The impact of HIP process and heat treatment on the mechanical behavior of an Al-Si-Mg alloy component

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Abstract

Castings generally contain pores and defects that can have a detrimental impact on mechanical properties. The hot isostatic pressing (HIP) process is usually applied to reduce internal porosities, which improves the mechanical properties because of the closed porosities. Therefore, this study investigates the effect of the HIP process on the mechanical properties of sand casting A356 aluminum alloys. This investigation was performed in collaboration with Unnaryd Modell, Quintus Technologies, and IAC Ankarsrum. Investigation of the complex interaction between the microstructural features on mechanical properties before and after the HIP process was examined using computed tomography scanning, in-situ cyclic testing, and scanning electron microscope. In the absence of large defects, the fatigue performance was improved. However, a significant variation in the result was found between the different conditions, whereas the coarser microstructure with larger porosities before the HIP process showed decreased ultimate tensile strength and elongation to failure. The samples tested under high cycle fatigue showed a reduced fatigue propagation zone in that the coarser microstructure. Moreover, large cleavage areas containing oxides in the fracture surfaces indicated that the HIP process closes all the porosities, but the oxide films are not creating a strong bonding. Furthermore, the samples tested under low cycle fatigue showed a difference in the crack propagation, whereas the coarser microstructure showed large cracks opened up away from the notch that assists the propagation leading to reduced fatigue life.

On the generation of excess solid fraction in the Rheometal process

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ABSTRACT

Rheocasting is getting more and more attention from the electronics and automotive industries. Mechanical properties and thermophysical properties such as thermal and electrical conductivity are affected by the amount of solid phase generated in the slurry process. The RheoMetal process specifically has a significant deviation from the expected solid fraction. This deviation is discussed, explained and a way to control the excess generation of solid phase is proposed.

Recent developments in ultrasonic melt processing: from fundamentals to practice

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Ultrasonic melt processing has gained a lot of attention in the last 15 years. The technology has been originally developed in the 1960s-1980s and applied to industrial scale processes such as shape casting, direct-chill casting and rapid solidification of Al and Mg alloys with the objectives to reduce porosity, refine grains and improve structural homogeneity. These earlier advances were superseded by Ar-rotary degassing, AlTiB grain refiners and deep-bed filtration that offered at the time technologically easier solutions. Current ultrasonic technology is based on much better (compact and reliable) equipment and attracts attention due to its environmental and economic efficiency. Advanced characterisation methods such as in situ synchrotron and high-speed observations and high-temperature cavitometers allow us to gain unprecedented insight into the mechanisms of ultrasonic processing, while sophisticated multi-scale numerical modelling gives an opportunity to scrutinise the physical phenomena and optimise the technology.

This presentation gives an overview of recent research done by the authors into the mechanisms of ultrasonic melt processing, i.e. refining of intermetallics and primary dendrites through cavitation-assisted nucleation on oxides and fragmentation; degassing of Al melts; deagglomeration; and distribution of acoustic pressure and cavitation activity in the treated melt volume. The experimental results are complemented with advanced numerical modelling that has been applied to ultrasonic melt processing upon direct-chill casting of Al alloys. Technological examples include degassing, grain refinement, intermetallic refinement and manufacturing of metal-matrix composites.

Atomic DFT simulation and experimental TEM APT observations on the distribution of modifying solutes within eutectic Si in Al-Si based alloys

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Modifying the eutectic Si from flake-like to fibrous in Al-Si based alloys (i.e. A356, A357) is of great necessity to improve the performance of Al-Si alloys. Three well-known modification mechanisms (the impurity-induced twinning (IIT) mechanism and the twin plane re-entrant edge (TPRE) mechanism as well as the poisoning of the TPRE mechanism) are generally accepted to be valid under certain conditions. However, IIT, TPRE or poisoning of TPRE mechanism cannot be used to interpret all observations accompanying modification, indicating that other factors may be also valid. Solute entrainment was therefore proposed [1]. In this talk, I will report atomic density functional theory (DFT) simulation and experimental transmission electron microscopy (TEM, including high angle annular dark field imaging (HAADF) and electron energy loss spectroscopy (EELS) in scanning transmission electron microscopy (STEM)) together with atom probe tomography (APT) on the distribution of modifying elements (Sr, Na and Eu) within eutectic Si. Both atomic DFT simulation and experimental TEM APT observation reveals that modifying elements have three different roles: (i) the adsorption at the intersection of Si facets, inducing IIT growth mechanism, (ii) the adsorption at the twin plane re-entrant edge, inducing TPRE growth mechanism, and (iii) the adsorption ahead of the growing Si twins, inducing a solute entrainment within eutectic Si. This talk not only demonstrates a direct experimental support to the well-accepted poisoning of the TPRE and IIT growth mechanisms, but also provides a full picture about the behavior of modifying solutes, including the solute entrainment within eutectic Si.

Corrosion Behavior of Friction-Stir Welded Al-Mg alloys

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Cyclic Corrosion Test (CCT) is now considered a more reliable and realistic test for automotive applications than the traditional steady-exposure methods, such as the salt spray test. Several automotive companies have established their own testing protocol for CCT. In this project, under certain uncoated conditions that represent the worst-case scenario for coupled bimetallic Al-Mg joints, following the SAE J2334 standards, we are conducting the CCT method on the Next generation Friction Stir Welded Magnesium-Aluminum Vehicle Joints. For Certain applications, such as the Stellantis-Magna ultra-light door, subassemblies using these alloys are up to 50% lighter than those using conventional steel-based alloys. The electrochemical analyses of corrosion resistance by open circuit potential (OCP) and potentiodynamic (PD) polarization scan have been performed. Scanning electron microscopy (SEM) characterization of the surface change during corrosion and the mechanical properties including micro indentation hardness mapping, nanoindentation, fatigue and lap shear strength have been conducted.

Removal of metallic impurities from molten aluminum

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Aluminum recycling is a topic of interest in the automotive and aerospace industries due to its economic and environmental benefits. Aluminum alloy scrap for recycling often contains impurities, such as Fe, Mn, Cu, etc. leading to casting defects and eventually degrading alloy mechanical properties. Scrap originates from different Al-alloys, with different alloying elements, in different amounts. The highly diverse composition of aluminum scrap makes it difficult for secondary aluminum recycling industries to achieve the targeted alloy composition economically. Impurity elements can be removed by cooling molten aluminum, resulting in the formation of intermetallic compounds containing only one or more impurity elements as solid inclusions when the molten aluminum containing the impurity elements is hypereutectic and subsequent removal of intermetallic sediments by decantation and filtration techniques. In the present study, simultaneous removal of Fe and Mn were studied from low and high Si containing Al-alloys via intermetallics sedimentation route. Calculation of Phase Diagrams modelling (CALPHAD) was also carried out to determine the suitable temperature for impurity-rich intermetallic phase formation in experimental alloys. The initial composition, cooling temperature and holding time have a significant influence on the removal of Fe and Mn. The alloys and sedimented particles were also examined by Scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS).

Mitigation of Solidification Cracking and Porosity in AA 6061 alloy during the Laser Powder Bed Fusion Additive Manufacturing Process

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AA6061 is one of the most commonly used aluminum alloys owing to its excellent material properties, e.g., high strength and ductility, good corrosion resistance, and high thermal conductivity. Due to the low silicon and magnesium contents, solidification cracking is consistently exhibited when AA6061 is processed without introducing grain refiner, external fields, and/or using a high-temperature build plate during the laser powder bed fusion (LPBF) additive manufacturing process. In addition, pores associated with gas segregation, shrinkage, and inappropriate selection of process parameters coexist with cracks. Both defects are detrimental to the mechanical properties of additively manufactured AA6061. In this study, a wide range of laser process parameters in LPBF, including laser power, scanning speed, and hatch spacing, were investigated via printed cubes. A process window was proposed to indicate the printability of AA6061 based on the levels of cracks and different types of pores. Three conditions that yield minimal defects were further selected to explore how a pulsed laser affects the microstructure and defect formation under different solidification conditions compared to the continuous wave laser. In parallel, computational modeling on the melt pool formation for LPBF was performed and coupled with the solidification cracking criteria developed by Rappaz, Drezet, and Gremaud. The modeling results were employed to interpret the experimental observations and assist the experimental design in eliminating solidification cracks. Tensile samples with different levels of solidification cracks were printed to examine the mechanical properties and failure mechanisms. Finally, process-structure-property relationships were discussed for mitigating defects in processing AA6061 via LPBF.

Structural and Spectral studies of Sm^{3+} doped $Li_2Mg_2(PO_4)_2$ nanoparticles

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Newly developed white LEDs are replacing fluorescent lamps and other widely used lighting sources to minimise carbon dioxide emissions and energy loss due to their promising and useful properties, such as longer lifespan, reliability, improvement in energy efficiency and luminous efficiency. Phosphates are effective dopant host materials for rare-earth ions for the production of luminescent materials or phosphors. The Intra-4f shell transitions shielded by rare earth ions provide effective and recognizable emissions across a variety of wavelengths. The combustion synthesis method was used in this work to produce the phosphate based phosphor $Li_2Mg_2(PO_4)_2$ doped with Sm^{3+}.The phosphor's structural and optical properties were investigated to ascertain whether it was appropriate for usage in white LEDs. This study provides a simple and economical combustion method for the synthesis of undoped and Sm^{3+} doped $Li_2Mg_2(PO_4)_2$ with different concentrations at 700°C. The XRD peaks confirmed that the synthesized $Li_2Mg_2(PO_4)_2:Sm^{3+}$ were stable in the orthorhombic phase with the space group Pnma. In UV-Vis spectra, the band gap widens with the addition of the dopant Sm^{3+} and tuning of the band gap then occurs. In the PL spectra, the Sm^{3+} ion's 4f-4f transition in the excitation spectrum results in the appearance of the three main peaks. Due to the improved properties of the manufactured transition metal-doped inorganic nanoparticles, it is now possible to develop brand-new materials for use in various plasma display panels, light-emitting diodes (LEDs), cathode ray tubes, optoelectronic devices, field emission displays and other optical materials.

Titanium metal matrix composite fabrication via cold spray additive manufacturing

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Cold spray additive manufacturing (CSAM) is a solid-state deposition method in which metal powder deposits onto a surface at supersonic velocities to produce a 3D structure. CSAM can process multiple powder feedstocks simultaneously to form a multiphase 'metal matrix composite' (MMC) in which reinforcement particles (added at a minority fraction) embed into the softer metal matrix. Cold spraying a pure metal such as CP Ti with a harder additive can thus produce deposits with increased strength without resorting to spraying an alloy powder such as Ti6Al4V, which generally requires higher deposition velocities and can entail larger residual stresses. In this research, commercial-purity titanium MMCs were cold sprayed using ceramic reinforcement particles (either $(ZrO_2)_{0.92}(Y_2O_3)_{0.08}$, TiB_2, or TiC) or metallic blending (with W). Secondary material choice was found to affect deposition efficiency and bulk density. Following cold spray, the deposits were vacuum heat treated. Final chemical compositions (XRD and ICP-OES), microstructures (backscattered SEM), and tensile mechanical properties were determined for the heat-treated deposits. The results show that 10 wt.% addition improves heat-treated CP Ti deposit strength by 8-27%, depending on the secondary material.

3D observation of microstructure evolution and casting defect formation during solidification in Al and Mg alloys

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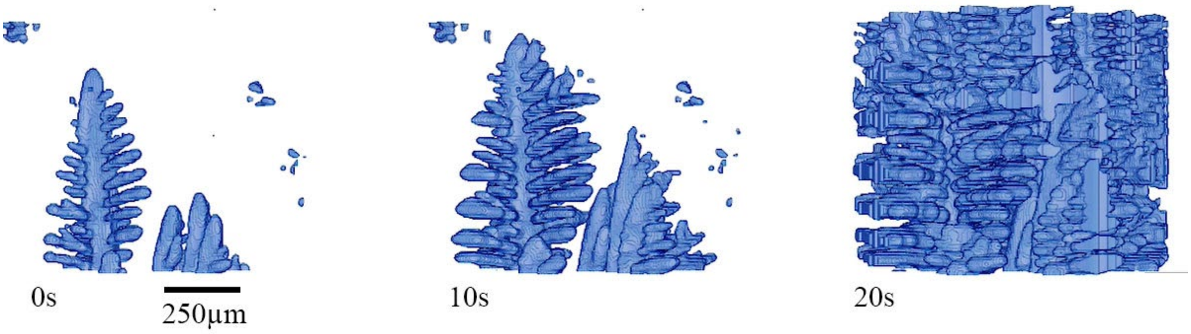
Control of solidification structure and reduction of casting defects have been an issue in improving the properties of castings. However, it is often difficult to understand how the solidification structure and the casting defects are formed in the solidification processes because the microstructure and the defects are observed after the solidification. Recently, time-resolved observation techniques (two- and three-dimensional imaging techniques) using synchrotron radiation X-rays have been developed. Recently, time-resolved tomography (4D-CT) allowed us to observe solidification phenomena *in situ* for most of the commercial alloys such as Al, Mg, Zn, Cu, Ni, Fe, and Ti alloys. In addition, we have developed an image processing technique using a phase field model (Phase Field Filtering, PFF). In the PFF, the solid-liquid interface is modified in terms of curvature. In general, the curvature effect is a dominant factor in determining the interface shape. Thus, the solid-liquid interface modified by PFF could satisfy the thermodynamic validity. The figure shows an example of the 4D-CT observation for Al-5mass%Cu alloy at a cooling rate of 0.16K/s. The development of secondary arms was clearly observed. Solid-liquid interfacial area, which could be used for the evaluation of permeability in the mussy region and microsegregation between the dendrite arms, was estimated as a function of time. In this presentation, the evolution of solidification structure in Al-Cu and Mg-Zn alloys and the defects induced by the semisolid deformation will be demonstrated.



