 7 out of 14 concentrates (3432 combinations), robust and poor experimental designs are identified. Following a simplified scale-up procedure, the number of flotation cells required to obtain a targeted recovery in an industrial rougher process is assessed. From this analysis, the impact of poorly-designed experimental tests on the capital and operating costs is discussed.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling

25146: Development of a thermodynamic database for antimony oxide-containing metallurgical systems

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Abstract: Antimony and its compounds, particularly antimony oxides (Sb_2O_3, Sb_2O_5), find extensive industrial applications such as semiconductors, batteries, catalysts, glasses, and flame retardants. Recognized as a critical and strategic metal by Quebec, Canada, the USA, and the European Union, antimony is currently facing a high supply risk. This has intensified the demand for increased production through the optimization of existing processes and the development of economically viable and environmentally friendly recycling pathways. For the efficient recovery of antimony from industrial residues and end-of-life products, reliable thermodynamic data are essential. However, such data are either scarce or missing in the literature. Generating these data using purely empirical methods is both costly and time-consuming. To address this, the current research aimed at establishing a thermodynamic database for the Sb_2O_3-Sb_2O_5-SiO_2-CaO-FeO system using a coupled modeling and experimental approach. This system was chosen based on the most general compositional range of potential primary and secondary resources. The methodology involves dividing the system into binary and ternary chemical sub-systems, conducting thermodynamic modeling and preliminary optimization of each, generating key phase diagram data using experiments, and performing a final thermodynamic optimization based on the newly generated data. Modified Quasichemical Model is employed for modeling molten oxide solutions. Experimental techniques include differential thermal analysis-thermogravimetric analysis, equilibration-quenching, and phase identification using electron probe micro-analysis and X-ray diffraction. This work presents the progress and key findings to date, contributing to the development of a robust thermodynamic framework for antimony recovery and processing.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling

25009: Recycling of lead-acid batteries - A review

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Abstract:
Lead from recycled lead-acid batteries is the primary source of lead worldwide. Worldwide, lead-acid batteries account for greater than 85% of lead consumption, and about 99% of the batteies in North America are recycled. Therefore, lead-acid battery manufacturing and recycling form a closed loop. Diffused uses of lead such as lead-based pigments, chemicals, fuel additives, solders (cathode ray tube) CRT glasses, etc. have diminished over the last six decades. In this paper, some of the processes and technologies used in lead–acid battery recycling are examined, and explain why recycled lead has become the material of choice for battery construction through the development of recovery and refining processes that exceed industry expectations.

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25151: Aluminum as a Metal Fuel for Sustainable Energy Storage and Transport: A Comparative Life Cycle Assessment

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Abstract: Metal fuels, particularly aluminum, are shown to be feasible candidates for long-term energy storage and the sustainable transport and trade of energy. Aluminum stands out as an energy carrier due to its natural abundance, well-established production and recycling infrastructure, high energy density, and stability (in sizes above the nanoscale). The aluminum-water reaction, especially under supercritical conditions, can release aluminum's chemical energy in the form of hydrogen and heat. However, aluminum production is highly energy-intensive and poses environmental challenges, such as direct CO_2 emissions during the smelting process. These emissions can be mitigated through the adoption of inert anode aluminum smelting technologies.

This study evaluates the feasibility of using aluminum, produced in Quebec with hydroelectricity, as an energy carrier to replace diesel generators in remote mining operations. While diesel generators are compact and reliable, they are significant contributors to greenhouse gas emissions. Aluminum is compared to hydrogen and ammonia in terms of life cycle environmental impacts, round-trip energy efficiency, and overall feasibility.

A closed-cycle system is proposed, where green electricity is used to produce aluminum, which is then transported to remote sites to generate energy through aluminum-water reactors. These reactors release stored chemical energy in the form of heat and hydrogen. The resulting aluminum oxide by-products are collected, returned to production facilities, and reduced back to aluminum, creating a sustainable material reuse loop (Figure 1).

The results of the comparative LCA study show that aluminum produced via the conventional Hall-Héroult process is environmentally unviable due to its high emissions. In contrast, aluminum produced using inert anode smelting technology significantly reduces emissions, making it comparable to other green alternatives like ammonia and liquid hydrogen, with life cycle emissions ranging from 0.24 to 0.33 kg CO_2/kWh. Figure 2 illustrates the contribution of various steps in each scenario and compares the life cycle global warming potential (GWP) of these scenarios to diesel, emphasizing the critical dependence of GWP on the energy source used for carrier production.

The round-trip energy efficiency of the studied scenarios is within the range of 18–22%. Additionally, aluminum’s stability and non-explosive nature make it safer than hydrogen, while its non-toxic and non-corrosive reaction by-products provide advantages over ammonia.

Figure 1. Proposed aluminum-based energy cycle to power remote locations.
Figure 2. Life cycle global warming potential associated with investigated scenarios.

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25152: Mechanism of Solid-State Reduction of ‘Ring of Fire’ Chromite Ore Using Self-Reducing Pellets

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Abstract: Chromite ore from the 'Ring of Fire' deposit in Northern Ontario was reduced carbothermically at 1300°C under an argon atmosphere. In the experiments, self-reducing pellets, made from mixtures of graphite and ore were used. The progress of the reaction was followed by measuring the gas evolution rate and mass change of samples along with detailed microstructural and chemical analyses of these samples. The aim of this study is to propose a mechanism that satisfactorily describes the solid-state carbothermic reduction of the 'Ring of Fire' chromite ore. The analysis of microstructures, X-ray diffraction, and composition changes in the reduced samples showed that an iron-chromium-carbon alloy (Fe-Cr-C) and carbides ($(Cr, Fe)_7C_3$) are the primary products of reduction. Iron and chromium are reduced simultaneously but at different rates. The reduction was shown to occur by the outward diffusion of ions (Fe^{2+}, Cr^{3+}, and O^{2-}) in the depleted layer. The simultaneous reduction of iron and chromium oxides by outward diffusion resulted in the formation of a depleted layer and eventually a Mg-Al-rich barrier layer, resistant to diffusion of Fe^{2+} and Cr^{3+} ions. The metal phase initially formed on the surface of the ore particles, and subsequent to the formation of the Mg-Al-rich barrier layer, iron-chromium particles later formed inside the ore particles. The internally formed metal was isolated from the carbon source and therefore did not contain any carbide and was also less rich in chromium than the externally formed metal particles.
Based on the analysis of these observations, a two-stage reduction mechanism is proposed. (1) **Primary Reduction Stage**, which includes the initial reduction of iron (Fe) and chromium (Cr) to form Fe-Cr-C alloy and $(Cr, Fe)_3C_7$ carbide, including the formation of a depleted layer. (2) **Secondary Reduction Stage**, which includes the formation of a Mg-Al-rich barrier layer and the subsequent precipitation of internal Fe-Cr alloy. The Mg-Al-rich barrier layer plays a crucial role in determining the reaction mode during each reduction stage and greatly influences the extent of chromium recovery in the metal phase. The mechanism for metallization during both stages will be addressed in more detail in the context of solid-state ionic diffusion. Overall, these findings suggest that the reduction in the self-reducing pellet is primarily controlled by the solid-state diffusion of ions (Fe^{2+}, Cr^{3+}, and O^{2-}) in the product layer formed around the reduced ore particle.

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25159: Iron Whisker Formation And Growth On Reduced Iron Ore Pellets: Mechanisms And Influencing Factors.

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Abstract: Direct reduction of iron ore (DRI) is a metallurgical process that involves the chemical transformation of iron ore pellets into metallic iron in the solid state. Reduction swelling of pellets, which is characterized by volume changes due to iron whisker formation, crystal transition, and carbon deposition, is a significant challenge in the iron ore reduction process. This phenomenon adversely affects the mechanical integrity of the pellets. It leads to reduced compressive strength, formation of cracks, disintegration into fines, and diminished gas permeability, thereby lowering the overall efficiency of the reduction process. One of the main causes of swelling is the formation of iron whiskers, which are elongated fibrous metallic iron structures that form during the reduction process, particularly during the reduction of wustite to metallic iron. The growth of iron whiskers is a complex process influenced by multiple factors, including basicity, reduction temperature, reduction degree, and reducing gas composition. This

study provides a comprehensive review of the key parameters influencing the iron whisker formation and growth on the surface of iron ore pellets.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling

25160: AI-Driven Optimization under Uncertainty for Mineral Processing: A Case Study of Phosphate Flotation

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Abstract: The increasing need for critical minerals to supply the clean energy transition will require significantly greater mineral processing capacity. Since it is difficult to systematically account for uncertainties that stem from the feedstock or are inherent to the process, mineral processing operations are typically optimized deterministically. This approach results in inefficient processing—producing vast quantities of waste, polluting local environments, and leading to lost revenue. Factoring in uncertainty can improve the efficiency (increasing economic value) and sustainability (reducing waste) of mineral processing plants. In this work, we consider uncertainty by employing an approach called sequential decision making under uncertainty (DMU). The problem is formulated as a partially observable Markov decision process (POMDP), which can then be optimized using an AI agent. A POMDP formulation accounts for the uncertainties in feedstock characteristics and throughout the mineral processing circuit. It can aid in decision making on what data to collect, where, how often, and with what level of accuracy in each process unit to inform optimal design and operation of the circuit.
As a case study, we focus on phosphate mining in Morocco, which is the second-largest producer of phosphate in the world and holds an estimated 70% of global reserves. Phosphate is a key component of fertilizer and is finding increasing use in lithium iron phosphate (LFP) batteries. Unfortunately, in Morocco, the tailings stream with greatest potential for environmental damage as well as for valorization, called phosphogypsum (PG), is dumped in the Atlantic Ocean.
To reduce the residual phosphate that ends up in PG waste, we begin by considering phosphate froth flotation and frame it as a POMDP. The key uncertainties are the feedstock composition (i.e., particle size distribution, chemical and mineralogical composition) and the internal physical processes (i.e., flotation kinetics, bubble-particle interactions, hydrodynamics) that together determine the concentrate grade and recovery. By accounting for these uncertainties and how future information can reduce uncertainty, a DMU approach provides a more comprehensive optimization of flotation that can be generalized to any form of mineral processing.
Ultimately, the goal is to build up to applying the POMDP framework to the entire integrated phosphate value chain and contribute to its redesign with circularity in mind.

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25164: Transitioning from Thermal to Hydrometallurgical Magnesium Extraction from Dolomite: Process Modeling and Environmental Assessment

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Abstract: Magnesium, renowned for its lightweight and versatile properties, is a cornerstone of innovation in transportation, electronics, and renewable energy technologies. However, its conventional production methods, particularly the energy-intensive Pidgeon process, impose substantial environmental burdens. This study explores the transition from thermal (pyrometallurgical) to hydrometallurgical magnesium extraction from dolomite, proposing a conceptual process flowsheet and assessing its environmental implications. The hydrometallurgical pathway involves leaching dolomite in hydrochloric acid (HCl) and subsequent steps to recover magnesium chloride ($MgCl_2$), which is further processed into magnesium metal via electrorefining. Process modeling with HSC Chemistry and life cycle assessment (LCA) using openLCA were applied to evaluate the technical and environmental performance of the proposed process. A comparative LCA, employing the ReCiPe 2016 method and LC-IMPACT v1.3, benchmarks the hydrometallurgical approach against the Pidgeon process. Results reveal significant advantages for the hydrometallurgical pathway in categories such as global warming and acidification, while challenges remain in resource efficiency and water consumption. These findings highlight the trade-offs inherent in transitioning to cleaner technologies and the need for optimization to address performance gaps. This research provides an integrated framework combining process modeling with environmental assessment, offering actionable insights into sustainable magnesium extraction methods. By advancing the understanding of hydrometallurgical alternatives, this study supports the broader goal of aligning industrial practices with global sustainability targets.