Three-dimensional observation of solidification in Al-5mas%Cu alloy at a cooling rate of 0.6 K/s. Voxel size is 6.5μm x. 6.5 μm x 6.5 μm. The reconstructed images were obtained every 2 s.

Magnesium Research and Applications: Opportunities and Challenges

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As the lightest structural metal and one of the most abundant metallic elements on earth, magnesium has been historically and increasingly used for lightweighting in the transportation and electronics industries, in addition to other traditional applications in aluminum alloying, steel desulfurization and protective anode. In recent years, magnesium research has shown significant growth potential in a variety of new applications from energy storage/battery to biomedical products. Figure 1a plots the global magnesium production in the last three decades, showing somewhat steady growth of magnesium industry with most of the production now concentrated in China. However, magnesium applications are presently limited due to a number of issues related to the structural and corrosion performance of commercial magnesium alloys. New magnesium applications still face tremendous technical and economic challenges, which has been reflected in the intensified global research efforts in the last 20 years (Figure 1b). This presentation will discuss the future opportunities and challenges for magnesium research and applications for the global magnesium community. It will also provide an overview of recent magnesium alloy development and process innovations at The Ohio State University in collaboration with its industrial partners, for structural and biomedical applications.

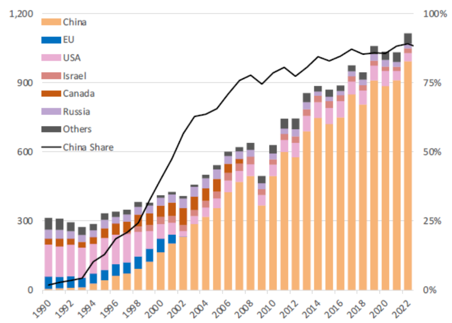

Figure 1a. Global magnesium production (Clark, IMA 2022, Barcelona, Spain, August 30, 2022).

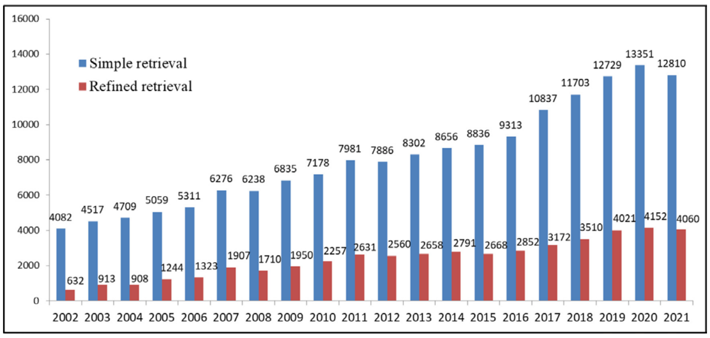

Figure 1b. Published Mg-related papers in the past 20 years in the Web of Science (WoS) Core Collection database (Song et al., JMA, 18:8, 2022, https://doi.org/10.1016/j.jma.2022.04.001).

In situ alloying of pure Ti with trace 316L stainless steel elements by selective laser melting

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Although the workhorse alloy Ti-6Al-4V (Ti64) is widely used for bio-implants due to its excellent mechanical properties, biocompatibility, and corrosion resistance, it is the subject of discussion because of long-term health effects caused by the release of vanadium (V) ions and aluminium (Al) ions into the human body, and “stress-shielding” issue. To address this challenge, here we explored an in-situ alloying approach to fabricate a cost-effective and low-toxicity Ti alloy with similar or superior mechanical properties to Ti64 by using a mixture of pure elemental Ti powder and a small amount of commercial 316L stainless steel powder through selective laser melting (SLM). The elements in 316L are effective columnar to equiaxed (CET) promoters and β stabilizers in Ti. The effects of its different content on the microstructure and mechanical properties were analysed. The results show that the addition of 316L stainless steel successfully promotes the transformation of columnar β grains into equiaxed grains, leading to a dual-phase microstructure of fine β+α’. This transformation significantly improves the mechanical performance compared to additively manufactured (AM) pure Ti or Ti64. This research could provide useful guidance for performance enhancement in AM-fabricated Ti alloys in a wide range of biomedical applications.

Laser powder bed fusion of Ti alloys with various Al contents

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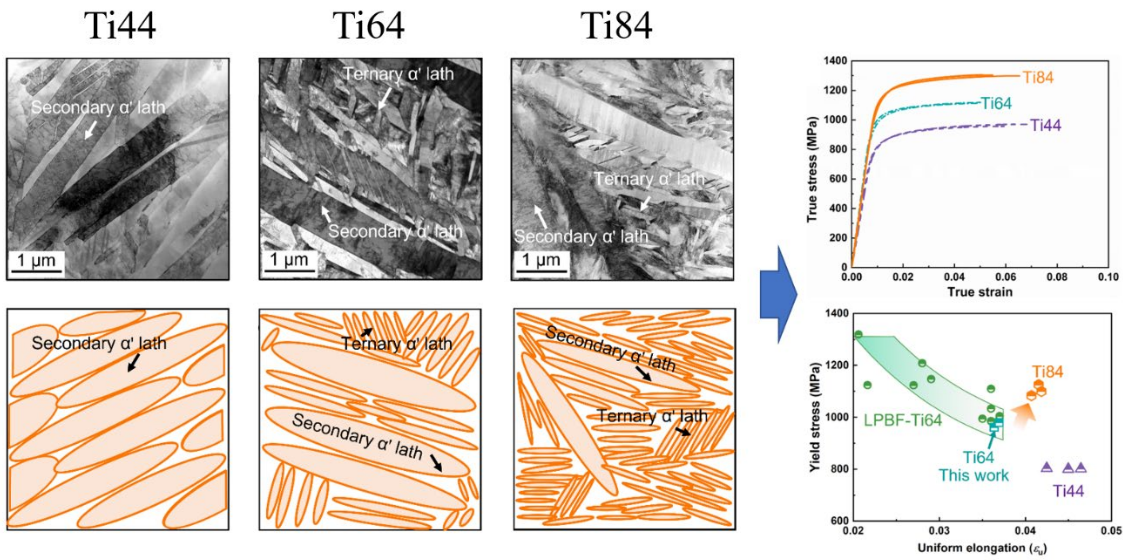
Laser powder bed fusion (LPBF) is an advanced technology to create metallic components with complex geometry. Ti-6Al-4V (Ti64) is one of the most frequently used materials for LPBF. The intrinsic high cooling rates and ultra-high directional thermal gradient of melt, however, lead to a hierarchical structure composed of fine martensitic α' within columnar prior-β grains in LPBF Ti64. This microstructure results in poor ductility and strong mechanical anisotropy in as-built Ti64 components, which largely limit their applications. Here, we report that the above shortcomings can be overcome by tailoring the Al content. By reducing the Al content from 6wt.% to 4wt.%, the LPBF Ti-4Al-4V (Ti44) alloy exhibits substantially improved ductility and mechanical isotropy. These improvements are attributed to grain refinement during solidification and the activation of multiple slip modes in the as-built material during deformation. By increasing the Al content from 6wt.% to 8wt.%, the LPBF Ti-8Al-4V (Ti84) alloy exhibits higher work hardening and uniform elongation values. This outcome is attributed to a more heterogeneous microstructure in Ti84 and the resultant hetero-deformation induced (HDI) hardening. This work offers a simple strategy to design new LPBF titanium alloys with improved ductility and isotropy for the aerospace industry.



Microstructure and tensile properties of Ti-xAl-4V (x=4, 6, 8, wt.%)

Friction Stir Spot Lap Welding in Aluminium/Acrylic Hybrid Joints

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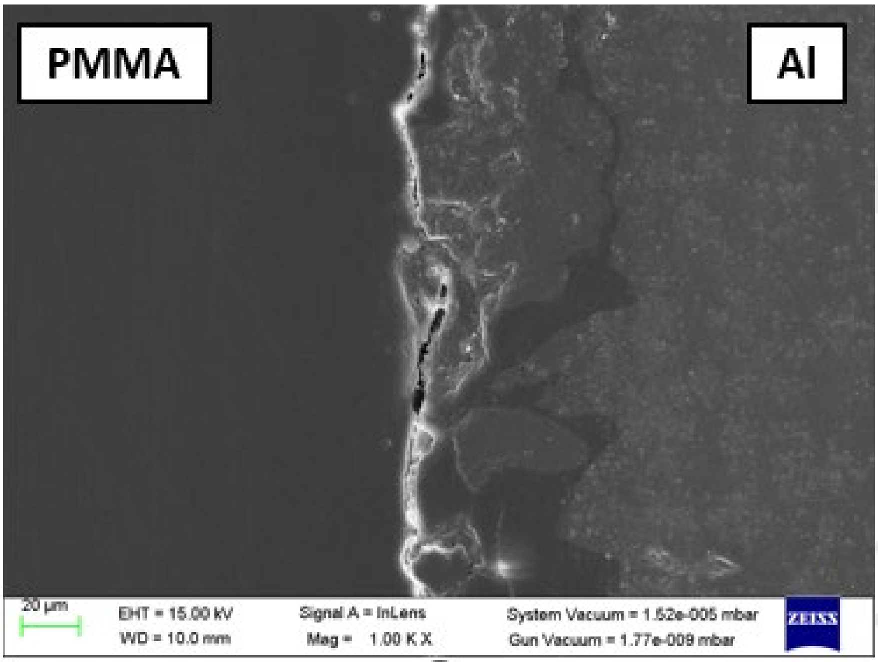
Abstract:

The requirement of lightweight structures in transportation field has increased many folds because of the need to control the carbon dioxide emission influences on global warming. Mainly, the amount of CO_2 emission is controlled by vehicles' weight (reducing 10% of the vehicle's weight reduces the usage of fuel by 5-7 %). Therefore, using a multi- materials structure open new approaches to invent new hybrid joints' welding techniques. In the current work, friction spot lap welding was used to develop hybrid joints between Aluminium alloy 6061 (100×25×3 mm^3) and poly methyl methacrylate (PMMA) (100×25×3 mm^3) using a taper pin FSW tool. Lap joint configuration was used. The process parameters (rotational speed, plunge rate, holding time) were (900 rpm, 5mm.min^{-1}, 5 s) respectively. Surface pretreatment on metal workpiece was applied using different polishing grades to create different surface roughness then cleaned the unwanted materials present on surfaces using acetone. Shear tensile test was used base on ASTM-D5868 to identify the joint strength, however, the joint interface was investigated using FE-SEM analysis. As a result, at low surface roughness, the fracture took place from the joint interface while at highest surface roughness the joint broke from the PMMA side showing shear strength more than 4 MPa with maximum load capacity ~3 KN. The more the surface roughness the more joining area which lead for more mechanical interlocking and increase the possibility for chemical bonding. SEM images at high magnification show proper adhesion between the polymer and metal surfaces without any voids.



Scanning Electron Micrograph of Hybrid Joint Interface

Tailoring titanium alloys toward processing by wire-arc directed energy deposition

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The development of novel metal alloys tailored for additive manufacturing has been a research focus in recent years. While substantial progress has been presented using powder-based processes, relatively few efforts have been made using wire feedstock (such as in use in wire-arc directed energy deposition) and most of the literature in this field deals with commercial welding wires, i.e., mostly Ti-6Al-4V. Due to the unique processing conditions prevailing during wire-arc directed energy deposition, several challenges arise including (a) formation of large primary grains; (b) solidification and subsequent phase transformation texture formation including variant selection; (c) anisotropic mechanical properties. Therefore, new alloy concepts need to be developed that can overcome these problems. Addition of alloying elements favoring constitutional supercooling such as Cu, Ni or Fe has been suggested. These elements also form intermetallic phases via an eutectoid reaction.

In the present work, we investigate the effects of various binary, ternary and quaternary alloying systems with the aim of modifying the solidification conditions toward a fine and untextured microstructure. Another focus is on the subsequently occurring solid-state phase transformations. Microstructural analysis is performed using electron microscopy, X-ray diffraction and atom probe tomography with thermodynamic calculations aiding our understanding of the phase formation sequences. Mechanical properties are assessed using microhardness measurements and compression tests.

The comprehensive analyses presented in this work suggests that the solidification microstructure can be favorably modified by alloying element additions and that the eutectoid transformation can be used to tailor the resultant microstructure. As a result, extremely fine microstructures can be produced. The resulting mechanical properties are significantly higher than those of conventional reference alloys.

A Magnesium Clean Energy Ecosystem Vision

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Magnesium (Mg) is an abundant and energy-dense metal. A new distillation technology called Gravity-Assisted Multiple Effect Thermal System (G-METS) could enable its use in multiple technologies for recycling and CO_2 drawdown. In addition to Mg alloy recycling, G-METS can enable low-cost primary production by MgO reduction in a reactive cathode Hall-Héroult cell with a tin or lead cathode. MgO feedstock can be made from seawater desalination concentrate. G-METS can potentially reduce the energy use of liquid Mg leaching and distillation for rare earth magnet recycling by up to 70%. Phinix LLC has licensed G-METS technology from WPI for Mg alloy recycling, and Excava LLC has optioned it for rare earth magnet recycling.

A molten salt Mg-air battery can convert Mg metal to electricity at up to 60% efficiency, with higher energy density than aqueous aluminium-air batteries. This can potentially propel ships across oceans, and shipping its anodes can transport over three times the energy/mass, and six times the energy/volume, of toluene-methylcyclohexane hydrogen. MgH_2 slurry in a light hydrocarbon is a potential zero GHG emissions aviation fuel, whose MgO nanoparticle exhaust absorbs CO_2 from the atmosphere as dilute $MgCO_3$ or $Mg(HCO_3)_2$ rain, with calculated aircraft range longer than for plain hydrocarbons. Carbon280 Pty Ltd. is commercializing MgH_2-mineral oil slurry for hydrogen storage.

Magnesium can thus potentially deliver carbon-neutral energy with best-in-class no-compromises performance for many applications. Despite its low production today, the examples above illustrate its extraordinary potential as a clean energy carrier which could disrupt our carbon energy system.

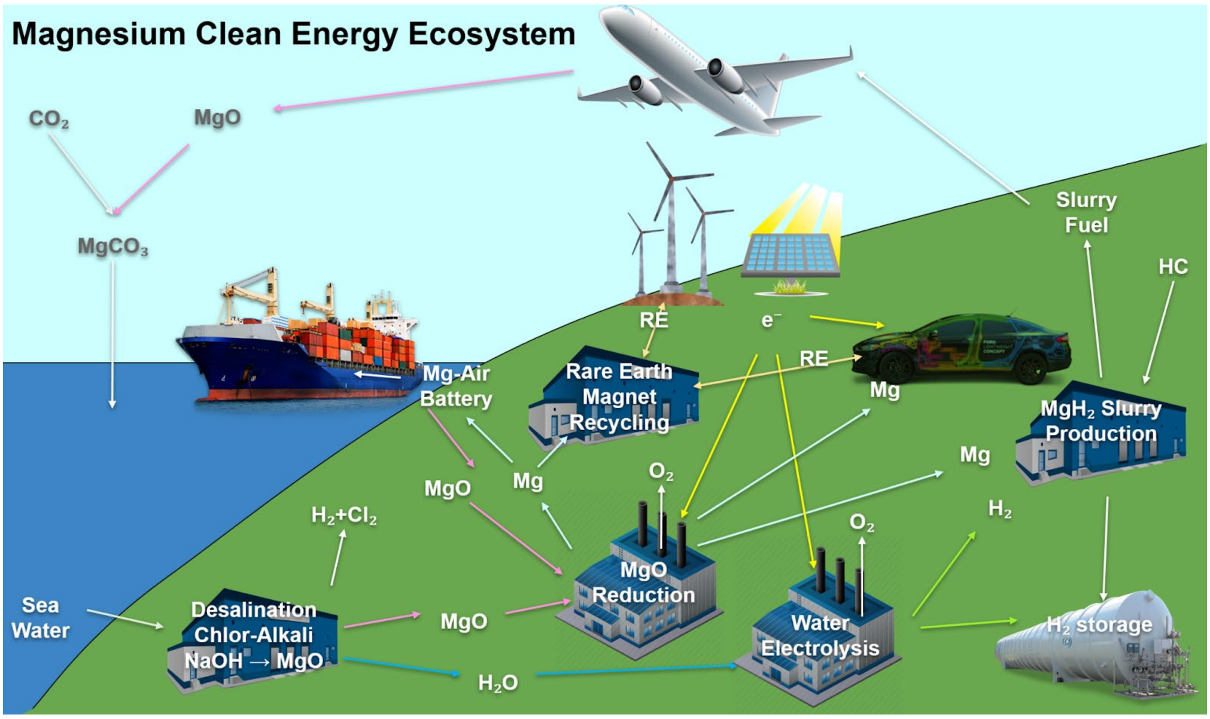

Figure 1: Magnesium clean energy ecosystem vision schematic overview.

Reconstruction of dislocation core structures in FCC and HCP crystals

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Abstract: Dislocations are the main carrier of plasticity in crystalline materials and their behaviour has strong consequences in the mechanical response of materials. The concept of the dislocation as a line defect was proposed in 1930's to explain the discrepancy between the theoretical shear strength of a perfect crystal and the experimentally measured yield strength and the work-hardening phenomenon. However, the remarkable achievements so far in dislocation analysis, observation and simulation have not led to a clear and complete understanding of dislocation behaviour. The current level of dislocation knowledge is not much different from that described by Cottrell in 1953. One of the fundamental problems is that the basic dislocation structure that has been adapted in all analyses is based on the atomic configuration for a simple cubic crystal. All simulations fail to construct a 3D supercell containing a properly defined dislocation line. The matter is that most metals possess a close packed crystal structure and the dislocation core structures are therefore substantially different from that for a simple cubic crystal. In the present work, the possible core structures of basal $<11\bar{2}0>$ $\{0001\}$ and pyramidal $<11\bar{2}3>\{11\bar{2}2\}$ dislocations in HCP crystals (e.g. Mg) and $<110>\{111\}$dislocations in FCC crystals (e.g. Al) are reconstructed using crystal visualization software, showing substantially different crystallographic features from those that are generally perceived. The possible decompositions of these core structures are discussed and the line tension and stress field in association with the core structures are analysed as well.

Key words: Dislocation core structure, HCP crystal, FCC crystal, dislocation decomposition, dislocation stress field.

Imaging real-time plasticity onset and single twinning events within a bulk polycrystalline magnesium alloy

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Adequate modeling of alloys in service requires understanding the dynamic response of bulk samples at both individual grain and grain aggregate levels with time resolution down to 10's milliseconds. However, experimentally observing this has been challenging. We have developed a real-time Synchrotron X-ray Laue diffraction technique to image the dynamic response of a polycrystalline magnesium alloy (20 µm grain size) in one-shot, avoiding the time-consuming aspects of diffraction data acquisition based on stage rotation or sample raster scanning. The tensile experiment was conducted at IMBL beamline at the Australian Synchrotron and used the polychromatic radiation in a highly collimated beam 200 µm in diameter. We focused on the onset of plastic yielding. Despite the smooth nature of the elastic-plastic transition evident in the stress-strain curve, the results show the intermittent nature of plasticity at the grain scale within timesteps of 44 milliseconds. It is also evident that bursts of plasticity are highly coupled across neighboring grains. Close inspection of the diffraction patterns shows that the largest strain bursts are due to single {10-12} twinning events. With this technique in hand, we are now able to begin to build models of yielding (and perhaps fatigue) based on an understanding of the nature of individual twinning events.

Effect of Sc and Zr on the precipitate distribution in pre-stretched Al-Cu alloys

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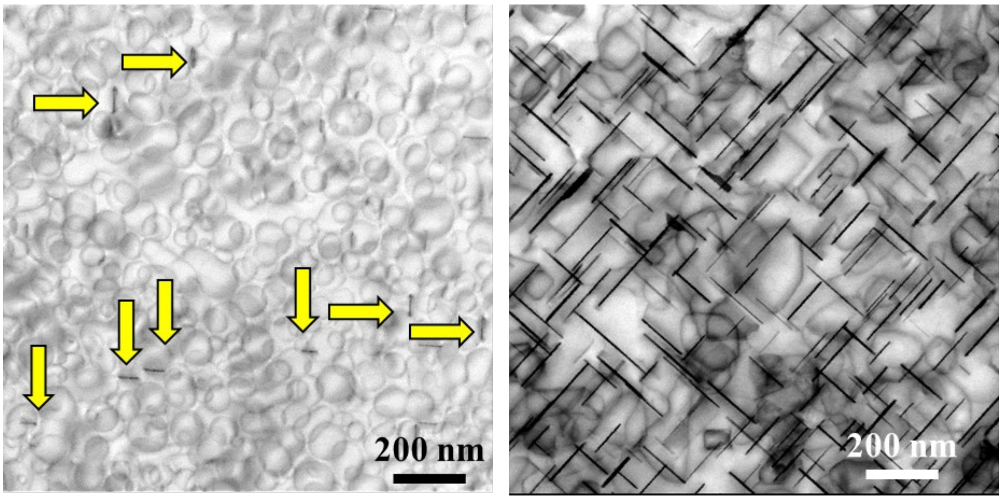
Pre-stretching is commonly conducted on Al-Cu alloys prior to ageing as it stimulates the formation of the hardening θ'' and θ' precipitates. This pre-stretching operation leads to preferential formation of precipitates in certain habit planes which results in anisotropic mechanical properties. This phenomenon is called 'stress orienting effect' which is caused by the local change in elastic strain energy induced by the pre-stretching. This is a major and ongoing issue in 2xxx-series Al-Cu alloys. In this work, we use minor additions of Sc and Zr to an Al-Cu alloy to promote the isotropic formation of precipitates. When the binary Al-Cu alloy was pre-stretched along the $[001]_{Al}$ zone axis, scanning transmission electron microscopy (STEM) observation reveals that θ'' precipitates formed preferentially on $(001)_{Al}$ plane (and not on the $(100)_{Al}$ and $(010)_{Al}$ planes), as shown in Fig. 1a. In the pre-stretched Al-Cu-Sc-Zr alloy, the fine dispersion of coherent Al_3(Sc, Zr) dispersoids was found to promote equivalent precipitate nucleation of θ' precipitates in all three habit planes (Fig. 1b). The presence of dispersoids was also shown to significantly modify the precipitation sequence by stabilising θ' instead of θ'' precipitates. Despite homogeneous precipitation, some level of mechanical anisotropy was predicted to remain with equal maximal strength in the axis perpendicular and parallel to $[001]_{Al}$ and a minimum strength when the angle is 45°.



(a) Al-Cu alloy (b) Al-Cu-Sc-Zr alloy

Figure 1. STEM images for the θ'' and θ' precipitates in the (a) Al-Cu and (b) Al-Cu-Sc-Zr alloys. The observation was carried out along $[001]_{Al}$ zone axis which is parallel to the stretching direction. The yellow arrows show that very little θ'' precipitates formed on $(100)_{Al}$ and $(010)_{Al}$ planes in the binary alloy [1].

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Understanding the Effect of Process Parameters on Structural Castings of Nemalloy HE700

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Abstract

The rapid global automotive transition from internal combustion engines (ICE) to battery electric vehicles (BEV) is fraught with challenges related to high vehicle weights that result in reduced driving ranges. Our present needs mandate a significant reduction in the curb weight of an automobile coupled with a critical sustainability and decarbonization strategy to ensure our continued pathway to net-zero carbon globally. The new Nemalloy-HE700™ aluminum alloy is an Al-1.1wt% Fe dilute-eutectic alloy with 4.7wt% Zn and 1wt% Mg additions to ensure castability for complex structural automotive components while being fully recyclable. The addition of Zn and Mg serves to impart solid state strengthening during subsequent heat treatments. Flat plate castings with three nominal plate thickness of 2.3, 2.5 and 3 mm were produced in a fully automated Bühler Carat 1200-ton HVHPDC machine using four separate L_9 orthogonal matrices for the design of experiment (DOE); with independent parameters being slow and fast shot speed of the plunger, melt superheat temperature, and shot delay interval times. Analyses of the plate castings through X-ray imaging and defect tracking revealed an increase of defect affected areas of 10-15% with the slow shot speed at an increased shot delay interval time. A statistical analysis was then carried along with a visual inspection of surface quality to identify the optimum process parameters that result in a high quality of the structural casting.