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25258: Recycling of Lithium Ion Batteries - Review of Physical Separation Methods

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Abstract: The proliferous use of small-scale electronic devices in modern society has created a sizeable quantity of spent batteries that continues to represent a significant source of valuable resources but also a distinct environmental and safety hazard due to the toxic materials contained within, and potential for fire and explosions. The recycling of Li-ion and other forms of batteries has garnered interest within industry, with some production projects being initiated. Currently, it is estimated that less than 5% of spent Li-ion batteries produced are being recycled, which presents a significant opportunity to recover lithium, cobalt, nickel, manganese, copper, aluminium, and other valuable commodities from this waste. This paper will update a 2020 review Li-ion battery construction, the recycling industry, and current recovery processes being used as well as the various aspects and mitigating efforts required for safe and economical recycling of Li-ion batteries. The design selection and operation of the SGS mechanical separation pilot plant which includes crushing and physical separation to separate the foils and metal-containing black powder will be discussed.

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25037: Extraction of High Purity Magnesium and Calcium from Phosphate Mine Waste Rocks by a Carbon-Neutral and Circular Hydrometallurgy

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Abstract: The global transition from fossil fuels to advanced green technologies has driven a growing demand for strategic metals. Magnesium (Mg), valued for its lightweight properties, electrical conductivity, energy storage capacity, catalytic activity, thermal stability, and biocompatibility, has many applications from the engineering industries to the health and food sectors. Despite its widespread application, the high supply risk of Mg has led the U.S. Department of Energy to designate it as the most critical metal for 2025-2035. To tackle this issue, Mg recycling from secondary resources, i.e., industrial and urban wastes, offers a promising solution. Dolomitic limestone waste rock (DLWR), which is produced during phosphate ore extraction, has a high potential not only for the recycling of Mg but also for the recovery of calcium (Ca), another valuable metal. Therefore, in the present research, we mainly aim to extract Mg and Ca from DLWR obtained from a Moroccan phosphate mine by a hybrid hydrometallurgical process involving dilute inorganic acid leaching and stepwise alkaline precipitation. Mineralogical characterization revealed that Moroccan DLWR mainly consists of 78% $MgCa(CO_3)_2$, with the remainder comprising Ca_2SiO_4, SiO_2, Al_2O_3, P_2O_5, TiO_2, Fe_2O_3, MnO, K_2O and Na_2O. According to the literature, the thermal decomposition of $MgCa(CO_3)_2$ to MgOCaO enhances the Mg and Ca leaching efficiency since metal oxides are thermodynamically more soluble than metal carbonates. However, thermal decomposition is energy-intensive and increases greenhouse gas emissions. In addition, no studies have investigated the impact of thermal decomposition on the co-leaching of impurities. To address these challenges, as the first specific objective, we revealed that maintaining the carbonate phase can assist in suppressing the co-leaching of impurities and increasing the Mg selective leaching. By creating a buffering effect, introducing hydrophobicity, and decreasing the surface area of DLWR compared to calcined DLWR at 900 ˚C, the carbonate phase could decline more than 50% of impurities co-leaching. Under optimal leaching conditions (0.5M H_2SO_4, S/L ratio of 10 g/l, particle size of 45µm, and 80 ˚C), 100% of Mg with selectivity of 85% could be leached. The separation of Mg and Ca is traditionally challenging due to their similar physicochemical properties. To overcome this issue, we developed a stepwise alkaline precipitation for selective Mg and Ca separation. Considering the Pourbaix diagram and single and multiple alkaline precipitation, the impurities in leachate were removed at pH 7 using 1M NaOH, followed by precipitation of $Mg(OH)_2$ at pH 9 with over 99% purity. Ca was then selectively recovered as $CaCO_3$ using $NaHCO_3$ and subsequently calcined to produce CaO. A further limitation of the process is the carbon footprint associated with carbonate ore leaching and $CaCO_3$ calcination, which leads to CO_2 liberation. Our third specific objective was to design a carbon-neutral process to mitigate this drawback. The generated CO_2 was captured using NaOH-rich effluent from the precipitation stage and utilized to regenerate $NaHCO_3$ precipitant. To sum up, our research presents a sustainable procedure to valorize DLWR. This process not only addresses critical metals supply risks but also advances the circular economy and reduces environmental harm.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling

25169: Low-temperature alkaline electrolysis of synthetic and natural magnetite suspensions for CO2-free iron production

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Abstract: Despite the recent efforts to increase recycling contribution, it cannot rise to meet the vast demand for iron and steel. Thus, iron ores are still predominantly the primary source of iron and steel production in blast furnaces, where the iron oxides undergo carbothermic reduction using coke and coal. Carbothermic reduction of iron oxides can lead to up to 2.3 tons of CO_2 per ton of crude steel. The enormous size of the iron and steel industry with about two billion tons of crude steel annually produced, makes this industrial sector one of the most carbon-intensive and responsible for about 10% of global annual CO_2 emissions. Among CO_2 mitigation remedies, the low-temperature alkaline electrolysis of iron oxides stands out as the most promising carbon-free and energy-efficient alternative. It involves the electroreduction of iron oxide suspensions in highly alkaline concentrated alkaline electrolytes at around 110 °C. Metallic iron is recovered at the cathode, and the only byproducts of this process are the non-polluting oxygen and hydrogen gases from water electrolysis. Hematite, the most occurring iron mineral in the Earth's crust, has been under the most extensive research as the feed for low-temperature alkaline electrolysis and has been found to be highly reactive and efficient. 85% Faradaic efficiency was observed at even high current densities up to 1100 $A.m^{-2}$. However, magnetite, the second most occurring iron mineral in the Earth's crust, remains underexplored. Furthermore, virtually all natural iron deposits on Earth contain more than one type of iron mineral and include certain gangue minerals and impurities, yet their reactivity has not been examined. In this work, the reactivity of various synthetic magnetite and its natural ore concentrates of different origins and characteristics such as particle size distribution (PSD) and composition, have been studied in terms of current density and Faradaic efficiency. Electrolysis of suspensions with 10 wt.% oxide in 50 wt.% $NaOH_{(aq)}$ electrolyte was investigated at 110 °C by applying 1.66 V between the cathode and anode for 4 hours. The electrodeposits have been thoroughly characterized in terms of morphology, phase and elemental composition, as well as iron purity. Moreover, synthetic hematite has been examined as the benchmark for the reactivity of magnetite based on the literature. Magnetite demonstrates promising reactivity, comparable with that of hematite. Iron electrodeposits are predominantly crystalline α-Fe with a purity of over 98%. In addition, a correlation seems to exist between oxide the PSD and mineralogy of the oxides and their Faradaic efficiency, which could be manipulated to enhance the reactivity of the oxides and the efficiency of the process.

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25042: Application Of A Combined Chemical And Microbial Approach To Critical Raw Material (CRM) Recovery, With A Particular Focus On Gold Recovery From End-Of-Life Printed Circuit Boards (PCBs)

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Abstract: The European Union's Parliament has recently enacted the Critical Raw Materials Act (CRMA) in light of the global energy transition and the concomitant growth in demand for critical raw materials, coupled with the advent of a modernised economy. This legislation has three clear objectives: to bolster the EU's strategic autonomy, diversify its critical raw material supply and reinforce recycling and circularity. In this context, the INN4MIN project has successfully tested an optimised approach to the recovery of gold, copper, zinc, tin and other metals from printed circuit boards (PCB). The de-soldering of the PCB components was achieved through a combined chemical and biotechnological approach. A ferric iron solution was

used to transform the solder metals, namely tin and lead, into their respective oxides and sulphates. At the same time, other metals such as copper, iron, nickel, cobalt, silver and zinc are dissolved and can be recovered from the solution. We achieved the regeneration of ferric iron through the utilisation of iron-oxidising bacteria within an aerated bioreactor. Despite the relatively long residence time, we can recover 96% of the aforementioned metals in an environmentally friendly manner. Once we have separated the gold from the components, we can use environmentally preferable leaching reagents, such as a solution of thiourea and ferric sulphate, to process it further. The recovery of gold depends on a number of influencing parameters, including the temperature and concentration of the individual components, as well as the pH and Eh conditions.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling

25043: Metso's Novel Alkaline Leaching Process: Unlocking the Value of More Lithium Minerals

Petr Zaitsev, Metso, Espoo, Uusimaa, Finland

Abstract: Reducing environmental impact while maintaining cost competitiveness is crucial for operators in the production of battery-grade lithium, both now and in the future. While spodumene is well-known as the primary source of lithium from hard rocks, the increasing demand for lithium has highlighted the importance of other lithium-bearing minerals. This paper discusses advancements in Metso's alkaline leaching technologies for various lithium minerals, including petalite, lepidolite, and zinnwaldite. The paper introduces a novel hydrometallurgical approach for processing non-spodumene lithium feedstocks, building on and expanding previous Metso alkaline leaching developments. Various processing options are conceptualized and presented based on common alkaline leaching chemistry. Cost optimization variants for the calcination, as well as core alkaline leaching process are considered. Test work results, which evaluate process performance and lithium extraction efficiency, are provided to support the processing concept.

The new alkaline technology realizes a sulfate-free, environmentally friendly, and efficient lithium extraction process while aiming to reduce costs and unlock the value of a wider range of lithium mineralogies.

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25265: ENHANCING GOLD MINE EFFICIENCY AND SAFETY THROUGH THE IMPLEMENTATION OF ONSITE PHOTONASSAY™

ANDREA MCLAREN[1], Michael de Sousa[1]

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Abstract: This presentation highlights the successful transition of Ravenswood Gold Mine from traditional analytical methods, such as fire assay, Pulverize and Leach (PAL) and aqua regia digestion, to the innovative onsite PhotonAssay™ technology. The implementation of PhotonAssay™ has significantly reduced the turnaround time for exploration and production samples while enhancing data accuracy. By deploying this technology onsite, the mine has minimized sample preparation needs, streamlined the measurement process and data QA/QC protocols, and eliminated the use of hazardous chemicals. These improvements have optimized operational performance and enhanced overall safety at the mine site.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling
25048: Extraction of Rare Earth Metals from Low-Grade Ores Using Organic Acids
José Eric Ortiz Castillo, University of British Columbia, Vancouver, BC

Abstract: **Extraction of Rare Earth Metals from Low-Grade Ores Using Organic Acids**
Student: José Eric Ortiz Castillo, Supervisors: Wenying Liu and David Dreisinger
Abstract
Rare earth elements (REE) are 17 metallic elements, including the lanthanides, scandium, and yttrium. They are crucial for high-tech applications, such as catalytic converters, wind turbine magnets, hybrid vehicles, and missile guidance systems. Over 80% of REE supply comes from China, posing a strategic risk for other countries. To reduce dependence, Canada has identified 31 critical minerals, including REE, and holds 40–50% of global REE reserves, offering strong potential for domestic production. Current REE extraction methods use highly corrosive agents with low selectivity, making them suitable for high-grade ores. This research explores indirect bioleaching with organic acids to extract REE from low-grade ores and waste, improving selectivity and reducing corrosive reagent use.
Thermodynamic calculations were first performed to evaluate the feasibility of using organic acids for REE extraction from various REE-bearing minerals. Experimental studies then tested organic acid leaching for extracting light (LREE) and heavy (HREE) REE from Canadian low-grade ore and phosphogypsum waste. The leaching of two heavy REE (Y, Dy) and two light REE (Ce, Nd) was studied under the following parameters: type of organic acid (tartaric acid, lactic acid, oxalic acid, citric acid), temperature (25, 65, 85 °C), particle size (-38, +38-58, +53-75 µm), and organic acid concentration (0.05, 0.2, 0.4 M). Maximum extraction efficiencies were found at 0.2 M citric acid, 85 °C and -38 µm particle size respectively (Ce 78%, Nd 74%, Y 47% and Dy 49%). Furthermore, the synergistic effect of organic acid (citric acid) with H_2SO_4 and HCl was measured by conducting different leaching experiments at different organic:inorganic acid ratios (0.2:0.0, 0.15:0.05, 0.1:0.1; 0.05:0.05, 0.0:0.2 M respectively). Selectivity of REE over impurities was studied by measuring the extraction of impurities (Mg, Al, and Fe) during leaching. The results show that citric acid could be used to reduce the amount of inorganic acid, offering higher selectivity compared to leaching with inorganic acid only.