Fabrication and Mechanical Performance of B_4C/Al Composites

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Particle reinforced Al matrix composites (PRAMCs) have wide potential applications in transportation, aerospace and energy industries. Components manufactured by PRAMCs are usually in service under harsh temperature conditions. B_4C reinforced Al matrix composite is a promising material that can be used in multiple purposes. In this presentation, we will report the manufacturing of the B_4C/Al composites with various B_4C particle contents and particle size, both in micro and nanoscale, via powder metallurgy and optimized processing, including hot rolling and heat treatment. The mechanical performance of the composites at various loading temperatures, from cryogenic temperature to elevated temperature, and the strengthening / fracture mechanisms due to the various particle addition strategies are comprehensively evaluated experimentally, along with theoretical analysis and actual three-dimensional (3D) microstructure-based finite element modeling. The deformation behavior, strengthening ad fracture mechanism of the fabricated composites will be compared. The results uncovered in this study will help the industry manufacturers modify the composition and processing parameters, which in turn, results in the enhanced mechanical properties, and help to ensure the service safety of the composites under various service temperature conditions.

Keywords: Al matrix composites; Powder metallurgy; Strengthening mechanism; Mechanical property

Weld Soundness Evaluation of Thin Sheet Friction Stir Weld Joints using Lamb wave

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The evaluation of weld soundness is crucial for determining safety and reliability in aerospace, automotive, civil, petrochemical, and mechanical industries. The weld joints are invariably examined in terms of soundness using non-destructive testing besides mechanical, metallurgical, and corrosion properties. A non-destructive helps in taking decision about acceptance of the weld joint and developing a window process parameters for sound welded joints. Conventional methods are expensive, time-consuming based on point-by-point analysis, while Guided wave-based Non Destructive Evaluation (NDE) proven to be efficient for long-range, cost-effective transmission, through-thickness and in-situ inspection. The proposed research aims to undertake theoretical as well as experimental investigations of Lamb wave interactions during non-destructive examination of dissimilar metals joining of thin section in lap configuration.

Experiments were conducted using two sheets having thickness of 2 mm each and 245 mm × 185 mm sizes are joined using Friction Stir Welding (FSW) in lap arrangement having constant overlap length of 25 mm. Retro-reflective strips were affixed on opposite sides of the weld-end zone both at a distance of 30 mm. Out-of-plane displacement was analyzed using a Laser Doppler Vibrometer (LDV). In order to create 60 V and 120 V pulses at different frequencies, a low-voltage amplifier was employed, and dampening tapes are introduced at the specimen boundary to reduce noise. After NDE investigation, FSW samples have also been cross-validated with X-ray, SEM and EDS for further weld characterization studies.

For the Al 5052-Al 6061 welded samples, both fundamental mode i.e. symmetric (S_0) as well as asymmetric mode (A_0) were utilized to characterize FSW parameters namely transverse speed and plunge depth. While frequency-wavelength filtering is used to separate and process other higher modes. As transverse speed increased from 65 to 75 mm/min, signal transmission loss decreased from 20.21dB to 4.55dB. The S_0 mode conversions cause the abruptly decreased transmission behavior at 60 kHz for 65 mm/min transverse speed. The results show that the maximum transmission is attained at a transverse speed of 75mm/min corresponding to 3.7mm of plunge depth. As the transverse speed decreases, material mixing inside stir zones is constrained due to a reduction in plastic deformation and frictional heating tendencies; results in inadequate weld formation. In other words, characteristics change inside the stir zone can be efficiently inspected by transmissional changes in amplitude, phase and lobe attributes of Lamb waves.

Keywords: Weld soundness, Thin section lap joint, Friction Stir Welding, Transverse speed, Plunge depth, Lamb wave

Effect of multimodal microstructure on fracture toughness behavior of extruded Mg-Zn-Y alloys

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Mg alloys are expected to be used as structural materials for transportation vehicles owing to their low densities. Recently, Mg-Zn-Y alloys with excellent mechanical properties have been developed. The microstructure of these alloys are characterized by multimodal microstructure that consists of: fine dynamically recrystallized (DRXed) α-Mg grains with a random crystallographic orientation, coarse-worked α-Mg grains with strong fiber texture in which the $<10\bar{1}0>$ of the grains are parallel to the extrusion direction (ED), and LPSO phase grains also have a $<10\bar{1}0>$ fiber texture[2]. However, influence of the multimodal microstructure on fracture toughness behavior have not been clarified yet. Therefore, in this study, the fracture toughness was investigated by using several Mg-Zn-Y alloys with different volume ratios of three regions.

The volume fraction of three regions were controlled by extrusion condition and alloy composition. In the $M_{97}Zn_1Y_2$ alloy, fracture toughness increased with increasing volume fraction of the worked grains (The loading directions were vertical to ED). It was observed that the worked grains and LPSO grains which were elongated along ED suppressed straight crack extension, and led to crack deflection and formation of secondary crack. This is due to texture orientation of the worked α-Mg and LPSO grains.

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Fluidity and microstructure of hypoeutectic Al-Ni alloys with trace element additions

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Hypoeutectic Al-Ni alloys have had seen increased interest due to both good electrical conductivity and good castability compared to Al-Si alloys. The Al-rich side of the Al-Ni phase diagram contains a non-faceted/faceted eutectic (Al-Al_3Ni), similar to that in Al-Si alloys. It is well known that trace element including Sr and Na, affect the micro and macro-structure of Al-Si alloys by influencing eutectic nucleation and growth. This work investigated if the Al-Al_3Ni eutectic is also susceptible to microstructure variations by similar mechanisms. The microstructure response to several trace elements was investigated and characterisation was performed using optical and Scanning Electron Microscopy (SEM) with Energy Dispersive Spectroscopy (EDS) and Synchrotron X-ray Fluorescence Microscopy (XFM). The effect of the trace element additions on the fluidity of an Al-5.3wt%Ni alloy was also investigated. The results support potential uses of Al-Ni alloys in castings and joining applications where electrical and heat conduction are important factors.

Atomic structure and evolution of $\{111\}_\alpha$ precipitate plates in Al-Cu-Mg-Ag alloys

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Al-Cu-Mg-Ag alloys exhibit high tensile yield strength and excellent creep resistance at elevated temperatures, which is attributed to a uniform distribution of Ω thin plates on $\{111\}_\alpha$ planes of the α-Al matrix. Despite of the many studies made on Ω over several decades, debates remain on the structure and formation mechanism of Ω. By using the atomic-resolution energy-dispersive X-ray spectroscopy (EDXS) scanning transmission electron microscopy (STEM) and high-angle annular dark-field (HAADF) STEM, we recently found a hexagonal precursor phase, designated Ω′, for Ω. Ω′ is metastable, and it transforms *in-situ* into Ω during continued ageing. Based on the density functional theory (DFT) calculations, we also confirmed that the "metastable Ω phase" is actually the equilibrium θ phase, and the experimentally observed orthorhombic symmetry of θ (i.e. Ω) in Al-Cu-Mg-Ag alloys is likely caused by the elastic distortion when θ (i.e Ω) is embedded as a thin plate inside α-Al grain.

Acoustic emission study on corrosion behaviour of extruded Mg-Y-Zn alloys with multimodal microstructure

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Wrought $Mg_{97}Y_2Zn_1$ (at%) alloys with long-period stacked ordered (LPSO) phase show excellent mechanical properties due to formation of multimodal microstructure during thermo-mechanical treatments such as extrusion. The multimodal microstructure in α-Mg/LPSO two-phase Mg-Y-Zn alloys consists of three regions: that is, fine dynamically recrystallized (RDXed) α-Mg grains with random crystallographic orientation, coarse hot-worked α-Mg and LPSO gains with $<10\bar{1}0>$-fibre-texture[1]. The DRXed grains improves ductility and the effective dispersion of the textured α-Mg and LPSO gains brings about strengthening of the alloys. Although the LPSO phase expects to act as alloy strengthening component, it works as cathodic site from viewpoint of corrosion engineering. In previous studies, it has been attempted to unveil their complexed corrosion behavior using electrochemical measurements[2], but their corrosion processes have not been clarified yet. Therefore, in this study, corrosion behaviour of the α-Mg/LPSO two-phase Mg-Y-Zn alloy was investigated by combination of electrochemical measurements and *in-situ* method – acoustic emission technique[3].

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Determination of Trace Impurities in Beryllium by Inductively Coupled Plasma Mass Spectrometry

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Abstract: The pure beryllium is normally prepared by magnesiothermic reduction method of beryllium oxide. The accurate determination of various impurity elements in beryllium is an important indicator for the quality of beryllium. Based on the method of GJB 2513A-2008 (Methods for Chemical Analysis of Beryllium), different impurity elements are determined by different methods one by one, which would take a long time for the whole process. In this experiment, a rapid method for the determination of 12 impurity elements (Fe, Al, Cr, Mn, Ni, Pb, Cd, Sm, Eu, Gd, Dy, Li) in pure beryllium was established by using inductively coupled plasma mass spectrometry (ICP-MS). The samples were dissolved with hydrochloric acid and nitric acid. Kinetic energy discrimination (KED) mode, sample dilution and online internal standard method were used to eliminate the influence of matrix effect. The linear correlation coefficient of the calibration curve of each element to be measured is greater than 0.999. The relative standard deviation (RSD, n=6) of the results is 0.76%-6.96%, and the recovery rate of spiking is 91.3%~114.5%. The method is used to determine the standard material of beryllium (YS/T 221-2011). The results of impurity elements above are consistent with the composition provisions in the standard material.

Unravelling hot tear formation dynamics using real-time X-ray imaging

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In the late stage of solidification of cast components, the liquid metal flows through the mushy zone to compensate for the volume change associated with the liquid-to-solid transformation. This shrinkage induced flow critically affects the formation of defects, such as hot tears, gas porosity and micro- and macro-segregation.
In this work, in-situ X-ray radiography experiments were carried out at the P05 beamline at the Petra III synchrotron (Germany) to measure the flow within the mushy zone and the evolution of hot tears in AlCu and AlCuFe alloys. The flow was tracked by adding a small amount of Pb to the alloys so that Pb droplets formed as a fine-scale emulsion in the liquid Al through a monotectic reaction. By tracking the movement of thousands of Pb droplets into and through the inter-dendritic regions during solidification and applying a simple analysis, we calculated the liquid velocity at each time step up to high solid fraction, just before the formation of defects. The evolution of hundreds of hot tears was characterized by analysing their nucleation, growth and merging behaviour and the results related to the solidification conditions and the presence of Fe-rich intermetallics growing in the interdendritic channels.

The Heat treatability, Conductivity, and Strength Properties of the Al-Fe-Ni-Mg-Si Alloying System

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Emerging applications such as aerospace and electric and hybrid vehicles require alloys with high castability, high electrical and thermal conductivity, and moderate mechanical properties. A heat treatable alloy is also highly desirable because it allows for the modification of microstructure, which changes the electrical and thermal conductivity and mechanical properties. The Al-Fe-Ni system is successful in maintaining a high conductivity because the low solubility of Fe and Ni in solid state Al (0.052 wt.% and 0.04 wt.%, respectively) results in thermally stable intermetallic phases. The addition of traditional alloying elements such as Mg and Si increases the strength and heat treatability, and reduces the electrical and thermal conductivity. The high solubility of Mg and Si (17.4 wt.% and 1.65 wt.%, respectively) allows them to dissolve into solution, and makes the alloy susceptible to heat treatment. The alloys were either solutionized (530-620 °C for 2-8 hours), aged (150-300 °C for 1-4 hours), or solutionized (530-620 °C for 2-8 hours) and aged (150-300 °C for 4 hours). Microhardness and electrical conductivity were measured prior to and after each heat treatment to determine their significance. Successful heat treatment procedures were applied to tensile samples to determine the effect of the treatment on the mechanical properties. The Al-Fe-Ni-Mg-Si alloying system has shown success in its adaptability, electrical conductivity (42-52 IACS%), and hardness (55-75 HV).

Effect of LSM on the microstructure of WE43, ZX21, ZXM211 biodegradable magnesium alloys

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Biodegradable Mg implants are desirable because they eliminate the requirement of revision surgery to remove the implant, have high strength-to-weight ratio, prevent stress shielding effect, exhibit osteoconductivity, and resulted in low medical image distortion. WE43, and Mg alloys comprised of Zn, Ca, and Mn are promising bioresorbable implant materials that exhibit good mechanical properties and biocompatibility.

Laser surface melting (LSM) can refine the microstructures and improve the surface hardness, wear resistance, corrosion resistance, wettability, and biomineralization of Mg alloys without the need of adding other materials. However, the relationship between the laser process parameters and the changes in the microstructure of these alloys induced by LSM is still unclear. In this study, we found that the grains in the melt pool of WE43, Mg-2Zn-1Ca (ZX21), and Mg-2Zn-1Ca-1Mn (ZXM211) were refined remarkably after LSM compared to the extruded alloys. Different types of grain morphology were identified due to the change in cooling rate in different regions of the melt pool. In addition to revealing grain refinement in the novel ZXM211 alloy after LSM, this study also shows the effect of different laser power, scan speed, and spot size on the microstructure of WE43, ZX21, and ZXM211. It was demonstrated that the depth of the melted layer increased with increasing laser power and decreasing scan speed due to the high heat input. More significant grain refinement was also observed at lower laser power and higher scan speed due to the increased cooling rate.

Advancements in electron microscopy techniques for characterizing dislocations in light metallic alloys

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Dislocations, as linear crystal defects, are the carriers of plastic deformation, and hence are the crust of alloy design and property prediction for advanced light metallic alloys for structural applications. Dislocations nucleate, glide, and interact with other defects. It is important to accurately describe the structure and evolution of characteristic dislocation configurations. However, experimental characterization of dislocations is thus far largely limited to 2D pictorial and static imaging to small areas, impeding our ability to accurately understand and tune the microstructure for improved mechanical properties.

This talk presents recent advancements in three aspects of dislocation characterizations, namely reconstruction of 3D topology, in situ dynamic measurement and meso-scale imaging of high density of dislocations. For determining dislocation line characteristics, an algorithm is developed to reconstruct the 3D topology based on stereological analysis. It allows fast and quantitative characterization using less than 10 diffraction contrast TEM images, thereby alleviating the process of image acquisition in a wide range of tilt angles. For revealing the critical dislocation evolution processes, in situ mechanical tests need to be carried out with specifically designed crystal orientations and mechanical boundary conditions. For characterizing relatively high density of dislocations, we employ EBSD pattern sharpness as a metric to reflect the local dislocation density and depict its variations across grains from the surface of bulk specimen. Case studies would be presented in various materials systems, such as dislocation junction evolutions in Al alloys, dislocation-twin interactions in Mg alloys and dislocation cell structures in additively manufactured metallic alloys.

Development of high strength aluminum alloy for hot stamping

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The limited formability is one of the major challenges for using high strength aluminum alloy sheets in automotive industry. The solution Heat treatment, Forming, and in-die Quenching (HFQ) process is an advanced technology to make complex-shape components instead of traditional stamping forming. The HFQ has been successfully applied in 5xxx and 6xxx Al alloys but less in forming high strength 2xxx and 7xxx alloys. In this research, the effect of alloy elements on the microstructure and essential properties of high strength 7xxx Al alloys suitable for the HFQ was studied. Meanwhile, the corresponding processing parameters were analyzed. An FE model was utilized to help design the hot stamping tools. Various thickness of industrial alloy sheets was produced and the B pillar component was been successfully made by the technology. A good match was achieved between the simulation and real product. Compared with high strength steel, the Al component has achieved a further weight reduction of 40% with a cost of only 2.1 times that of steel parts. This technology can help increase the application of Al alloys in vehicle lightening.

Hydrogen diffusion behavior of titanium alloys during Thermohydrogen processing (THP) based on neutron imaging

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Titanium alloys play significant roles in aerospace, marine, biomedical and chemical industries. Thermohydrogen processing (THP) is an attractive approach that uses hydrogen as a temporary element to modify the microstructure and properties of titanium alloys. Therefore, hydrogen content and diffusion behavior are the key factor for the optimization of the THP process. In this work, we introduced neutron imaging as an efficient tool for three-dimensional (3D) hydrogen distribution and quantitative determination in hydrogenated titanium alloys after THP. Thermal neutrons were provided by the reactor CARR to picture the samples with a spatial resolution of ~50 μm. A series of calibration samples of TC17 alloys with varying hydrogen content were prepared and elaborated neutron imaging experiments and image data processing were performed. In this way, the 3D hydrogen distribution of the hydrogenated samples was obtained and the quantitative relationship between the hydrogen content and the neutron images was determined. The hydrogen diffusion behavior with different heating temperature and holding time of THP process were illustrated in Fig. 1. We made the unique observation that hydrogen content decreased from the center to the edge of samples due to the hydrogen was released from the centre hole. It could be deduced that hydrogen diffused faster with the increase of heating temperature and the extension of holding time. The hydrogen distribution obtained by neutron imaging was consistent with those by the inert gas fusion thermal conductivity method. In a word, neutron imaging provides a new method for research on hydrogen-related materials and fields.

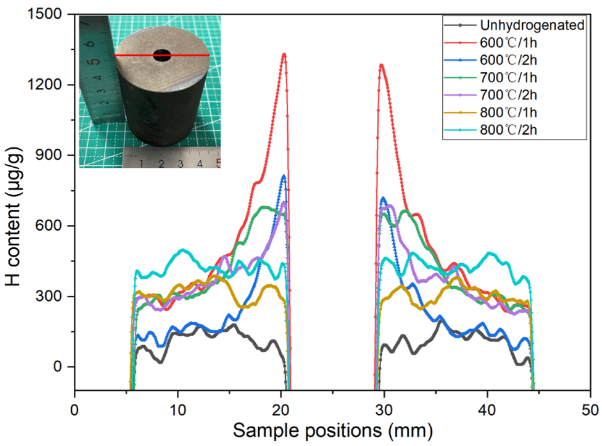

Fig.1 The hydrogen diffusion with different THP process conditions obtained by neutron imaging

An Overview of the Processing and Forming Behavior of Mg-Ca-Al Wrought Alloys

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The increasing demand for lightweight materials has led to growing interest in the use of magnesium and its alloys, especially in the automotive and aeronautic industry. While cast magnesium products remain the focus of industrial applications, wrought products have gained attention for their excellent mechanical properties. The Mg-Ca-Al alloy system is considered highly promising due to its cost-effective raw materials, low oxidation behavior, age-hardening capabilities, and attractive grain refinement designs. Despite the challenging deformation behavior, recent studies on various Mg-Ca-Al alloys using forming processes like rolling, forging, and extrusion have shown impressive results.

In this work, we will provide an introduction to Mg-Ca-Al wrought alloys by presenting examples of processing possibilities, forming performance, microstructural features, and mechanical properties. Processes involving precipitation hardening and those without heat treatment are presented and their characteristics discussed. Eventually, the results of our own work, using indirect extrusion of non-heat treatable Mg-Ca-Al-Mn at moderate temperatures will be discussed in a broad context.

Microstructure and solidification cracking in WAMed aluminium alloys by integrated analytical and process modelling.

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High performance alloys in the 6XXX and 7XXX series are desirable targets for additively manufactured structural materials though they are prone to solidification cracking when processed with welding and welding-adjacent technologies, for example Wire and Arc Additive Manufacturing (WAM). Some research effort has been directed to address the weldability of these alloys via the addition of a grain refiner in the form of high temperature substrates to act as heterogeneous nucleation sites. Grain refinement is a simple strategy to homogenise mechanical properties and improve part performance, however solidification cracking is a complex process. Predicting the likelihood of cracking requires information about the local evolution of solidification, which, for a casting, is well understood. For layer-wise addition of material, such is the case for WAM, several key solidification parameters, such as the heat evolution and its effect of local microstructure, at any site assessed for cracking likelihood must be known. The formation of microstructure in WAM results from the dynamics of a moving heat and fluid mass source deposited on a large-scale substrate. Like other additive technologies, the spatiotemporal evolution of the solidification conditions can vary considerably over the build due to the geometrical details of the mass and heat input, the local heat extraction rate through the existing deposited material, and the overall part design and build strategy. Given this inhomogeneity in solidification conditions over a build, and the propensity to crack for these high strength alloys, it is desirable to computationally assess possible designs and build strategies before generating physical specimens to test experimentally. To this end, we present an approach to a fast time-to-solution solidification cracking predictor that integrates several established analytical models of key solidification parameters, such as grain size and dendrite arm spacing, to predict the local cracking tendency. A plugin that implements this model integration is linked to a thermomechanical process simulation. The thermomechanical simulation communicates local thermal history data to the plugin as input and compares the output to prediction of the local strain rate from the mechanical solver. Predictions of the model integration are compared with builds of identical build strategy We demonstrate the utility of this approach in process design of WAMed parts.

Microstructure evolution during thermo-mechanical WAM process simulation

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Additive manufacturing (AM) is becoming an indispensable part of modern parts manufacturing especially for small batches, since it has lesser tooling costs and greatly reduces scrap. The mechanical properties of AM parts strongly depend on residual stresses and the microstructure, which in turn depend on the temperature evolution and boundary conditions.
Accurate simulations of AM processes can therefore reduce the number of trial runs when designing components. This work presents such a simulation model, which was used during the project M4AM by the industrial partner RHP.
The model covers the thermo-mechanical simulation of a single wall made by Wire Additive Manufacturing (WAM) and its microstructure evolution. A layer-based approach combined with element activation was used with the FEM solver LS-DYNA®. Capabilities for simulating the microstructure and welding process were implemented directly into the solver as user-defined functions (UDF). One model is based on Interdependence (ID) theory and describes the grain growth during solidification. After solidification, another model describes grain boundary movements in the solid phase and is coupled with a dislocation density based flow stress model. Since hot tearing is a major problem in aluminium WAM, a hot tearing model based on a modified RDG model was also implemented.

Mg-Gd-Y-Zn-Zr magnesium alloy with high strength and ductility fabricated by wire arc additive manufacturing based on cold metal transfer

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ABSTRACT: The Mg-Gd-Y-Zn-Zr (GWZ) alloy with LPSO (long period ordered stacking) phase is a new high strength and ductility Mg-RE alloy developed in the last decade, presenting great potential for light-weight applications in the fields of aviation and aerospace. Motivated by the ability of blocky LPSO phase at grain boundaries to inhibit grain growth and thus maintain thermal stability, a group of strong and ductile Mg-Gd-Y-Zn-Zr alloys has been synthesized. In order to investigate the suitability for WAAM, as-manufactured microstructure and mechanical properties of the GWZ alloys, the single-track deposition and single-track multilayer deposition experiments were carried out by wire arc additive manufacturing based on cold metal transfer (WAAM-CMT). The results show that the single-track clad of GWZ alloys does not contain detrimental solidification defects, with the microstructure composed of α-Mg matrix, blocky LPSO phase and $(Mg, Zn)_3RE$. The yield strength, tensile strength and elongation of the as-manufactured GWZ941 alloy reaches 175 MPa, 288 MPa, and 13.6%, respectively. After solid solution treatment, grain growth is seriously hindered by the fine diffuse blocky LPSO phases at grain boundaries in the insufficient heat-affected zone. After peak aging treatment, the GWZ941 alloy displays the best tensile mechanical properties with the yield strength, tensile strength and elongation of 221MPa, 377MPa and 11%, respectively. Such properties of the GWZ941 alloy fabricated by WAAM are much higher than those of casting alloy and are close to those of wrought alloy. Therefore, the alloys fabricated by WAAM are promising candidates to replace the conventional cast counterpart.

Towards dense corrosion-resistant plasma electrolytic oxidation coating on Mg-Gd-Y-Zr alloy by using ultra-high frequency pulse current

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Ultra-high frequency (≥10 kHz) was employed to produce plasma electrolytic oxidation (PEO) upon the surface of Mg-8Gd-3Y-0.5Zr alloy (GW83, in wt%) to understand its mechanistic contribution to the growth of PEO. The maximal pore area of the resulting PEO coatings was reduced by about one order of magnitude when frequency was increased from 0.5 kHz (65.8 μm^2) to 20 kHz (7.1 μm^2), which is attributed to the ten times reduction in single pulse energy. Cross-sectional SEM micrographs and electrochemical impedance spectroscopy confirm that the PEO coatings obtained at low frequency (i.e. 0.5 and 5 kHz) were consisted of an inner barrier layer and an outer porous layer, while ultra-high frequency PEO coatings were divided into three distinct layers: an inner barrier layer, an intermediate compact layer, and an outer porous layer. Moreover, thickness of the effective corrosion barrier layer of PEO coating including inner barrier layer and intermediate compact layer increased as a function of frequency, resulting in high corrosion resistance of the ultra-high frequency PEO coating. Those findings are anticipated to provide new insights to guide design and preparation of high-quality PEO coatings to tackle corrosion challenges of Mg alloys.

Is it possible to Design a Magnesium Alloy that is Stronger than Steel and Titanium?

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Abstract

Titanium, steel, and aluminium alloys are the most common structural engineering alloys. Magnesium (Mg) alloys have historically struggled to compete with these materials due to their lower strength, ductility, and corrosion resistance. The structure of most Mg alloys is hexagonal close packed, but modest additions of lithium (Li) to Mg can convert this structure to body centred cubic. The addition of Li to Mg also creates some of the lowest density (lightest) alloys in existence. Most significantly, the change in crystal structure drastically alters the microstructure and subsequent properties of magnesium. By standard metallurgical processing, we discovered very unusual bulk and surface microstructures in specially designed Mg-Li-Al alloys, which translated to an outstanding combination of high specific strength, ductility and corrosion resistance. This results in alloys with the highest specific strength of any commercially available engineering alloys, making them desirable for applications in the automotive, aerospace, defence, biomedical, sporting, and electronic goods sectors.