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25052: Life-cycle assessment as a tool to develop sustainable smelting technologies
Mari Lindgren[1], Paivi Suikkanen[2], Hannu Johto[3], Juha Malinen[3], Peter Björklund[4], Miikka Marjakoski[4]
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Abstract: Life-cycle assessment (LCA) is a valuable tool in the development of processing technologies. In the development process, it can be applied at different levels. LCA offers a comprehensive understanding of environmental impacts, extending beyond carbon footprints. In copper production, LCA can be applied at the smelting technology level to evaluate differences between various smelting technologies, smelter feed capacities, and concentrate copper grades.

Once the core technology has been selected, equipment and technological choices can be assessed. Finally, after technology and equipment selections are made, the impact of various digital tools for process improvements can be calculated.
Examples of life-cycle assessments at various levels, with focus on carbon footprint, are presented. These examples include the overall smelting technology selection, technology selection for an anode furnace, and the impact of using a digital tool for process improvements. The influence of key variables is also demostrated and discussed.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling
25173: Overview of a new Indonesian Nickel Smelter with focus on sustainability efforts, including operational readiness activity
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[1]Analyze and Improve Inc., Oakville, Ontario, [2]Mitra Murni Perkasa (MMP), Jakarta, Jakarta Raya, Indonesia, [3]Analyze and Improve Inc, Oakville, ON

Abstract: A new Nickel Smelter plant is being built in the Kariangau, Industrial park, northwest of Balikpapan, East Kalimantan, Indonesia. The company, Mitra Murni Perkasa (MMP), had selected a mature and proven RKEF (Reduction, Kiln, and Electric Furnace) technology with capacity of 2 lines x 48 MVA. The plant will produce ~22,000 Metric Tonnes of nickel or ~27,000 metric tonnes of nickel matte with 76%-78% nickel content to support the global battery development as part of green energy initiative. The Smelter is strategically located near the port to receive nickel ore and exporting nickel matte (product). This Smelter (project) will approach sustainability in the following ways:

- Utilize a portion of the electrical power from renewable energy supplied by the solar farm
- Use the existing power supply for the remaining of the electrical needs without the needs of building a new power plant
- Recycle the heat energy from the off gases to the feed and other use
- Repurposing empty backhaul vessel for nickel ore inbound shipment instead of dedicated barges
- Avoid using ground water/ surface water and deploy seawater reverse osmosis for process water needs and others
- Implement Operation Readiness activity to bridge the gap from project to operation

MMP appointed China Engineering Corporation (ENFI) as the Engineering, Procurement and Construction (EPC) company for this Smelter complex from conception to completion. ENFI is the major provider of consulting & engineering services, construction services, technical products and project integrated solutions for non-ferrous mine projects and smelting projects in China.
To reduce risks in operational delays, costs, and other challenges, MMP hired a Canadian consultant firm, Analyze and Improve (A+I Inc.) to assist with the Operational Readiness (OR) aspect. Operation readiness is related to ensuring that the capital project / asset being delivered is capable of an effective start up, ramp-up as planned and a sustainable productive operation. And when it is done properly and effectively, it can increase the value in delivering the product/service through established systems, processes and procedures, while simultaneously minimize risk to both the project and the business.

This presentation provides a journey of the new plant being built with an emphasis on sustainability, including operational readiness (Define, Plan, Execute).

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling

25174: Purification Process of Recycled Graphite Concentrates from Spent Potlining

Amira Merchichi[1], Gabriel-Étienne Mailloux-Keroack[1], Mahamadou Traoré[2], Etienne Belanger[3], Théo Gaxotte[4], Lucie Coudert[5], herve Gauthier[6], Laurent Birry[7], François Lagacé[8], Jean-Francois Boulanger[9]

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Abstract: Graphite is used in many industries owing to its unique properties such as high thermal/electrical conductivity and heat resistance, as well as the ability to act as anode material in Li-ion batteries. A significant increase in demand is forecasted for this application owing to the electrification of vehicles. The global consumption of graphite in 2022 amounted to approximately 3.8 million tonnes, supported by growth in the industrial applications with the adoption of renewable energy sources. Graphite recycling is of great importance for many reasons. For example, it enables a diminution in the raw natural materials required and decreases the environmental impacts of the mining sector. In particular, the recycling of Spent Potlining (SPL) from aluminum production is an upcoming approach. SPLs contain recoverable graphite in large quantities and could represent an important secondary source. Recycling graphite from secondary sources, in addition to decrease extraction and processing costs, can also lead in a non-negligible diminution of waste to be disposed of and associated environmental impact at the industrial scale. Therefore, this approach suits the idea of a circular economy where materials are reused several times to increase resource efficiency.

The primary objective of this project was to examine the purification methods for graphite obtained from SPL with the aim of obtaining a graphitic carbon (Cg) suitable for Li-ion battery applications (i.e., a content of approximately 99.95% being a typical targeted specification). A graphite concentrate with 90% Cg, obtained by Low Caustic Leaching and Liming (LCLL) treatment followed by flotation of SPL supplied by Rio Tinto Alcan (RTA), was submitted to physical (specific gravity and surface area, particle size analysis), chemical (inductively-coupled plasma atomic emission spectroscopy) and mineralogical (optical microscopy, SEM-EDS, quantitative SEM mineralogy, and X-ray diffraction) characterization. Two purification techniques were tested: i) static alkaline fusion and ii) aqueous alkaline leaching, both followed by hydrochloric acid leaching (80 °C for 1 hour). Alkaline fusion used a NaOH:graphite ratio of 3:1 at a temperature of 500°C for a period of 1 hour, while aqueous alkaline leaching tests were carried out with a 50% NaOH solution at various temperatures ranging from 100 °C to 140 °C. The alkaline fusion-acid leaching approach provided the best results, achieving a maximum purity level, based on total carbon content, of 98.25% C and removing >80% of the impurities. Comparatively, tests conducted on the [-106 +20 µm] size fraction resulted in purities of 97.97%, while the use of NaOH in aqueous form (50% NaOH solution - w/w) gave 97.89% C. The remaining impurities were mainly Na, Al and Si, at 0.29 %, 0.28 % and 0.19 % respectively, in

the case of the alkaline fusion approach. Mineralogical investigations following alkaline fusion showed that the Si was mainly present in the form of silicon carbide, a very refractory material that reacted slowly under the conditions used. Optimization tests are under underway to improve purity. Performance tests, including coin batteries, are also planned.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling

25212: Microscopic Analyses of an Ion-Adsorption Rare Earth Deposit From South America

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Abstract: Ion-adsorption clays or ionic clays are an attractive resource for rare earth element (REE) mining, known for their simple extraction, high content in valuable heavy rare earths and low content of radioactive elements. Despite the advancements in ionic clay mining, direct microscopic research on deposits outside of China is limited. The high variability between deposits and the fact that many countries outside of China have begun prospecting for REEs within their own territories, has pushed the urgency of investigating other sources of ionic clays. This study addresses the lack of clarity on these ionic clay sources by using several characterization techniques to derive a holistic understanding of a unique ion-adsorption deposit in South America. Utilizing alkali fusion and inductively coupled plasma (ICP) it was found that the REE content was >4000 ppm, X-ray diffraction (XRD) and Raman revealed the major crystal phases of kaolinite ($Al_2Si_2O_5(OH)_4$), muscovite ($KMg_{0.18}Fe_{0.16}Al_{2.35}Si_{3.3}O_{10}(OH)_2$), goethite (FeO(OH)) and monazite ($REE(PO_4)$). Morphological and local composition details were thoroughly investigated with the application of laser ablation, scanning electron microprobe-energy dispersive X-ray (SEM-EDX) and Tescan integrated mineral analyzer (TIMA). This approach revealed many of the monazite particles are amalgamated within different phases of the clay at varying levels of exposure to the surface. This analyses also provided extremely detailed topographical information, including trace element distribution within other phases. Lastly, surface chemistry and distribution of REEs were examined with X-ray photoelectron spectroscopy (XPS) and time of flight secondary ion mass spectroscopy (ToF-SIMS), these revealed sparsely distributed REEs on the surface of this ionic clay, along with common oxidation states of major elements on the surface. The results elucidate potential pathways for full extraction of REEs and highlight optimization routes for this ion-adsorption clay.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling

25055: Building Canada's Critical Mineral Reprocessing Capacity through Government of Canada Investments

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Abstract: Critical minerals are the building blocks for clean technology. As the world transitions to meet its net-zero emission goals, the demand for these materials is expected to increase by two to three times by 2030, as indicated by the International Energy Agency. The critical minerals industry in Canada requires both primary and secondary sources to compete on a global level and meet increased demand. Reprocessing can help bolster the security and sustainability of critical

mineral supplies in Canada for the clean energy transition. Growing Canada's critical minerals secondary source capacity and combining with primary sources has several advantages such as growing a diversified economy; providing viable alternatives to natural resources and making mine deposits and recycling operations more economically viable; reducing energy, water, and waste requirements for processing; and promoting a circular economy. Natural Resources Canada's Critical Minerals Research, Development and Demonstration (CMRDD) and Global Partnership Initiatives (GPI) contribution funding programs enable Canada's Critical Minerals Strategy by supporting the technology commercialization advancement of industry partners' pilot and demonstration projects, several of which are focused on recycling or reprocessing priority critical minerals such as rare earth elements, lithium, nickel, cobalt, and graphite. Piloting projects eligible for CMRDD and GPI contribution funding can help grow the domestic recycling knowledge and capacity of these critical minerals for uses throughout the value chains and for meeting Canada's climate goals. Reprocessing projects which are funded by CMRDD or GPI will be presented.

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25019: (1974 to 2024) – 50 years of (pyro)metallurgical pilot scale activities at Eramet Ideas for improving nickel operations in electrical arc furnaces

Jonathan Lamboley, ERAMET, Trappes, Yvelines, France

Abstract: Eramet Ideas is the innovation and research center of Eramet, a French metallurgical company producing critical metals such as lithium, manganese, and nickel. Since 1974, when the first pilot-scale operation at Eramet Ideas aimed to replicate phenomena observed in industrial nickel operations, twenty pilot-scale projects have been conducted over the past 50 years on various pilot equipment. Most recently, a dedicated electric arc furnace with a capacity of 700 kW (2.2 m inner diameter) has been used to successfully simulate industrial nickel operations, accurately representing the physico-chemical phenomena involved (thermal, electrical, metallurgical, and fluid dynamics). This equipment has enabled Eramet Ideas to mitigate risks in nickel operations, providing insights into smelter processes and ensuring that various types of nickel ores and reductants can be used without compromising the integrity of industrial smelters. This presentation offers a review of 50 years of Eramet Ideas' piloting capabilities in nickel production.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling

25196: Supercritical fluid extraction for recycling of lithium-ion batteries cathode material

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Abstract: This study explores an innovative approach to recycling valuable metals from NMC black mass in end-of-life lithium-ion batteries using supercritical carbon dioxide (SC-CO_2) as a green solvent. The method integrates a tributyl phosphate-nitric acid adduct and hydrogen peroxide as chelating agents, with hydrogen peroxide playing a critical role in enhancing metal solubility within the SC-CO_2 medium. Key operational parameters, including temperature, pressure, adduct-to-solid ratio, and hydrogen peroxide concentration, are optimized through factorial design experiments. Detailed pre- and post-treatment analyses elucidated the underlying mechanisms of the supercritical fluid extraction (SCFE) process. Under optimal conditions, the method demonstrated exceptional efficiency, recovering over 90% of the target metals. This approach aligns with green chemistry principles by employing CO_2 as a safer, environmentally friendly solvent, reducing reliance on hazardous acids commonly used in traditional processes. The results offer a sustainable, high-efficiency solution for black mass recycling, providing a cleaner, more environmentally responsible alternative to conventional methods in the battery recycling industry.

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25058: Advances In low Grade Gold ore Heap Leaching

Damian Connelly, METS Engineering Group Pty Ltd, Perth, Western Australia, Australia

Abstract: The very high current gold price is seeing waste dumps from 20 years ago being processed with new technology to recover gold by heap leaching. The crush size sensitivities of these ores has meant finer crushing and agglomeration was required to achieve a high gold recovery. High Pressure Grinding Rolls (HPGR) is a newcomer to grinding circuits and offer energy savings, lower media wear and recovery gains which make it hard to resists compared to conventional grinding circuits. In addition the use of ore sorting and gravity pre concentration techniques are discussed to demonstrate how low grade gold heap leach flowsheets are changing. The laboratory small scale and pilot testing is well established and reliable. Scale up and design predictability is reliable. From an operational aspect the ability to change operating pressures and screen apertures offers significant operational flexibility not offered by a SAG mill. In addition the rolls life has greatly increased due to innovation and change out times have shortened. The reliability of HPGR has been shown to be equal to SAG mills. The importance of agglomeration and percolation testing to achieve high gold recoveries is also discussed.

Successful HPGR applications started with cement clinker and then hard iron ores, gold ores and now lithium projects. Recent gold heap leach applications are cited and discussed in detail including operating history.

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25059: The Options For Smelting Nickel Ores and Concentrates

Damian Connelly, METS Engineering Group Pty Ltd, Perth, Western Australia, Australia

Abstract: The rotary kiln electric arc furnace (RKEF) technology consists of three main stages, viz: drying of nickel ore in a rotary dryer (RD), reduction of moisture content in a rotary kiln (RK) and smelting of nickel ore to produce crude FeNi in an electric furnace (EF). To support operations, the smelter is equipped with a coal fired power plant and supporting facilities, including: seawater intake and discharge facilities. The main facilities are drying, rotary kiln reduction, the electric arc furnace to produce ferronickel ingots and slag. Historically these plants operated in Russia, Macedonia, Brazil and China however recently there has been a rapid expansion of RKEF plants in Indonesia. For nickel sulphide concentrates Outokumpu Flash smelting, Inco or Noranda smelting has been used. Converting was done separately but over time the Flash Smelters were modified to produce matte with hydrometallurgical processing of the

matte. More recently Chinese Bottom Blown Furnaces have been developed for smelting base metals including nickel. Going forward all of these smelting processes face challenges with their carbon footprint particularly RKEF.
This paper will look at a number of recent nickel smelting projects.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling

25219: Combination of mechanical and biotechnological process steps for the recovery of valuable metals from black mass from the recycling of lithium-ion batteries

Jens Markowski[1], Claudia Glaser[1], Max Hoffmann[1], Christian Abendroth[1], Harvey Arellano-Garcia[1]
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Abstract: The storage of electrical energy is essential for the intended transformation of the energy industry towards the predominant use of renewable energy sources. Lithium-ion batteries are an approved storage media for mobile and stationary use. There is a need to recycle them and reuse the valuable materials they contain once they have reached the end of life or in the event of defects. In addition to collection and recycling, the new EU-battery regulation also stipulates, that significant quantities of recyclates must be used in the production of new batteries (Regulation 2023/1542 of the European Parliament and of the Council concerning batteries and waste batteries). State of the art in recycling Li-ion-cells are processes in which, after shredding the cells or complete modules, a so-called black mass as main product is processed. In addition to the NMC from the cathode coating (Nickel-Manganese-Cobalt), the black mass from NMC-based lithium-ion cells also contains entrainments (residues of copper, aluminium, plastics, binder, graphite etc.) and cannot be used in new technical applications without special treatment. Actually there are no industrial scale technologies available for cleaning black mass to eliminate the interfering impurities or to separate the valuable metals (esp. nickel and cobalt). Industry-related R/D-projects favour chemical or thermal treatment and combinations thereof.
At BTU different processes for dismantling and recovery of Li-battery components were developed in the last few years. With a combination of several mechanical processing steps and the use of biotechnological methods any remaining impurities (e.g. copper particles) can be completely removed or separated from the black mass and over 70% of the nickel and cobalt compounds contained can be specifically dissolved. The use of indirect bioleaching for the recovery of metal components from the black mass is completely new. Bioleaching originally utilises bacteria that occur free in nature and are harmless to humans and environment to release metals from concentrates or tailings that are low in valuable materials.
A mixed culture consisting of various iron- and sulphur-oxidising bacteria (incl. Ac. ferrooxidans) is used in the bioleaching of black mass. The bioleaching technology was originally developed at BTU for recycling of valuable and precious metals from E-scrap and was now adapted to process black mass. The parameters for bioleaching were optimised in comprehensive tests and the upstream and downstream treatment processes were designed accordingly. Mechanical processing of black mass is demanding, as it is an extremely fine-grained material (D50 between 10-15 µm), which can lead to undesirable effects in the process stages (e.g. agglomeration).
The result of the procedure are metallic products that can be used proportionally in the production of new cells or for other applications. The advantage is the separate solution of the components, which makes it possible to process cells of different ages and from different

manufacturers together in one system.

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25012: Sustainable Process Design through Metallurgical Sample Selection
Mélanie LaRoche-Boisvert[1], Jordan Zampini[2]
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Abstract: Metallurgical testwork plays a key role in the design and development of mineral processing facilities in the mining industry, at all stages of project development. Proper metallurgical testwork on representative samples is crucial to ensure that the mineral processing facility can achieve the recoveries, throughputs, and efficiencies for which it was designed. Without representative sampling, the mineral processing facility may be designed to treat material which differs from the typical types of material coming from mining, resulting in loss of recovery, increase consumable/reagent consumption, or generate bottlenecks that were not anticipated, reducing capacity. Therefore, proper sample selection plays a crucial role in ensuring an efficient process design. Results generated by current metallurgical sample selection methods may be limited or biased and may not properly represent the orebody as a whole or its evolution over time. A new metallurgical sample selection method was developed to address these limitations and ensure a more robust and sustainable design.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling
25235: Effect of Sodium Hydroxide Concentration, Sodium Persulfate Concentration, Temperature and Time in the Leaching of Copper from Cu-As Ore
Bryan Patrick Carrasco[1], Cyrille Aerl Saladaga[1], Arvie Tugawin[1], Candy Mercado[1], Joy Marisol Maniaul[2], Terence Lucero Menor[3]
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Abstract: Philippines is a region rich in metals and minerals resources. The country has an estimated copper mineral reserves amounting to 4 billion. Most of the Cu minerals are in the form of chalcopyrite with pyrite and traces of gold and silver. In recent years, these reserves continue to be depleted and mined deposits become increasingly more complex. This is evident in the occurrence of detrimental element arsenic. It is imperative to develop an efficient method in processing Cu-As ore to be able to cope with the demand for valuable metals. In this study, alkaline leaching of copper is performed. Central Composite Design (CCD) is employed to determine the optimum settings of factors such as NaOH concentration, $Na_2S_2O_8$ concentration, and temperature. The kinetic model for alkaline leaching is proposed. It was found that NaOH and $Na_2S_2O_8$ concentrations and their interaction are the most significant factors. At low persulfate concentration, increasing hydroxide concentration can decrease Cu recovery. At persulfate concentration > 1.64M, Cu is oxidized and will stay in leach solution. At < 1.57M NaOH, there is no significant change in Cu dissolution. Although at > 1.57M NaOH, Cu recovery can be drastically improved. Increasing the leaching temperature from 50-90^{o}C, increases Cu recovery. The predicted optimum parameters for alkaline Cu leaching are as follows: temperature of 85^{o}C, NaOH concentration of 1.05M, and $Na_2S_2O_8$ concetration of 0.99M. Kinetic analysis suggests that alkaline leaching of Cu follows an intradiffusion-product

layer diffusion model. This method of alkaline leaching of copper has the potential to efficiently process Philippine Cu-As ore.

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25182: Towards a Dynamic Optimisation of Comminution Circuit under Geological Uncertainties

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Abstract: Geometallurgical programs are crucial for designing mineral processing plants that maximize comminution throughput. However, the variability of complex ore bodies, such as platinum group element (PGE) deposits, poses challenges in developing these programs into profitable mine-to-mill production. This paper investigates the geological characteristics of different lithologies hosting the complex PGE orebody located in the Northern Limb of the Bushveld igneous complex in South Africa and assessed their impact on metallurgical efficiency in comminution circuits. The regression machine learning techniques were employed to analyse the ore mineralogical dataset from two lithologies (Feldspathic Pyroxenite and Pegmatoidal Feldspathic Pyroxenite) and predict the Bond Work Index (BWI), a key comminution parameter for calculating processing plant throughput. The results indicated that BWI is strongly influenced by chlorite, silicates, iron oxides, and the relative density of the PGE deposit. Using both simulated and laboratory-measured throughput values, a particle swarm optimization (PSO) algorithm was applied to maximize the plant's comminution throughput through tactical blending of low-grade and high-grade ore stockpiles. The PSO algorithm was shown to be an effective tool for stockpile management and tactical mine-to-mill operation in response to feed mineralogical variability. This first-time innovative approach addresses complex geological uncertainties and lays the groundwork for future geometallurgical studies. Potential areas for further research include incorporating additional lithologies for tactical ore stockpile blending and optimizing parameters critical for ore mineral flotation.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling

25262: Cement decarbonization by co-production of OPC, SCM and SGA from silicates

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Abstract: The production of cement alone accounts for 8% of global CO_2 emissions due to the use of CO_2-bearing limestone ($CaCO_3$) as a feedstock and high process energy requirements. Addressing this challenge requires a solution governed by the laws of thermodynamics and capitalism, where lower-cost options replace higher-cost ones. Approaches such as carbon capture and storage (CCS) are too expensive, while novel materials carry high perceived risk, making decarbonizing the existing process the most viable option. To enhance the economics of producing OPC, the only scalable option is co-production with another high-demand commodity. Brimstone has developed a breakthrough, deeply decarbonized process to co-produce ordinary Portland cement (OPC), supplementary cementitious material (SCM), and smelter-grade alumina (SGA) from carbon-free calcium silicate ores instead of limestone. Metallurgy is at the heart of Brimstone’s process, which involves leaching calcium silicate rocks, followed by selective precipitation of calcium and aluminum-rich products, and thermal treatment to produce OPC and

SGA. This presentation will discuss Brimstone's approach to decarbonizing cement and lessons learned during pilot plant operations.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling

25243: From Tradition to Innovation: Establishing Circularity in the Lifecycle of Metals Products

Mélanie Kahle, Hatch, Montreal, QC

Abstract: Metal recycling has been practiced for centuries, with single-material objects such as iron, copper, and aluminum being reclaimed throughout history. However, as society progresses, the complexity of metal-based products—ranging from electronics to lithium-ion batteries—has introduced significant challenges to recycling efforts. The lag between the production of these advanced materials and the implementation of recycling systems underscores the need for forward-thinking in technological and systemic innovation. This presentation explores the evolution of metal recycling, contrasting historical practices with the intricacies of modern-day material recovery. It highlights the importance of factors such as perceived value, accessibility of collection systems, and technological readiness in driving recycling adoption. With a focus on emerging streams like electronic waste and critical metal-based components, we examine how systems thinking and technology can enable recycling even in highly complex systems, emphasizing the importance of establishing circularity early in the lifecycle of new products. This session will engage stakeholders across mining, metallurgy, and recycling to foster a multidisciplinary approach to building a sustainable and resilient metals value chain.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling

25070: Sustainable Ironmaking Using Iron Segregation Roasting

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Abstract: Iron segregation is pre-dated by copper and nickel segregation processes, where the experimental methodology and reaction chemisty are established. The accepted reaction sequence for segregation involves the generation of hydrogen chloride, the chloridization and volatilization of the metal chloride, and then the precipitation of the metal from the metal chloride in the vicinity of carbon.
Iron segregation roasting offers a potential extraction solution for processing oxide deposits with complex mineralogy or waste streams such as; Minette-type iron deposits, nickel laterites, ilmenite, red mud, electric arc furnace (EAF) dust, mill scale, and slag. After subsequent magnetic separation, one is left with a high-purity metallic iron powder, which can be marketed for powder metallurgy or briquetted to serve as a direct reduced iron (DRI) product. The non-magnetic portion, depending on the initial feed material, will be concentrated oxides, including: synthetic rutile, alumina, material suitable for green cement, or simply concentrated values of vanadium, phosphorus, rare earths or other critical minerals, that may be economically recoverable with subsequent processing.
Iron segregation roasting also lends itself well to decarbonization, as the reactor type is ideally an indirect-fired kiln or screw conveyor furnace, in order to contain the volatile chlorides, which

act as a transport catalyst within the reactor. Therefore, an electrically heated reactor can take advantage of a renewable electrical energy source. Additionally, microwave heating has also been tested with success for segregation roasting as the materials involved are susceptible to microwave radiation.
Unlike the coke required to maintain bed stability and reducing properties in traditional blast-furnace ironmaking, iron segregation roasting can use different types of renewable biochar/biocoal, as the bed is not fluidized. Additionally, hydrogen injection at the end of the process can increase metallization and further reduce the amount of carbon necessary for ironmaking. Although the exact ratios have not been optimized, the concept has been proven. While iron segregation roasting has been tested only 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.
An additional benefit that comes from the transport catalyst phenomenon is that comminution energy requirements can be significantly reduced by avoiding the necessity of fine grinding since the iron is transported away from the gangue material. In turn, capital expenditures can also be reduced in this case, as substantially less grinding equipment is needed. By eliminating the need for wet-grinding and if subsequent physical separation is carried out on a dry basis, there would not be a need for any process water.
Testwork performed by the authors shows promising results that may aid in future development of the process. Segregation roasting of iron will likely never displace traditional beneficiation and ironmaking technologies; however, it has great potential in niche markets where a premium exists for green steel or high-purity iron, current technologies generate substantial waste, and traditional technologies have failed.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling
25183: Hydrogen direct reduction: pellets vs. briquettes
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Abstract: Hydrogen ironmaking is becoming increasingly important in the field of scientific and industrial research. In particular, direct reduction proves to be an extraordinarily effective system for reducing harmful emissions in the steel sector. Naturally, the efficiency of the entire process is strongly linked to the type of agglomeration of the ferrous minerals. This work is dedicated to the analysis of the direct reduction of pellets or briquettes in a reducing atmosphere containing hydrogen. Naturally, we demonstrate that depending on the porous structure of the agglomerated minerals, the reducibility and level of metallization change considerably. In addition, carburization levels also tend to change, for the same process condition, depending on the agglomeration state. Here we propose a numerical-experimental model developed through finite element calculations supported by a detailed kinetic analysis for the prediction of the best direct reducibility conditions.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling
25247: A family portrait of lanmodulin selectivity for enhanced rare-earth separations

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Abstract: Proteins offer a novel molecular design space to create bespoke ligands for the sustainable separation of critical metals, like rare earth elements. However, data-intensive approaches to fine-tune their selectivities are bottlenecked by the low-throughput nature of existing methods. We invented an assay called SpyCI-LAMBS to measure metalloprotein selectivities en masse. This 96-format workflow was used to study the selectivity of 621 lanmodulin (LanM) orthologs for 15 rare earth elements, revealing eight distinct selectivity profiles based on sequence-to-function analyses. We discovered >200 LanMs with greater rejection of low-value La^{III}/Ce^{III} relative to the prototypical LanM. This includes a new LanM capable of performing a challenging all-aqueous one-stage separation of technologically critical Pr^{III} from La^{III} at 99.97 mol% purity and 83.16% yield. SpyCI-LAMBS is a powerful tool for metalloprotein design, enabling rapid collection of high-fidelity selectivity data to inform metal ion separations and machine learning assisted metalloprotein design.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling

25073: Rapid microwave-assisted leaching for the recovery of lithium from pegmatite heaps containing mixture of lepidolite and zinnwaldite

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Abstract: Interest in lithium-bearing clay minerals has significantly surged in the past few decades due to the growing demand of the lithium-ion battery (LIBs) market, despite the challenges posed by their low grades and complex mineral compositions. Lepidolite and zinnwaldite are among the primary lithium-bearing clay minerals found in nature, with Li_2O content ranging from 1.2% – 5.9% and 2% – 3%, respectively. However, current industrial extraction methods, such as acid roasting, alkaline treatment, and carbonate roasting, are energy-intensive and have a marked environmental impact. Herein, we propose an alternative low-temperature and highly efficient process to extract lithium from the mines of *Pegmatitica*, Portugal. Firstly, the mine tailing samples containing zinnwaldite and lepidolite phases were treated with HCl under microwave heating. The influence of various parameters such as HCl concentration, temperature, solid-to-liquid ratio, leaching duration, and particle size on lithium leaching was studied systematically. Under optimal conditions, more than 95% of lithium was leached into the solution. Microwave leaching with HCl offers the advantage of exceptional selectivity against silicate impurities. Furthermore, the extraction kinetics was rapid, with nearly complete extraction within one hour. Compared to direct leaching, microwave-assisted leaching has 70% low acid consumption.

Subsequently, ammonium benzoate was added to the leachate to selectively precipitate the co-extracted aluminium as $C_{21}H_{15}AlO_6$. The pH and the amount of ammonium benzoate were optimized to remove > 94% of aluminium from the solution. The ammonium benzoate precipitation method offers a significant advantage by obviating the separation of metals from the precipitating agent prior to the subsequent precipitation of Li_2CO_3. Furthermore, this approach effectively prevents the formation of invaluable salts, such as NaCl and KCl. The remnant leachate with > 95% lithium will be subsequently treated using solvent extraction to further purify the leachate solution. Finally, the battery-grade precursor of lithium carbonate will be obtained by an electrolysis step with concomitant regeneration of HCl and NH_3 gas.

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25248: Optimized Acid Leaching of Ultramafic Nickel Tailings for Indirect Mineralization of CO2

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Abstract: The extraction of divalent metals from ultramafic mine tailings offers a promising pathway for large-scale CO_2 sequestration. This study explores the acid leaching of ultramafic nickel tailings, rich in magnesium silicates, using hydrochloric acid and citric acid to evaluate their efficiencies under varying conditions. Key variables included acid concentration (0.5–2 mol/L), solid-to-liquid (S/L) ratio (0.01–0.5 g/mL), temperature (25–65°C), and multi-stage leaching. HCl demonstrated higher metal extraction efficiency, particularly for magnesium (Mg) and iron (Fe), due to its strong acidity and higher mineral breakdown capability. Citric acid, though weaker in acidity than HCl, effectively leached Mg with a reduced sensitivity to acid concentration. Efficiency declined with increasing S/L ratio, linked to reduced contact between leaching agent and solid and increased slurry viscosity. Temperature influenced leaching differently across the two acids: while HCl's leaching efficiency decreased for some metals at higher temperatures due to their precipitations, citric acid benefited from elevated temperature, enhancing leached metal complexation and solubility. Multi-stage experiments revealed diminishing returns after the first stage, attributed to accessible metal depletion and passivating layer formation. Mg extraction decreased notably from 23–24% in the first stage to 3–5% in later stages. Mineralogical analyses indicated the persistence of lizardite, partial brucite dissolution, and increased magnetite formation, highlighting selective mineral dissolution. These findings demonstrate the feasibility of HCl for rapid and broad-spectrum metal extraction, while citric acid provides an environmentally friendly alternative. Insights from this study advance the optimization of acid leaching conditions for indirect CO_2 mineralization, paving the way for sustainable mining practices and scalable carbon sequestration technologies. Future research will focus on leveraging the resulting leachates for effective CO_2 capture.

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25253: A Design Of Experiments Investigation Into Lithium Extraction By Phosphoric Acid Leaching Of Spodumene

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Abstract: Lithium is expected to remain in demand in the long term, due to its critical role in state-of-the-art lithium-ion batteries. However, the process steps involved for lithium recovery from the primary lithium-bearing mineral, spodumene, remain complex and energy-intensive. Preliminary results have shown that leaching β-spodumene with phosphoric acid at atmospheric pressure allows for selective extraction of lithium while leaving a delithiated residue, like what is observed following conventional sulphuric acid roasting. However, the process appears to be limited, with less than 50 % of the total lithium being extracted after 8 h of residence time, and a marginal increase after a total residence time of 24 h. The statistical method of response surface

methodology was used to model the second-order interaction effects of the leaching system. A four-factor central composite design was applied to evaluate and optimize the phosphoric acid concentration (2 – 8 M), leaching time (2 – 12 h), liquid-to-solid ratio (2 – 8 mL/g), and temperature (55 – 95 °C) for selective lithium extraction. Analysis of the model derived from the data indicated that temperature and residence time are the only statistically significant factors driving leaching performance. The effects of temperature alone account for 85 % of the variation in lithium extraction, with leaching time accounting for a further 8 %. Acid concentration and liquid-to-solid ratio are insignificant. The optimal conditions (2 M, 12 h, 2 mL/g, 95 °C) resulted in lithium extraction that was still below 50 %. However, by increasing the temperature beyond what was possible at atmospheric conditions, higher extraction was observed. Increasing the temperature to 180 °C in a pressurized vessel resulted in greater than 85 % lithium extraction. With further optimization and understanding of the leaching mechanism, phosphoric acid could prove to be a suitable alternative for selective lithium extraction from spodumene.

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25080: Transforming Carbon Dioxide into Valuable Magnesium-Based Materials

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Abstract: The rising urgency of climate change requires innovative approaches to mitigate carbon dioxide (CO_2) emissions. Addressing innovative challenges needs technologies that not only reduce CO_2 emissions but also repurpose CO_2 into valuable resources. Such technologies are broadly classified as carbon capture and utilization (CCU) technologies, which can be further divided into organic and inorganic CCU processes. The inherent stability of CO_2 in organic CCU processes necessitates the use of highly efficient catalysts. This requirement poses significant challenges for commercialization and industrial-scale applications, as it involves costly and time-intensive development efforts. In contrast, inorganic CCU processes, such as ex-situ CO_2 mineralization, are more scalable and do not require additional energy consumption or the use of catalysts. In ex-situ mineralization CO_2 reacts with solid materials—often industrial waste streams—to produce carbonates, offering great promise for sustainable applications. These technologies align with circular economy principles by transforming solid waste streams into functional and sustainable materials for industrial use.
This presentation focuses on utilizing serpentine tailings—a magnesium-rich mining byproduct solid waste stream—as a feedstock for ex-situ carbonation and exploring pathways to produce high-purity magnesium-based materials. In this process, serpentine tailings react with CO_2 under controlled conditions to yield carbonate intermediates, which are further processed into micro- and nanostructured magnesium-based products. Comprehensive characterizations have revealed that these materials exhibit high purity (95%–98%), desirable morphologies (e.g., whisker-like and flower-like structures), and optimized structural and textural properties, including high crystallinity (>98%), and surface areas ranging from 50 to 150 m^2/g. These features contribute to significant CO_2 utilization efficiency and enable a wide range of potential industrial applications such as flame retardant agents, fillers for composites and nanocomposites, and materials for energy storage & conversion.

Keywords:
Carbon dioxide utilization, magnesium materials, serpentine ex-situ mineralization, sustainable materials.

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25084: Phase equilibria in the NaO0.5-SnO-SnO2-SiO2 system

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Abstract: Integrated experimental and thermodynamic modelling study of the phase equilibria in the $NaO_{0.5}$-SnO-SnO_2-SiO_2 system in air as well as in equilibrium with liquid metal has been undertaken for better understanding the thermochemistry of slag in smelting side streams enriched in Sn and optimising the fuming process. New experimental phase equilibria data at 1100-1610 °C in air, and at 610-1300 °C in equilibrium with liquid metal were obtained using high-temperature equilibration of synthetic mixtures with predetermined compositions in sealed silica ampoules or in Re / Pt-Ir foils, a rapid quenching technique, and electron probe X-ray microanalysis of the equilibrated phase compositions. Phase equilibria and liquidus isotherms in the quartz/tridymite (SiO_2), cassiterite (SnO_2), sodium silicate (Na_2SiO_3), sodium stannate (Na_2SnO_3) primary phase fields in the $NaO_{0.5}$-'SnO'-SiO_2 and $NaO_{0.5}$-'SnO_2'-SiO_2 systems were revealed. New experimental data were used to develop the thermodynamic database describing these ternary systems.