Development of die-cast Mg-Al-based alloys for high thermal conductivity

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Abstract

Magnesium (Mg) alloys have been becoming significantly attractive as light-weight structural materials in the past few decades. However, Mg alloys usually have inferior thermal conductivity to their competitive Al alloys. Therefore, in order to replace aluminium alloys for the deep lightweight and heat transfer requirements in emerging structural applications including engines in drones and handheld powered tools, and electric motors and battery packs in electric and unmanned aerial vehicles, the thermal conductivity die-cast Mg alloys have to be improved. In reality, aluminium (Al) is a popular and key alloying element in cast Mg alloys for improving castability and ambient mechanical properties, but plays a key role in reducing the thermal conductivity of Mg alloys.

A quantitative strategy was reported to design and develop Mg-Al-based alloys to achieve high thermal conductivity, in which the specific RE elements can be introduced to reduce the Al concentration in Mg matrix and to suppress the formation of Mg17Al12 phase through the formation of new intermetallic phases. Based on quantitative calculations, the strategy was demonstrated by a novel die-cast alloy, which provided the thermal conductivity of 114.3 W/(m·K) at ambient temperature and 137.5 W/(m·K) at 300 °C. Meanwhile, the alloy also offered excellent ambient yield strength of 143.2 MPa and elongation of 8.2%.

The newly developed alloys have been used in a European company for making small engines in massive production.

Developing precipitation hardening Mg alloys: limitations, successes and the future

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Global demand for the lightweight structures especially in the automotive sector has driven research into Mg alloys in the last two decades. In recent years texture control has been considered to be the way forward for the development of wrought alloys with only some consideration given to the development alloys that may be precipitation hardened through thermal treatment as the loss in strength due to heat treatment has prevented the use of precipitation hardening in all but few RE containing Mg alloys. Large amount of work on understanding the role of trace additives in improving the age hardening response of Mg alloys was made in the last 15 years with some understanding into a framework for picking trace additives that is more likely to be effective in enhancing the precipitation hardening. In this presentation, the work on developing an understanding of the trace additives in enhancing the precipitation of Mg alloys will be discussed with work on developing precipitation hardenable alloys developed for twin roll casting of Mg alloys.

An extruded Mg-Zn alloy with abnormal dual textures and improved tension-compression yield asymmetry

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Texture plays a dramatic role in determining the mechanical properties of Mg alloys. Here we report an unusual texture with the crystallographic c-axis parallel to the extrusion direction (‘C-texture’) in an Mg-6.5Zn alloy that occurs in bands. We show that this texture requires heavy alloying and that it is not linked exclusively to the presence of second-phase particles. It is associated with higher extrusion ratios and does not depend heavily on the starting texture. The most likely mechanism is that the texture arises from the action of pyramidal < c + a > slip stimulated by high solute levels. A sample containing only ~20% C-texture grains is seen to display a favorable tension-compression yield asymmetry of 0.9. (Other non-rare earth containing alloys can displays asymmetry ratios as low as 0.5). This significantly improved yield asymmetry is mainly attributed to the notably higher compressive strength of the C-textured grains (controlled by <a> basal slip and compression twinning) compared with the tensile strength of the typical extrusion-texture grains (accommodated by <a> basal, non-basal <a> prismatic and <a> pyramidal slip). The work points the way towards wrought alloys that display favorable yield asymmetries but which do not require the addition of critical and expensive rare-earth elements.

Enhanced Thermal Conductivity and Mechanical Properties in a New Aluminium Casting Alloy for Aerospace Applications.

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Motors, electronics housings, batteries and inverter units in aerospace and defence applications present specific material performance challenges related to thermal management. Lightweight materials that deliver improved performance across a spectrum of design parameters including cost, mechanical properties, and thermal conductivity for example, are understandably important. Traditionally, air-cooling systems such as fins or pinfins remove heat from castings more effectively however these quickly reach a limitation based on the exact alloy and conditions of operation.

The Al-Si-Mg alloys such as A356 are relatively low cost to produce and have good castability. Through heat treatment these can develop moderate levels of mechanical properties. However, around 7% silicon is present together with additions of magnesium. Because of these additions, they are therefore limited in that they have a ceiling on room temperature thermal conductivity of around 150 W/m.K in the fully strengthened T6 temper.

The current paper presents a study of new aluminum casting alloys based around Al-2Si-XMg, with the goal being the achievement of greater than 175 W/m.K thermal conductivity at room temperature. This goal was achieved in an alloy able to be produced easily in a production environment. Because the alloys developed have reduced silicon present, they are able to be conventionally anodised various colours including black or blue without silicon smutting, meaning that their emissivity properties and corrosion resistance may be high.

Despite the reduced silicon content, the alloys displayed excellent castability. They also displayed surprisingly high ductility together with good values of yield and tensile strength. Tests of sand and investment castings showed that the use of rapid cooling for refining the microstructure (e.g. by the use of chills) was not required because there was little residual cast microstructure following heat treatment, similar to many cast steels. The outcomes of the study display a desirable combination of properties that find particular application in modern electronics castings suitable for aerospace and defence applications.

Core-shell $Al_3(Sc,Zr)$ precipitation monitoring in Al-Mg-Sc-Zr alloys

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The addition of Sc and Zr to 5xxx-series aluminium alloys leads to significant strengthening due to the formation of core-shell $Al_3(Sc,Zr)$ precipitates. The aim of this study is to investigate the interactions between the Mg solute atoms and the $Al_3(Sc,Zr)$ precipitates and to assess their impact on the properties of the material. The precipitation kinetics were first investigated with thermo-electric power, mechanical and resistivity measurements. The evolution of precipitate size, volume fraction and chemistry were further analysed with a combination of electron imaging and *in situ* resonant small-angle X-ray scattering. These techniques revealed that the presence of Mg affects the precipitation behaviour of $Al_3(Sc,Zr)$ because of a modification of the thermodynamics of the system and/or because of local chemical heterogeneities. The formation of other secondary phases that might impact precipitation of $Al_3(Sc,Zr)$ was also observed. To further clarify the impact of Mg on the formation of $Al_3(Sc,Zr)$, the precipitate formation was modelled with a new approach which consists in maximising the Gibbs energy dissipation. These results will help optimising the composition and thermos-mechanical treatment of Sc and Zr containing 5xxx-series aluminium alloys.

Secondary ageing, formability, and weldability of an Al-Cu-Mg alloy (2024) in various tempers

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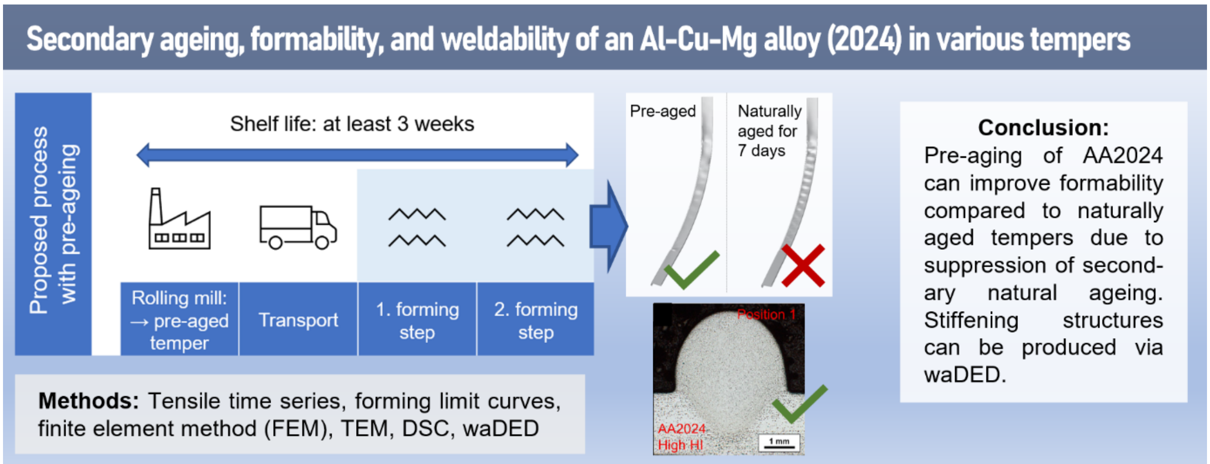
AA2024 is a high-strength aluminium alloy used in aircraft components such as frames and stringers. While the alloy is relatively soft and formable in the solution annealed and quenched state (W temper), rapid onset of natural ageing increases hardness and reduces ductility within a few hours, creating a logistical challenge for the manufacture of frames by roll forming and bending, or other sheet metal forming operations. Here we investigate pre-ageing heat treatments of AA2024 with the aim of creating more stable and formable material conditions. Additionally, the production of stiffening structures on the formed sheet by wire-arc directed energy deposition (waDED) was studied. The evolution of materials properties after heat treatment is compared to natural ageing by extensive tensile test time series. Inhibition of secondary natural ageing by pre-ageing is demonstrated and a possible microstructural explanation is presented based on transmission electron microscopy and differential scanning calorimetry: S-phase is present in the pre-aged temper, and we propose that the formation of Mg/Cu-clusters is suppressed. Formability is assessed by forming limit curves and finite element simulation of three-roll-push bending of frame profiles. We observed improved processability of the pre-aged temper compared to a one week naturally aged condition. The modification of cold-formed sheets by stiffening structures made via waDED demonstrated that crack-free structures can be produced using AA2024 filler wire, enabling the additive modification of sheets and profiles with chemically compatible feestock.



Graphical abstract

Insights of Laser Additive Manufacturing Light Metals using in-situ Synchrotron X-ray Imaging

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Laser Additive Manufacturing (LAM), has the potential to revolutionize manufacturing processes for gernerating complex geometries directly from digital design. However, processing light metals such as aluminium and magnesium alloys have been problematic in LAM due to the excessive evaporation of low evaporation temperature elements and a high tendency to crack, not to mention high residual stresses and distortions, anisotropic microstructures and a large distribution of entrained defects. Therefore, the wider industraliasation of LAM for light metals is currently inhibited. It is critical to establish a scientific understanding of how to control and improve the printability of light metals in defect formation and thus optimise mechanical performance in LAM. Working with experts in alloy design, laser technology and Synchrotron radiation, synchrotron X-rays with an in-situ LAM rig, to observe, in both real and reciprocal space, the laser-matter interaction, defects formation, phase transformations and evolution of microstructural features in light metals at fast speed (> 40 kHz) was used. Taking advantage of the outstanding photon flux density at the European Synchrotron (ESRF) and Advanced Photron Source (APS), the ultra-high temporal resolution in combination with coherence levels which allow for imaging with high sensitivity makes the fast synchrotorn in situ X-ray imaging and diffraction of the LAM process possible. In this presentation, I will showcase our efforts in improving the printability of aluminium and magensium alloys using three different routes: change of environment pressure, modification to the alloying elements and change of thermal history. X-ray images clearly showed the improvement of the mechanical integrity of the build process for microstructure and defects control and provide us insight into the LAM process including the solidification pathway and formation of defects and microstructural. The results that I will present will provide new perspectives into the LAM process with relevance to microstructure and defects control in AM fabricated light metal components. They provide information that can contribute directly to industrial practice while producing quantitative data to inform and validate physical models in support of digital twins.

The effect of intermediate annealing on grain structure and texture evolution of thin 6016 aluminium alloy sheet

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Abstract

An intermediate annealing process was employed to study the grain structure and texture development of aluminium sheets produced from homogenized slabs. The as-received cold-rolled samples were examined following a solution treatment ranging from 5 and 30 minutes. The X-ray diffraction (XRD) was used to determine the structural development, and electron backscatter diffraction (EBSD) was used to establish the grain orientation of the as-rolled 6016 Al sheet alloy. The results indicated that the Al solid solution for each alloy sample at varying thermal annealing treatment crystallized in the fcc cubic system with varying dissimilar lattice parameters. Concurrently, the grain orientation of the samples showed relatively recrystallized equiaxed grains which were oriented randomly. When compared to the other alloys, it was discovered that the texture configuration for the 5min sample had a spatial distribution of {111}<101> cube grains.

Keywords: Al 6016 alloy; Homogenized Slabs; Annealing Process; EBSD.

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Scandium and rare earth light metal alloys: new opportunities from cheaper master alloys

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Scandium (Sc), yttrium (Y) and rare earth (RE) elements in particular cerium (Ce) and lanthanum (La) have long been considered as alloying elements for aluminium and magnesium but their application has been limited by the high prices of these elements.

Current light alloy RE hardener production uses expensive electrolytic or halide based processes. Scandium, in particular, has high prices but also has excellent increase in mechanical properties in 1xxx and 5xxx alloys, e.g.for marine applications.

Much of the scandia used to make master alloy is produced in China as a by-product from titanium pigment production. Platina Resources has a high grade scandium deposit in New South Wales and wishes to add value by developing a low cost AlSc master alloy production process. AlSc master alloy was produced by the team.