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25086: Pulverization and Inactivation of Small Electrical Devices Containing Lithium-ion Batteries by Electrical Pulsed Discharge in Water for a Safe and Novel Recycling Process

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Abstract: The demand for lithium-ion batteries (LiBs) is expected to increase. Although in-vehicle LiBs account for a large proportion of these devices, the increase in the use of small electrical devices cannot be ignored. Since the EU battery regulations came into force, there has been an urgent need to improve the recovery and recycling rate of spent LiBs. Technological improvements to reduce energy consumption and costs should be continued. In particular, recycling nickel-cobalt-manganese oxide ternary cathode materials is essential for a sustainable supply of elements. Although there are many research papers on LiB recycling technology, most of them focus on electrode sheets and cathode materials after they have already been removed from the cells. Very few research papers mention processes that overcome the hazards of discharging and deactivation of charged LiBs. Numerous fires and incidents of LiBs in waste treatment facilities have endangered workers and caused considerable economic losses. This also means that the LiBs that cause such fires are not on proper recovery routes, which is also a problem with recycling. Furthermore, it is very difficult to remove LiBs because many LiBs are embedded in electrical devices. Therefore, manual disassembly and sorting are often required in waste-treatment facilities. A process should be developed to deactivate LiBs and safely recycle the battery material. Both processes should be connected seamlessly.

Pulverization by high-voltage electric pulsed discharge in water is known as the electrical disintegration (ED) method, and commercially available setup machines are available. Owing to

the pulsed current, this method consumes less energy than crushing or heating with conventional equipment. In this study, crushing and deactivation in water using the electrical pulsed discharge method were conducted simultaneously without generating fire or dangerous heat.

A small portable electric fan (called "handy-fun," 1,400 mAh, 3.7 V) that is widely available in Japan was fully charged and placed in an electric pulse device (Impuls Tec GmbH). When continuous electric pulses were discharged at 40 kV to the chamber filled with 20 L of water, the outer plastic casing was crushed less than 20 times, and the battery part was exposed. A voltage drop to 2.5 V was observed after 500 discharges, and complete discharge was confirmed by placing the LiB in water. Although the LiB was embedded inside the handy fan and could not be removed, it was possible to crush and deactivate it by electric pulse discharge without contact. In addition, even when the electric pulse was discharged in a fully charged state, there was no fire or noticeable rise in the water temperature. This result suggests that crushing and deactivation proceeded while preventing short circuits due to metal contact and rapid reactions with oxygen in the air. This method allows for avoiding the dangerous processes of manually removing LiBs. In addition, because all the components of crushed LiB are present in water, it is possible to proceed to the wet process and hydrometallurgy seamlessly. The filtration of water also makes it a possible dry process.

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25088: Towards Sustainable Phosphate Mining: Reducing Energy, Water, and Carbon Footprint

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Abstract: Phosphate is a vital resource for numerous industries and sectors, including energy transition, medicine, and food security. However, phosphate mining and processing present significant challenges due to their inherently energy- and water-intensive nature. These challenges are compounded by the growing need to reduce carbon emissions and address the environmental impacts of production, particularly in regions affected by climate change and water scarcity. This study investigates the key areas of energy consumption, CO_2 emissions, and water usage within a phosphate mine. It introduces new scenarios for optimizing water and energy consumption. These scenarios build upon previously developed phosphate waste reduction models and are structured into a three-tier framework. The first-tier addresses phosphate material flows, the second models energy consumption, and the third designs a water consumption flowsheet. The three sub-models present an integrated optimized model for producing phosphate with less waste, less conventional energy, and less water.

A system dynamics simulation employing a hybrid model is used to analyze real-time water and energy consumption over a one-year period. Predictive modeling further estimates the environmental benefits of proposed interventions. The study simulates both the current state and potential outcomes of transitioning to renewable energy sources and reducing water usage.

The findings reveal that the mining fleet is the largest contributor to CO_2 emissions. Consequently, scenarios are explored to transition the fleet's energy source from traditional fuels to hybrid, electric, or hydrogen-based energy. Results indicate that CO_2 emissions can be

significantly reduced through these transitions. Additionally, replacing conventional water sources with recycled water and optimizing water usage can alleviate water stress in the mining region, which is situated in an arid zone.
The study highlights pathways to achieving a more sustainable phosphate production chain, offering defined actions for reducing environmental impacts and enhancing the sustainability of the mining sector.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling
25090: Coupled thermodynamic modeling and experimental study of the In2O3- and GeO2-containing systems
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Abstract: Indium and germanium are rare and critical metals mainly used in production of transparent conductive oxides for flat panel displays, semiconductors, fiber optics and solar panels categorized as highly important products in electronic and telecommunication industries. Their concentrations in the Earth's crust are approximately 200 ppb and 1.5 ppm, respectively, making them exceptionally scarce despite their increasing demand. In addition, there are no specific natural minerals for these metals and they usually exist non significantly in minerals enriched in zinc, lead and sometimes copper. Due to this geological characteristic In and Ge are being recovered as by-products of above mentioned basic metals, with current recovery rates remaining very low ending up to industrial wastes such as slag and dust. Knowledge of thermodynamics is of utmost importance for maximizing the indium and germanium recovery rates, reducing the process residues from the primary production, and designing and developing environmentally neutral and economically viable recycling processes. However, the relevant thermodynamic data of indium/germanium-containing systems are inadequate or missing in the literature. This research project, therefore, focuses on developing new thermodynamic and phase equilibrium data for In2O3-GeO2-containing systems using CALPHAD© (CALculation of PHAse Diagram) approach. The system of study, PbO-ZnO-CaO-SiO2-GeO2-In2O3, was defined based on the most prevalent resources for the production of these metals. All the literature data was collected to construct the thermodynamic models, and preliminary optimization of model parameters was conducted. Key phase diagram experiments were identified in each binary system to validate and refine the thermodynamic models and their parameters. These experiments were performed using static equilibrium-quenching followed by phase analysis and dynamic differential thermal analysis-thermogravimetry. This work presents the results of thermodynamic modeling and experiments conducted to date, along with a discussion of experimental challenges encountered in measuring these systems and potential solutions to address them.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling
25186: Towards zero-waste mine exploitation: co-recovery of F, REEs, and phosphorus from an apatite concentrate
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Abstract: The mining industry is a major contributor to the Canadian economy, providing raw materials that are essentials for industrial activities and our everyday lives. However, the exploitation of mineral resources produces large amounts of solid wastes that must be managed adequately. The co-valorization of critical and strategic elements (CSEs) from processing plant residues is becoming a promising approach to reduce the amount of problematic mine residues, while maximizing resources uses and diversifying sources of CSEs worldwide.
This study investigated the performances of inorganic acid leaching to solubilize CSEs (i.e., F, REEs and P) from a fluorapatite concentrate originated from an active deposit of ilmenite. First, a detailed physicochemical and mineralogical characterization was performed. Then, leaching experiments were conducted on 30 g of fluorapatite mixed with 300 mL of leaching solutions at a constant agitation. The effect of operating parameters, including the type (i.e., H2SO4, HNO3, HCl) and concentration (from 0.5 to 8 N) of the leaching solutions, has been evaluated. Additionally, the effect of temperature (ambient vs 80°C) and agitation time (from 10 to 180 min) on the solubilization of targeted CSEs was assessed using a parametric approach. Solid/liquid separation was performed by vacuum filtration, liquid and solid samples were collected for further analysis by ICP-OES. Solid samples (i.e., concentrate, leaching residue) were digested using borate fusion with 10% HNO3 prior to ICP-OES analysis. Fluoride analysis was conducted using a fluoride-selective electrode (HI 4110).
Chemical analysis showed that the fluorapatite concentrate was mainly composed of P2O5 (40.8%), Ca (39.5%) and F (2.13%). While non-negligible concentrations of REEs (0.22%) mostly light rare earth elements (LREE) were found. XRD analysis confirmed the presence of fluorapatite, while indicating small amounts of ilmenite (FeTiO3). Preliminary leaching results showed that the use of HCl and HNO3 was highly efficient in solubilizing REEs, achieving 99% efficiency at an acid concentration of 3 N, at room temperature, after 2 h of agitation. However, nitric acid was eliminated from further experiments due to its high cost and extensive bibliographic research. Sulfuric acid showed limitation in solubilizing REEs with a maximum efficiency of 28% at a concentration of 2 N due to the formation of gypsum. Kinetic tests showed that the equilibrium was reached after 180 min for HCl and 120 min for H2SO4. An increase in temperature (from ambient to 60°C) showed an improvement in P and F recoveries in the presence of H2SO4, while REE and Ca efficiencies and kinetic remained similar. The best performing conditions were identified as following: HCl (2.5 N), room temperature, agitation of 3 h, resulting in up to 96% REE, 100% phosphorus, 99% calcium, and 92% fluorine solubilization. Further experiments on the use of resin-in-leach using sulfuric acid are underway to improve the recovery of REEs prior their losses in gypsum through co-precipitation or encapsulation.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling
25096: Integrated Energy System Modelling for Decarbonization of Heavy Industries
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Abstract: Decarbonization of heavy industries represents a significant challenge in net-zero

energy transition pathways, as emerging technology solutions are often expensive, equipment with long lifetimes may present rare opportunities for replacement, and mining areas are typically remote and lack access to energy infrastructure. Modelling of industries within broader integrated energy system models is critical for planning feasible net-zero pathways, however, the diversity and complexity of industrial processes makes this challenging. In the North American TIMES Energy Model, an economy-wide optimization model, the mining and metallurgical sectors have been modelled with their major processes and a range of emerging technology solutions – including the production and transmission of electricity, hydrogen, and other clean fuels. We explore the optimal decarbonization pathways for processes and end-uses in these sectors under different transition scenarios – including technologies such as trolley assist for electric trucks, hydrogen fuel-cell vehicles, hydrogen use in direct reduction iron furnaces and in boilers, along with the deployment of the associated infrastructure.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling
25022: Using Bio-Based Frothers in Froth Flotation
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Abstract: With a growing emphasis on ESG initiatives, there is significant potential for companies to lead with environmentally friendly and sustainable solutions. Integrity Mining and Industrial (IMI) leverages its renewable carbon index (RCI) to classify the carbon origins in its biopolymer-based products, highlighting their sustainable, renewable sources versus petroleum derivatives. This approach supports IMI's mission to provide eco-friendly mining solutions without compromising performance. IMI's TegraFroth, a bio-based frother, offers a sustainable alternative to leading synthetic frothers while meeting environmental regulations. Initial testing across copper, potash, and gold mines demonstrated that TegraFroth matched or exceeded performance, showing no negative impact on metal recovery or grade when compared to industry-standard frothers. These results position TegraFroth as a promising option for sustainable mineral processing.
Building on this success, IMI plans additional flotation trials in early 2025. Potash and copper flotation trials are scheduled for Q1 2025. The outcomes of these trials will be presented to further validate TegraFroth's performance against alcohol-based frothers, propylene glycol, and other glycol ethers. This ongoing research underscores IMI's commitment to advancing sustainable mining practices and providing the industry with innovative, eco-friendly solutions.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling
25104: Graphite Recycling from Spent Lithium-Ion Batteries: An Integrated Approach to Address Supply Chain Challenges and Enhance Material Recovery
Yvan Teddy Chegang Kwebou, McGill University Department of Materials Engineering, Saint-Hubert, QC

Abstract: As the global transition to renewable energy and electric vehicles accelerates, the demand for lithium-ion batteries (LIBs) and their critical components, particularly graphite, is surging. Graphite, a vital material for LIB anodes, accounts for up to 20% by weight of a typical LIB and is indispensable for its electrochemical functionality. In 2023, the global demand for LIBs exceeded 700 gigawatt-hours (GWh), with forecasts predicting a sharp increase to 4,700

GWh by 2030 and a further rise by 2050, driven by EV adoption and renewable energy storage systems. The global graphite market, valued at approximately USD 54 billion in 2023, is expected to reach USD 182 billion by 2030, highlighting its critical role in this transition. Currently, China dominates over 60% of the global graphite supply chain, including mining, processing and purification. Recent restrictions on graphite exports by China have further underscored vulnerabilities in the supply chain, emphasizing the need for sustainable recycling solutions to secure domestic supplies of critical materials and reduce geopolitical dependencies.
This study presents an innovative, multi-step recycling process to regenerate high-purity graphite from spent LIBs, combining physical separation, hydrometallurgical treatment, and high-temperature graphitization. Initial physical separation utilized shaking table stratification followed by Dense Medium Separation (DMS) or Falcon centrifugal separation to exploit density differences between graphite and metallic impurities, such as copper and aluminum from current collectors and silicon from graphite-silicon composite anodes. These stages efficiently removed bulk impurities, reducing the chemical load required in subsequent processes.
Hydrometallurgical leaching using phosphoric acid (H_3PO_4) effectively targeted residual contaminants bonded within the graphite structure, such as lithium, fluorine, and phosphorus, which originate from the solid electrolyte interface (SEI) and decomposed electrolyte salts. Phosphoric acid was selected over alternative acids, such as hydrochloric acid (HCl) or sulfuric acid (H_2SO_4), due to its lower corrosivity, reduced environmental impact, and ability to be recovered and repurposed, enhancing the sustainability of the process. Following the leaching stage, the H_3PO_4 was recovered in the form of sodium phosphate (Na_3PO_4), a high-value compound commonly used as a fertilizer. This not only reduces the chemical waste generated but also creates an additional revenue stream, demonstrating the circular potential of the process.
High-temperature graphitization further completed the recycling methodology by restoring the graphite's crystalline hexagonal lattice, optimizing interlayer spacing to 0.335 nm, and eliminating remaining volatile impurities. The synergy between phosphoric acid leaching and graphitization ensured both the chemical and structural restoration of the graphite, yielding a regenerated material with high purity and enhanced stability, suitable for lithium-ion battery applications. The dual advantage of impurity removal and resource recovery underlines the environmental and economic viability of this innovative recycling approach.
Impurity quantification using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) revealed significant reductions in contaminants, including copper, fluorine, phosphorus, lithium, and aluminum. Carbon content increased from 97.4% to 99.8% following the leaching step. Complementary characterization techniques, such as XRD, SEM-EDS, and XPS, confirmed impurity removal and structural restoration, validating the process's ability to regenerate high-purity graphite suitable for LIB anodes.
This research demonstrates that graphite recycling can effectively reduce dependency on primary graphite sources, mitigate environmental impacts, and secure critical material supplies for the global energy transition. With LIB-grade graphite requiring a purity of at least 99.5%, this process exceeds industry standards, ensuring the recycled graphite meets performance requirements. The presented methodology not only aligns with the growing demand for sustainable electrification but also provides a scalable, environmentally friendly pathway for LIB recycling, ensuring supply chain resilience in an era of increasing material scarcity.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling
25106: Mineral Residue Management in The Extraction of Lithium from Spodumene

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[1]Hatch, Montréal, QC, [2]Hatch Ltd., Montreal, QC, [3]Hatch, Montreal, QC

Abstract: Growing global demand of battery applications has sparked the race for lithium production. Quebec (Canada) has been garnering the attention of key battery players in the lithium industry in recent years due to economically viable renewable green energy, proximity to natural resources and the US market, and government support to rejuvenate the economy of Quebec. Though attention has been focused on the production of lithium, the lithium refinery residue (LRR) should not be overlooked as solutions to its disposal or revalorization significantly affect the business case and social acceptability. The focus of this paper will be to cover: a brief overview of lithium production from spodumene concentrate, a summary of the LRRs generated, and current residue management strategies in Quebec and globally.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling
25108: Strategies and Hubs: Catalyzing Canada's Battery and Magnet Value Chains
SOSTHENE UNG, The Transition Accelerator, Montreal, QC

Abstract: The global transition to clean energy has highlighted the strategic importance of critical minerals for emerging technologies, particularly EV batteries & magnets and, more broadly, energy storage. This talk will present insights from two initiatives involving the Transition Accelerator and its partner organizations, such as the Battery Metals Association of Canada and the Energy Future Labs, to strengthen Canada's position in the critical minerals and battery and magnet value chain. The first project is Critical Mineral Strategies for Canada's Battery and Magnet Value Chain, which provides a comprehensive analysis of Canada's capacity in key minerals, including lithium, nickel, graphite, iron, phosphate, rare earth elements, vanadium, and copper. This roadmap highlights opportunities for scaling domestic production, refining capacities, and processing infrastructure to meet projected EV demand. Within a sustainability framework, it evaluates market trends, supply chain gaps, opportunities for synergies, circularity and the regulatory landscape, offering actionable recommendations for federal and provincial policymakers.
The second initiative focuses on establishing a Western Canadian Battery Hub, emphasizing an integrated supply chain from mine to battery cell production. Targeting Alberta, Saskatchewan, British Columbia, and Manitoba, this project explores the potential for coordinated development of critical mineral extraction, processing, cathode/anode production and battery manufacturing. The hub aims to align with North American battery supply chain goals while promoting economic and environmental resilience by leveraging regional industrial clusters, clean energy resources, and domestic assets.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling
25109: Linear Regression Model and Response Surface Analysis for Selective Lithium Extraction from Industrial Lithium-Ion Battery Waste
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Abstract: This study focuses on industrial-grade lithium-ion battery waste and explores a direct, efficient, and highly selective leaching process for lithium recycling. The main challenge lies in the complex composition of battery waste, which includes $LiFePO_4$ powder, graphite powder, copper (aluminum) foil fragments, and trace impurities from other types of batteries, such as nickel, cobalt, and manganese. Orthogonal experiments and linear regression analysis were used to systematically evaluate the effects of key factors on lithium leaching efficiency and selectivity. The individual and interactive influences of these factors were analyzed, providing a solid theoretical basis for optimizing experimental design and production processes. To further refine the process, response surface analysis was employed, revealing trends in leaching efficiency and selectivity under varying conditions. This approach also identified a reasonable range of experimental parameters, offering guidance for precise process control. The consistency between predictions and experimental results validated the reliability of the models. Optimal conditions were determined as 0.2 mol/L formic acid, 2% v/v hydrogen peroxide, and a liquid-to-solid ratio of 18 mL/g. Under these conditions, lithium leaching efficiency exceeded 99%, while the leaching efficiency of impurities, such as iron, nickel, cobalt, manganese, copper, and aluminum, remained below 1%. This demonstrates excellent leaching selectivity. Furthermore, the linear regression model predicted the optimal conditions to achieve both high lithium recovery and outstanding selectivity. This interdisciplinary effort, integrating theory, experimentation, and engineering, significantly contributes to advancing lithium-ion battery recycling technologies.

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25189: Evaluation of MgO solubility in MgF2 – LiF and MgF2 – LiF – MF2 (M = Ca, Ba) at 1053 – 1203 K

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Abstract: Recently, high-purity magnesium (Mg) metal has been produced from magnesium oxide (MgO) via molten salt electrolysis and vacuum distillation. Because the electrolysis of MgO is conducted in magnesium fluoride (MgF_2) – lithium fluoride (LiF) molten salt at 1053 K, the solubility of MgO in fluoride-based molten salts is crucial. This study investigates the influence of time, temperature, and composition of molten salts, such as MgF_2 – LiF, MgF_2 – LiF – calcium fluoride (CaF_2), and MgF_2 – LiF – barium fluoride (BaF_2), on the solubility of MgO. Before the experiments, the oxygen (O) concentration in the salt was reduced to below 88 ppm via electrolysis at high temperatures by removing oxide impurities. The solubility of MgO in MgF_2 – LiF, MgF_2 – LiF – CaF_2, and MgF_2 – LiF – BaF_2 molten salt at 1053 K was saturated to 0.210, 0.188, and 0.148 mass%, respectively, after 30 h. In addition, the solubility of MgO at 1053 K decreased with increasing concentrations of CaF_2 or BaF_2 in the molten salt. Furthermore, at 1203 K, the solubility of MgO in MgF_2 – LiF molten salt was increased, reaching 0.264 mass%. The study results provide a deeper understanding of the molten salts used in the novel Mg production.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling

25111: Managing Liquidus Temperatures of Ni Smelting and Refining Slags by Adjusting Their Compositions

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Abstract: Nickel production has seen substantial growth in recent years, driven by increasing demand for nickel in the manufacture of electric vehicle batteries, nickel-based superalloys, and stainless steels for special purposes. The majority of nickel is sourced from laterite ores of saprolite or limonite types, which constitute around 70% of world's nickel resources. Saprolites are processed into ferronickel through drying, calcination and smelting processes. The resulting iron-silicates smelting slags exhibit high melting temperatures (exceeding 1550 °C) due to significant concentration of MgO (up to 20 wt.%). Introduction of recycled lithium-ion batteries and other e-waste into primary nickel smelting can be economically beneficial but will result in high levels of Al_2O_3 in slags from aluminium casings and ceramics. If poorly managed, this will result in higher liquidus temperatures and viscosities. Addition of CaO as a flux allows extra flexibility in slag chemistry but makes the system even more complex. A detailed understanding of high-temperature phase equilibria in these multicomponent slags is essential for optimising the processes
The integrated experimental and thermodynamic modelling approach has been applied to investigate phase equilibria in Ni smelting and refining slags. It includes thermodynamic modelling of the multicomponent slag systems, such as $FeO-Fe_2O_3-SiO_2-NiO$, $NiO-Al_2O_3-SiO_2$, $FeO-SiO_2-NiO-Al_2O_3$ and $FeO-SiO_2-NiO-MgO$. The improvement of the thermodynamic models relies on generated experimental data on high-temperatures phase equilibria. The experimental technique involves high-temperature equilibration of the predetermined mixtures, quenching and electron probe X-ray microanalysis (EPMA) of the samples.
Key outcomes of this work include verified phase diagrams for these systems at high temperatures in equilibrium with ferronickel. Liquidus projections and isothermal sections were constructed, and the distribution of nickel among liquid slag, metal, and solid oxide phases was determined. Additionally, the effects of fluxing agents on liquidus temperatures were quantified. This research is a part of a larger project dedicated to complete thermodynamic description of the gas-slag-matte-speiss-metal-solids equilibria in the Cu-Pb-Zn-Fe-Si-O-S-(Al_2O_3-CaO-MgO-Cr_2O_3)-(As-Sn-Sb-Bi-Sn-Au-Ni-Co-Na) system. The findings are relevant to pyrometallurgical processes in Cu, Pb, Zn and Ni pyrometallurgy.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling

25190: Development of the Direct Titanium Hydride Powder Production via Magnesiothermic Reduction of Titanium Dioxide in a Hydrogen-Mixed Gas Atmosphere