We are also investigating metallothermic reduction of oxides of Y, Ce and La as cheaper routes to make master alloys (see abstract in these proceedings by D. Rhamdani). We have verified that aluminium and magnesium can be used to reduce RE oxides to Al-RE intermetallics.

Similar metallothermic reduction chemistry can be used to recycle lithium ion batteries and extract nickel and cobalt. (see paper by D. Nababan in the proceedings).

Alloy opportunities include the use of Ce as an alternative to Si in aluminium casting alloys. Sc and Si are not compatible but Ce with Sc can potentially produce high strength casting alloys.

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Solidification-microstructure relationship study of single tracked laser scanned Mg-La based alloys

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Magnesium (Mg) is the lightest structural metal, and its high specific strength makes it competitive in weight-sensitive applications. It is difficult to manufacture complex-shaped parts with internal structures via conventional manufacturing. Hence, additive manufacturing (AM), a net-shape technology with high cooling rate nature, becomes an attractive fabrication method for Mg alloys. However, due to the high reactive nature and low evaporation temperature of Mg, it is pricy and dangerous to manufacture Mg alloys by AM. There has been limited work in additive manufactured Mg alloys, the solidification-microstructure-mechanical property relationship is still incomplete.

In this work, a cheaper and safer way, single-tracked laser scans with various linear energy input, was applied to Mg-La based alloys to mimic the rapid solidification during AM process. After laser scan, a refined cellular structure with diameter around 2 microns could be found within the melt pool, while the matrix (manufactured by high pressure die cast) has a microstructure around 20 microns. Besides, coarse grains were found within the melt pool, and each grain contains several cells, which is not found in the matrix material. Additionally, an elongated to equiaxed cellular structure morphology transition could be observed along the heat transfer direction. The work aims at understanding the formation mechanisms of the different grain structures and cellular structures and illustrating the effect of rapid solidification on microstructure evolution.

Comparing Microstructure and Mechanical Properties of AlSi10Mg Alloy Produced by Laser Powder Bed Fusion and High Pressure Die Casting Processes

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Laser powder bed fusion (LPBF) is an upcoming manufacturing technology finding its place in mainstream manufacturing with some benefits over high-pressure die casting (HPDC). This study examines differences in the microstructure and mechanical properties of AlSi10Mg alloy produced by these processes. Plates with different thicknesses were manufactured by both technologies. The HPDC microstructure was much coarser than that seen in LPBF. Differences in eutectic structure, solute silicon levels, and Si precipitation were detected. The plate thickness was found to have the opposite effect on the tensile properties of both manufacturing processes. The plate surface hardness of HPDC material was relatively high compared to the core. The opposite trend was observed in the LPBF samples. HPDC samples also showed greater tolerance to localised straining during tight radius bending than the LPBF samples. Substitution of LPBF for HPDC will require careful consideration of ductility requirements.

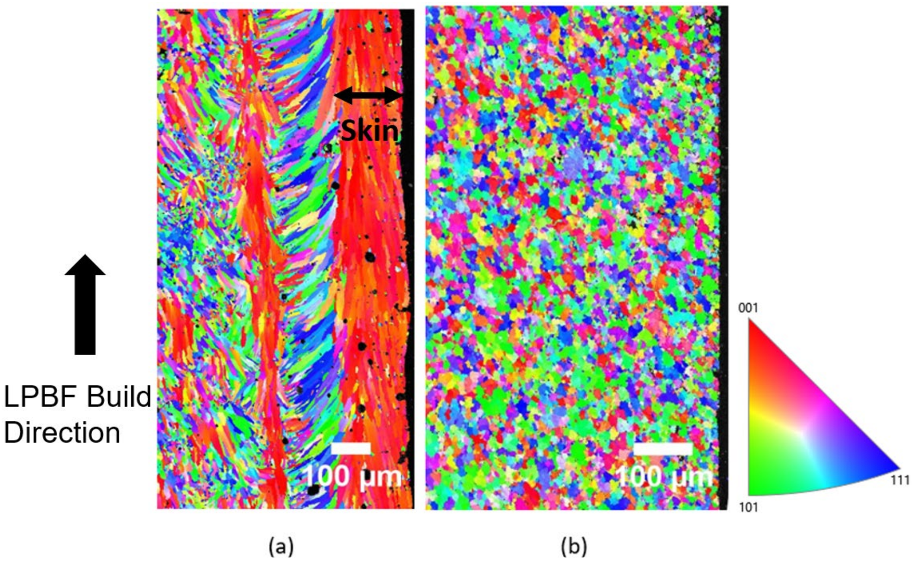

***Figure:** EBSD map comparison of the LPBF and HPDC AlSi10 alloy skin (a) Highly textured LPBF skin oriented along the build direction (b) Relatively low textured HPDC skin*

Inoculation treatment of additively manufactured aluminum alloys

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Considerable studies on metal selective laser melting (SLM) have proved the necessity to refine microstructure parts fabricated by SLM in order to eliminate property anisotropy, hot-tearing and to increase the SLM-processability. In the present works, several novel inoculants were discovered for various SLM-fabricated aluminum alloys. The inoculation treatment was capable of substantially eliminating the hot-tearing cracks and columnar structure, and refining the grains in the SLM-fabricated aluminum alloys in a broad processing window. The substantial grain refinement in the inoculated alloys was attributed to the coherent interface with Al matrix and the inoculators, and therefore significantly promoted the heterogeneous nucleation of the α-Al during solidification of melt pools in the SLM process. After proper heat treatments, all the SLM-fabricated alloys exhibited a superior balance of strength and ductility, which was comparable to their wrought counterparts. This work can be considered as a breakthrough in research of fabricating high-strength aluminum alloys using SLM.

Machine learning for high-performance Al alloys design assisted by failed experiments

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The increasing demands on the design of high-performance metallic alloys make the traditional trial-and-error approach impractical. Machine learning (ML) approached through empirical optimization and data-driven modeling bears great potential to streamline this process. However, such predictive models require high-quality data, the availability of which is limited by human biases in reporting results in the context of metallic alloy. In the present works, the significance of failed experiments to ML in designing high-performance aluminum alloys is demonstrated. The ML model initially trained only with successful Al alloys reported in the literature failed to discern the boundaries of success and failure. The designed alloys exhibited extremely poor ductility. The integration of this small amount of unsuccessful data points during training led to significant improvement in predictive performance, and thus designed high-strength Al alloys with acceptable ductility.

Efficient Computational Methods for the Prediction of Mechanical Behaviour of Additively Manufactured Parts

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The mechanical properties of additively manufactured (AM) parts are of critical importance in determining their suitability for the intended application. Due to the spatial variation in the microstructure of AM parts caused by local cooling rates, AM parts can have anisotropic, location-specific mechanical properties, which cannot be measured efficiently with physical testing. Additionally, the destructive testing of high-value AM parts is expensive. These factors motivate the need for the prediction of mechanical properties using computational homogenization (CH). CH is a mathematical technique that allows for the calculation of mechanical properties and associated quantities using microstructures as the input. We implement this technique for laser powder bed fusion (LBPF) AlSi10Mg parts and show that the predictions agree with the stress-strain curves obtained via mechanical testing. These results demonstrate the accuracy and efficiency of CH for AM parts allowing for: a reduction in the amount of destructive and expensive physical testing required for qualification and certification; the completion of a missing link in the process-structure-property-performance relationship in the Integrated Computational Materials Engineering (ICME) paradigm; and faster and more efficient builds.

In-situ Electro Plastic Treatment of Cold Sprayed Additive Structures: A New Solid-State Manufacturing Route for Rapid Reduction of Porosity and Brittleness in Cold Sprayed Grade 5 Titanium

Mohammed Abdul Khalik, Saden H. Zahiri, Suresh Palanisamy, Syed H. Masood,

Stefan Gulizia.

Keywords: Titanium CP, Cold spray additive manufacturing, Thermomechanical treatment, Thermomechanical processing, CP Titanium, Recrystallization, Grain refinement, Electroplastic.

Abstract:

Grade 5 (Ti-6Al-4V) is one the most used titanium alloys in aviation and defence for its superior properties. The high strength and hardness of the Grade 5 alloy make deformation and fabrication into final components more challenging. Cold Spray Additive Manufacturing (CSAM) of Ti-6Al-4V is an attractive high-output manufacturing option to produce Grade 5 Ti. However, CSAM structures, in general, and for Ti-6Al-4V in particular, suffers from the presence of porosity and brittleness. Heat treatment had been proposed to reduce porosity and improve mechanical properties. These treatments so far are found to be lengthy and energy-intensive, especially for titanium which needs a highly controlled oxidation prevention atmosphere at elevated temperatures.

This work presents a new (patented WO2018232451) process, In-Situ Electro-Plastic Treatment (ISEPT), to rapidly treat grade 5 titanium without the need for costly protective heating systems. In this process, the deformation load and electric current are applied simultaneously to the material in the same direction with the possibility of batch and continuous manufacturing. Initial findings indicated a reduction in recrystallization temperature below 500^{o}C from the reported 700^{o}C. The additively manufactured cold spray grade-5 titanium subjected to successive ISEPT treatments substantially reduced porosity and brittleness. The porosity was decreased from 12% to 0.1%, and that was accompanied by significant improvement in mechanical properties. The ISEPT also resulted in strengthening by grain refinement with a resulting grain size of 2 μm. The ultimate tensile strength (UTS) increased from 184 MPa in the as-CSAM condition to 1096 MPa after six passes. The ISEPT process that was conducted in the air without a protective atmosphere led to a maximum 0.15% increase in oxygen. Some discussion on the mechanism that led to a transformation of cold spray splat structure to dynamically recrystallized wrought structure will be provided.

Bifilms and my Churchill Fellowship

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Churchill Fellowships were established in the mid-60s in Australia after the death of Sir Winston Churchill. They assist individuals from all walks of life to "learn globally and inspire locally". My Fellowship focuses on gaining practical experience from overseas foundries that have embraced and adopted John Campbell's methods to reduce bifilms and produce superior quality casings. Upon return home this experience will be shared with Australian foundries by working with individual companies on adoption, plus presentations to promote outcomes. An overview of findings to date from visits to foundries in the UK and Norway will be presented. Case studies from Australia of some recent adoptions of John's methods for high performance automotive engines will be provided. The methoding from these case studies will be explained and shown in some detail.

An oxygen-stabilized face-centred cubic phase with superior mechanical properties in additively manufactured Ti-6Al-4V

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The existence of a face-centred cubic (FCC) titanium (Ti) phase in Ti alloys remains under debate over the past decades. In general, Ti has high chemical affinity with interstitials such as oxygen, leading to the formation of intermetallic compounds and dramatically diminishing ductility. Here, we demonstrate that interstitial oxygen can be incorporated into a Ti-6Al-4V alloy to improve its mechanical properties through the formation of an oxygen-containing FCC solid solution phase. This is achieved via selective laser melting, where the combination of high thermal stresses and thermal gradients facilitates a new phase transformation. Electron microscopy, atom probe tomography and density functional theory were used to reveal the crystallography (Fig. 1a) and chemical composition (Fig. 1b) of the new FCC phase. Our mechanical testings revealed that the introduction of the FCC phase dramatically enhances both the strength and ductility of the material (Fig. 1c).