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Abstract: The Kroll process, a conventional method for producing high-purity Ti metal, has drawbacks such as low productivity, high energy consumption, and toxic chlorine gas usage. Recently, the production of low-oxygen Ti metal from TiO_2 through reduction followed by deoxidation using Mg in an H_2 atmosphere has been developed to overcome the limitations of the Kroll process. In this study, we investigated a single-step reduction process using Mg metal in an H_2 atmosphere to obtain high-purity Ti hydride powder directly from TiO_2 to achieve environmental and economic sustainability. The reduction was conducted via magnesiothermic reaction of TiO_2 in $MgCl_2$ – KCl molten salt at 973 K under a 10 % H_2 mixed gas atmosphere. The results indicate that oxygen concentration in the Ti product decreased when particle size of TiO_2 decreased in a range of 45 – 300 μm. Specifically, the oxygen concentration in the TiH_2 powder was reduced to 0.209 mass% when the TiO_2 particle size was 45 – 75 μm. These results demonstrated the feasibility of directly producing low-oxygen TiH_2 powder via a single-step reduction of TiO_2 using Mg metal at 973 K under an H_2 mixed gas atmosphere.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling
25114: Double Salt Formation and Process Design Using Alternative Bases for Critical Metal Refining
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Abstract: In recent years, the clean energy transition has led to an exponential increase in demand for critical metals such as nickel, cobalt, and lithium, in order to manufacture cathode active materials used in lithium-ion batteries (LIBs). The conventional hydrometallurgical refining processes for these critical metals generate significant amounts of sodium sulphate, a low value byproduct with limited industrial applications and with challenges associated with its disposal. To avoid the production of sodium sulphate, environmentally friendly processes using alternative bases such as potassium hydroxide and ammonia have been proposed. These bases form high-value sulphate byproducts with applications in the fertilizer industry. However, both have unique properties in solution which must be considered during process design. Among these properties, potassium and ammonia base cations tend to form undesirable double salts with valuable metals, unlike sodium base reagents. Process conditions can be modified to prevent double salt formation.
In this article, the chemistry of potassium and ammonia double salts with nickel, cobalt, and lithium in hydrometallurgical sulphate processes is discussed. Gaps in literature are identified, and experimental data is compared to publicly available thermodynamic software models. The use of solubility diagrams to validate process design and effectively separate critical metals is demonstrated.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling
25007: Setting up the first production site for metal extraction from ore and residues Industrialisation of new technology with a case study on residuals from the steel and mining industry
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Abstract: GreenIron has a technology to extract metals from ores, waste, residuals, and secondary flows. To this date fossil free and emission free, iron, nickel, copper, manganese, and molybdenum metal has been produced using GreenIrons technology. The presentation will

focus on the journey to industrialise the technology and commissioning the first production site for commercial deliveries of fossil free metals. GreenIron is taking the first production site into operation in Sweden during 2024.
The presentation will dive deeper into case studies of hydrogen reduction of by-products and waste from the steel industry. Examples of by-products are mill scale, slag and filter dust. So far, approximately 100 different materials have been processed in the pilot plant and the feasibility will be demonstrated using pilot plant data.
GreenIron uses its patented process- and system solution for highly energy efficient and fossil-free reduction of metal oxides to pure metal. The solution is a small-scale operation with a capacity of 40.000 tonnes input per annum and furnace. The small footprint of the furnace enables its placement in each locality where there is a need to reduce iron-based oxides to pure iron/steel.
GreenIrons technology allows for **local handling** of waste and residuals from e.g., steel plants or foundries where the output from the GreenIron furnace can be reinstated into the steelmaking process. Thereby being sustainable and recycling internally at the site.
GreenIrons focus is to **recycle waste and residuals** from steel- and milling plants, grinding swarf from metal workshops and manufacturing industry, recycling stations, foundries with high contents of metal oxides of interest.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling

25008: Environmental Benefits of Ultra-high Temperature Purification of Natural Graphite

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Abstract: Fluidized bed reactors (FBR) have been used for the ultra-high temperature purification (UHTP) of natural graphite for sulfur, metals and silica removal. Environmental benefits associated with UHTP, compared with its competitor processes, include the avoidance of acids usage (HCl and HF), minimum caustic usage, and no chlorination requirement. The challenges facing a more widespread application of UHTP for natural graphite include the limited capacity of traditional reactors (single stage cylindrical), in terms of tonnage and residence time distribution. A new reactor concept (plug flow) is described, which can significantly reduce those limitations, while maintaining the environmental advantages of UHTP.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling

25025: Valorization of Dolomite-Rich Phosphate Mine Waste: A Sustainable Approach to CO_2 Sequestration and Alternative Cementitious Material Development

Zouhir BALAGH, Mohammed VI Polytechnic University, BENGUERIR, Marrakech, Morocco

Abstract: The rapid growth of the global population is driving an unprecedented demand for construction materials to meet the increasing need for infrastructure, housing, and services. This urban expansion has resulted in a significant rise in the consumption of Ordinary Portland Cement (OPC), a key component in construction materials such as concrete, bricks, and beams. Projections suggest that OPC consumption could reach 4.68 Gt/year by 2050. However, OPC production is a major contributor to greenhouse gas emissions, ranking as the third-largest source

of CO_2 emissions globally. According to the International Energy Agency (IEA), the cement industry emitted approximately 2.4 Gt of CO_2 in 2019, accounting for 26% of total industrial emissions. The energy-intensive process of clinker production, involving the calcination of limestone [$CaCO_3$] to lime at approximately 1450°C, is responsible for 50–60% of these emissions, with each ton of cement emitting 0.5–0.6 tons of CO_2. Furthermore, the industry's environmental footprint is exacerbated by the reliance on nonrenewable energy sources such as coal, fuel, and oil, as well as the depletion of natural resources. To address these challenges, researchers have explored innovative approaches using industrial by-products, such as phosphate mine waste and phosphogypsum, to develop sustainable and eco-friendly binders, including Supplementary Cementitious Materials (SCMs). These materials are being utilized in geopolymers, mortar, compressed bricks, and concrete to reduce OPC dependence and mitigate CO_2 emissions. Despite these advancements, decarbonizing the cement industry remains a complex task.

This study investigates the valorization of dolomite-rich phosphate mine waste rock (DRWR) by converting it into portlandite [$Ca(OH)_2$] and brucite [$Mg(OH)_2$] using Sodium Hydroxide in an aqueous medium. Concurrently, CO_2 is permanently sequestered as stable sodium carbonates [$Na_2CO_3 \cdot xH_2O$]. Experimental results demonstrated significant conversion rates, with up to 79.74%. Reaction efficiency was found to increase with longer durations, higher alkalinity, and sufficient water to dissolve NaOH, facilitating enhanced reactants interaction. Data analysis using Design Expert software validated the experimental model, highlighting the robustness of the findings.

Further optimization experiments identified the autoclave as a promising method to achieve even higher conversion efficiencies. The scalability of the process was confirmed through reproducibility in larger-scale experiments. This study presents an innovative, economical, and sustainable approach to synthesizing multifunctional products from phosphate mine waste, contributing to the circular economy and reducing environmental impact. Importantly, the methods used in this study comply with ecological standards, generating no harmful waste, and leveraging phosphate waste for material valorization.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling

25124: Rock Solid Design: Ensure Strategic Mineral Production with Simulation

Simon Delisle, Hatch, Montreal, QC

Abstract: The International Energy Agency estimates, based on a detailed review of all announced projects, that there is a significant gap (up to 50% for some minerals) between prospective supply and demand for some strategic minerals based on announced pledges for 2035. This includes the production of existing assets, those under construction, and projects that are likely to proceed. Unfortunately, production ramp-up to nameplate capacity does not always go as planned. Investigations into plants that have been constructed and are struggling to ramp up often point to problems that could have been identified and mitigated in the engineering design phases. Common issues include inadequate equipment redundancy, insufficient buffering, and inadequate catch-up capacity of equipment. Although inadequate often means insufficient in relation to these three issues, overdesign can also occur and drive the capital cost of projects outside of what is acceptable for investors. Balancing design robustness and cost is a challenging endeavor, and having a process twin as a quantitative tool to assess this trade-off is often useful.

Through experience-inspired examples, this presentation will showcase how developing a discrete-event simulation model of the operation during early engineering phases helps to mitigate the risk associated with the aforementioned downfalls, and how the balancing act between design robustness and capital cost can be achieved.
To meet the growing global demand for strategic minerals, it is crucial to minimize risks in these complex projects and to get the design right early in the cost curve. The methodology presented here contributes to achieving this goal.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling
25125: Sim-to-Real and Virtual Reality of Mineral Processing and Tailings Operations
Alessandro Navarra, McGill University, Montreal, QC

Abstract: The integrated simulation of mining and mineral processing operations depends on the representation of distinct modes of operation. These operating modes are defined at a high level as mass balances within a system of nodes, representing the various components of the system, to higher or lower degree of resolution, depending on the objective of the simulation, and the data available. Within the mass balance of a mining system, the capacity to handle tailings is seen increasingly as a critical constraint, especially with the increased prominence of filtered tailings ("dry stack") that may eventually overtake traditional tailings ponds. Whether considering mining, mineral processing or tailings operations, or integration thereof, simulation development requires careful consideration of the circumstances that would trigger a change in operating mode, or other corrective action; to this effect, previous work has implemented machine-learning-enabled control strategies within discrete event simulation of mineral processing plants, which can be extended for modes of tailings emplacements. Whereas a high-level representation considers dynamic mass balances, and the fluctuating material flows passing the nodes (grinding mills, flotation cells, filter presses, thickeners, etc. in the case of mineral concentrators, and reservoirs, filter presses, backfill plant, etc. in the case of tailings management), a more detailed representation may benefit from immersive experiences, into a computer-powered virtual reality (VR) representation of the operations. Particularly for tailings emplacement, the earthmoving operations may depend on data generated by expert human operators within a VR environment. Transplanting and adapting of earthmoving techniques that have been successful at one mine, may not be so simple for other mines, given human resource considerations. The chronic shortage of dozer operators is especially acute for specialized tailings emplacement, but VR-based training is a promising means to transfer expertise to operators working in civil construction. Moreover, VR of processing plants and tailings facilities, are of pedagogical value for engineering students, and will likely impact the way future engineers and operators execute their projects and operations. The current work will present the progress of a VR representation of a mineral concentrator, and of tailings and earthmoving operations, and describe how these efforts could be merged with the simulation testing of machine-learning enabled control systems, and other emerging challenges.

Symposium: Sustainable Metal Supply: Mining, Processing and Recycling
25028: Lithium recovery from end-of-life lithium ion batteries using the Nano-filtration membrane process
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Abstract: Lithium is one of the elements used in lithium-ion batteries (LIBs) for automotive applications, and the demand for lithium has increased rapidly in recent years owing to its widespread use in electric vehicles. Lithium compounds are typically extracted from ores and salt lakes and purified from their extracted solutions. End-of-life lithium-ion batteries (EOL-LIBs) are also a future lithium resource for compensating for future supply shortages. All resources originally contained various impurities, such as monovalent ions, multivalent ions, and other components. To obtain lithium compounds from these resources, multiple purification processes are required over a wide pH range. Nanofiltration (NF) membranes have a composite structure consisting of a separation function layer based on a cross-linked polymer, porous support layer, and nonwoven fabric, and can selectively separate various substances depend on the pore size formed by the cross-linked polymer comprising the separation function layer. They are used to remove hardness components and pesticides from groundwater and river water and for desalination and purification in food and biotechnology applications. However, a disadvantage of conventional NF is their vulnerability to highly acidic/alkaline solutions, limiting their application to solutions in the neutral region. Another limitation is the insufficient selectivity for multivalent ions, which hampers the separation efficiency.
Under these circumstances, we have designed and introduced a molecular backbone capable of developing high acid resistance and, based on this, have succeeded in creating a cross-linked polymer membrane with a precise pore structure of less than 1 nm. As a result, we have developed a new NF membrane with approximately five times the acid resistance of conventional products and 1.5 times the ion selective separation capacity.
In addition, we developed a membrane process utilizing this new membrane for resource recovery applications. Considering its application to the resource recovery of lithium from used lithium-ion batteries (LIBs), we succeeded in recovering lithium ions from a mixed acidic solution with multivalent ions. If this is applied to an LIB recycling system, it is expected to reduce CO_2 emissions by 30% or more compared with the conventional wet refining process. Furthermore, the lithium loss rate and the recovery rate of lithium carbonate from the actual acid leachate and from the high-purity lithium solution obtained by applying a new NF membrane process to the actual acid leachate were measured in each process. The results confirmed that the loss of Li occurred when the residues of multivalent ions were removed, while the NF treatment essentially reduced the Li loss. and improved the recovery of lithium carbonate. Thus, NF treatment is particularly effective for improving Li recovery from acid leachates derived from LIB.