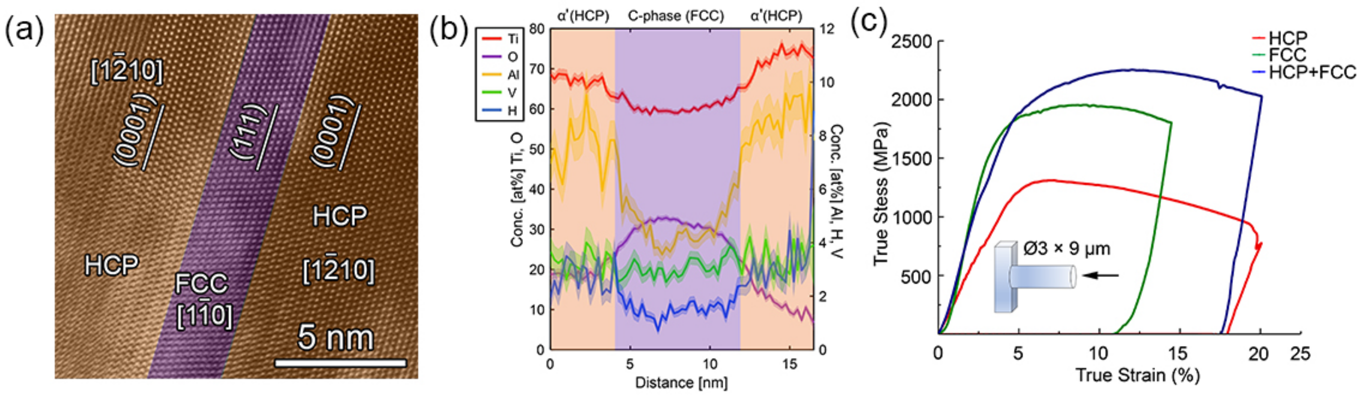

Figure 1. *(a) Atomic-resolution image taken from a dual-phase region. (b) Atom probe tomography result revealing the O rich nature of the FCC phase. (c) In-situ micro-pillar compression tests.*

Integrated Computational Materials Engineering for Rapid Light Materials Design: Additive Manufacturing to Fatigue Performance

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The use of additive manufacturing techniques such as selective laser melting (SLM) has increased in recent years, especially in the aerospace industry. Understanding and predicting the fatigue performance of these materials is important to assess their suitability for service applications. As fatigue property assessment can be time-consuming, accurate modelling techniques are an essential aid in reducing the experimental burden. Modelling and simulations ensure a rigorous assessment of a material through exposure to a variety of loading conditions. This is particularly critical for extreme environments as it is not always possible to inspect systems during service. The aim of this study was to develop a capability to accurately simulate the cyclic behaviour of titanium alloy Ti-6Al-4V, manufactured using SLM. A microstructure-sensitive crystal plasticity finite element (CPFE) model was developed to ensure the deformation-dependent internal stresses of the complex microstructure were included. The method utilises a modified Armstrong-Frederick kinematic rule, a latent hardening model, and a crack-band theory modified damage model, to integrate deformation damage and cyclic softening. The model was validated against symmetric strain-controlled cyclic experiments, where the softening and hardening behaviour of cyclic plasticity is modelled. The new capability will be used to investigate asymmetric loading, predict crack initiation, and evaluate the fatigue performance of additively manufactured light alloy materials and components during service.

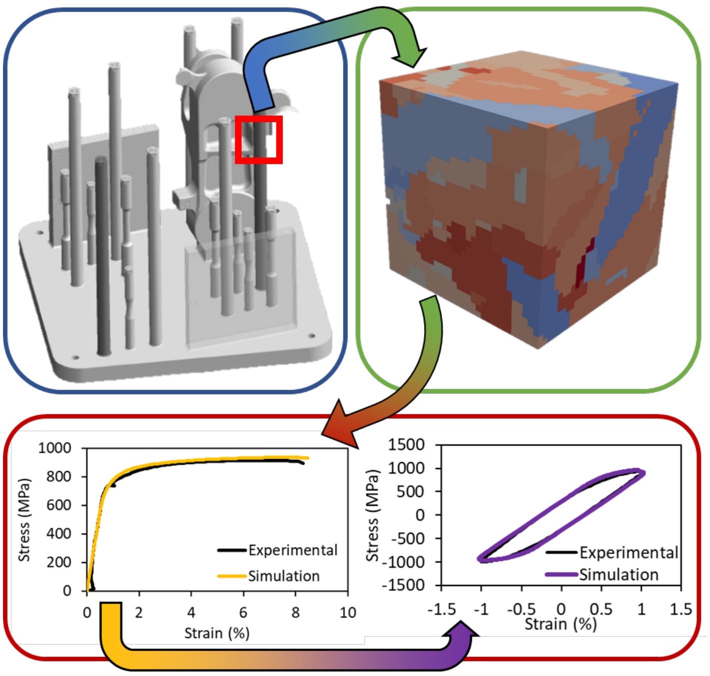

Figure 1 – Selective laser melted Ti-6Al-4V alloy specimens (top left) are characterised to construct statistically equivalent representative volume element (top right) for CPFE modelling. The model is calibrated using uniaxial tensile behaviour (bottom left) and validated against experimental data under fully reversed uniaxial cyclic loading (bottom right).

Aluminothermic Reduction for Recycling of Electronic Waste

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Electronic waste including end-of-life (EOL) lithium-ion batteries (LIB) contains valuable metals that can be recovered. The global increase in electric vehicles (EVs) uptake accelerates the number of EOL LIB that need to be managed and recycled. In this work, the use of different aluminium sources (chemical grade, waste swarf, and waste dross) as reductants for the recycling of $LiCoO_2$ LIB (the most common type of LIB for EVs) was demonstrated with focus on the separation of the Li and Co. Systematic thermodynamic analyses have been carried out using the FactSage thermochemical package to compare the effect of using different aluminium sources; to identify the optimum conditions and to evaluate the reaction products at various temperatures. Selected experiments were carried out to investigate the process. Particular processing conditions were observed to generate an ignition leading to melting of the samples (Fig. 1). In the case of reduction with chemical grade aluminium, Co could be extracted as Co metal or Co-Al alloy; while Li is distributed to Li (g) and slag. The impurities in the waste swarf and Al dross were found to affect the Co and Li products and their separation mechanism.

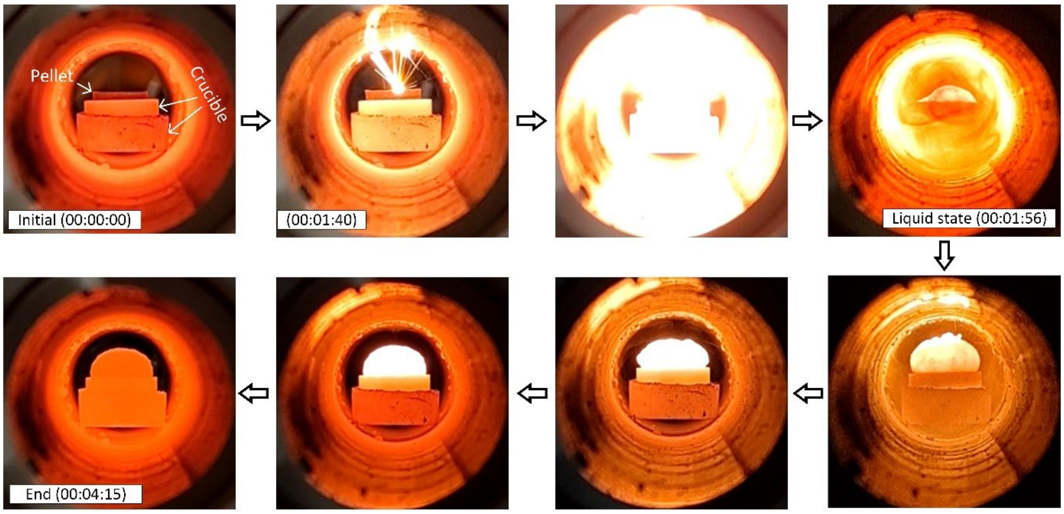

Figure 1 – Aluminuthermic reduction of LCO using pure Al showing the thermite ignition.

The project is funded by the Department of Industry, Science and Resources (DSIER) Australia, CSIRO, and Swinburne University of Technology

Rare earth light metal alloys: direct production route from rare earth oxide

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Rare earth elements alloying to Al or Mg could improve their mechanical and corrosion resistance properties. The current production route for making Al/Mg-RE alloy is expensive, thus limiting its application. One of the options that could significantly reduce production costs is by changing the RE source from RE Metals or halides to oxides; as the RE oxides price is approximately half of the price of RE metals in their equivalent metal content. Thermodynamics assessment shows that an Al/Mg-RE alloy could be made by means of metallothermic reduction. Even though Al/Mg oxide is less stable compared to most of RE oxide, Al/Mg could form an intermetallic or go into a solution which would enable the reduction process to proceed. Experimental study was also conducted to study the metallothermic reaction between Al or Mg with RE oxide (RE: La, Y, Ce). Results show that La_2O_3 and CeO_2 could be reduced by Al/Mg. La and Ce could dissolve or form intermetallic with Al or Mg. On the other hand, Y_2O_3 was not reduced by Al/Mg. In the Mg system, the Y_2O_3 was unreduced; while in Al system, Y_2O_3 was reacting with Al_2O_3 to form complex Y_2O_3-Al_2O_3 oxides. This metallothermic reduction process could potentially reduce the production cost and expand the application of Al/Mg-RE alloy.

This work was funded by BRIN, Platina Resources, Magontec, Grandfield Technology, CSIRO and Swinburne University of Technology.

Precipitation Sequence in Al-Sc-Zr Alloys Revisited

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The use of Scandium in Aluminium provides significant strengthening without affecting other key alloy properties such as corrosion resistance. Zirconium is also commonly added as it forms an Al_3Zr shell around the Al_3Sc particles, which enhances their thermal stability. Recent results have shown that Fe and Si impurities modify the precipitation kinetics of these $L1_2$ dispersoids but the full extent of these effects remains poorly understood.

Hardness and resistivity evolutions are commonly used as indirect techniques to rapidly assess the state of precipitation in aluminium alloys. In this work, we combine hardness and resistivity with thermoelectric power (TEPs) measurements to better understand the sequence of precipitation in a range of Al-Sc-Zr alloys. Using high-resolution energy dispersive X-ray spectroscopy (EDX) and atom probe tomography (APT), the presence of Si and Fe is detected in the core of the dispersoids, where their content decreases as a function of ageing time. The role of Si and Fe in the precipitation process is clarified through Density functional theory calculations. The presence of a new class of Fe-rich plate-like precipitates in the $\{100\}_{Al}$ is revealed via HAADF-STEM.

The impact of these findings on the development of new scandium containing aluminium alloys will be discussed.

Development of a non-equiatomic Ti40Zr25Nb25Ta5Al5 medium entropy alloy (MEA) for biomedical applications

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Abstract

A non-equiatomic Ti40Nb25Zr25Ta5Al5 medium entropy alloy (MEA) was designed by replacing 5 at.% Ta with 5 at.% Al in Ti40Nb25Zr25Ta10 alloy to reduce its density from 7.2 g/cm^3 to 6.5 g/cm^3, while maintaining its strength and ductility. The as-cast MEA showed tensile yield strength (σ_{ys}) of 990.4 ± 7.7 MPa and ductility of ~17%, above the minimum yield strength−ductility (759 MPa-10%) requirement for mill-annealed medical-grade Ti6Al4V (wt.%) alloy, which is premier implant material. The elastic modulus (E) of the Ti40Zr25Nb25Ta5Al5 MEA is 85 ± 7.8 GPa, which is significantly lower than that of Ti6Al4V alloy (120 GPa) and other recently reported HEAs/MEAs. Its admissible strain (ψ) was 1.16%, which exceeds that of Ti6Al4V alloy (0.74 %). A lower corrosion current density (i_{corr}) (6.1 × 10^{-5} mA/cm^2) was evident in Hank's solution than that of Ti6Al4V alloy (3.7 × 10^{-4} mA/cm^2), indicating its better corrosion resistance performance. The major surface oxides measured of this Ti40Nb25Zr25Ta5Al5 MEA were TiO_2, ZrO_2, Nb_2O_5, and Ta_2O_5, which provided excellent corrosion resistance. The excellent combination of strength-ductility and corrosion resistance properties makes this MEA a potential candidate for future metallic implant materials.

Eliminating defects, promoting equiaxed grains and improving the mechanical properties of additively manufactured titanium alloys with super-transus Hot Isostatic Pressing

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Solidification based processes including additive manfuacturing are susceptable to forming coarse microstructures and defects including porosity. This is particuarly relevent when using low quality feedstock that has impurities or surface contamination. This work demonstrates a technique for eliminating very large porosity (up to and exceeding 2mm in size) in titanium alloys while simultaniously promoting the columnar to equiaxed transformation with Hot Isostatic Pressing. After this transformation, part anisotropy is elminated and superior mechanical properties exceeding relevent ASTM standards are possible.

Microscopic and mesoscopic deformation behaviors of dual-phase Mg-Li-Gd alloy

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The Mg-Li dual-phase alloys, comprised of hexagonal and body centered cubic phases, exhibit a good combination of strength and ductility than Mg single-phase alloys. In this work, the deformation behaviors of Mg-6Li-2Gd and Mg-2Gd alloys, representatives of dual-phase and single-phase alloys, have been studied at both microscale and mesoscale to elucidate the underlying mechanisms. Using nanoindentations, the intrinsic strengths of the α-Mg phase and β-Li phase were evaluated. The Mg-6Li-2Gd alloy possesses a soft β-Li phase and a harder α-Mg phase than the single-phase Mg-2Gd alloy. Texture evolution and slip trace analysis show that during in-plane tension, the dominant slip system in the α-Mg phase of Mg-6Li-2Gd alloy is prismatic <a> slip, while that in the Mg-2Gd alloy is both basal slip and prismatic <a> slip, suggesting a lower ratio of CRSSprismatic /CRSSbasal in the former. The intergranular deformation incompatibility between the hard α-Mg phase and the soft β-Li phase is partly accommodated by local slip activities, as evidenced by the activation of multiple slip systems in the α-Mg grains neighboring the β-Li grains, yet still gives a HDI stress that strengthens the dual-phase alloy. DIC analysis reveals that the dual-phase alloy exhibits homogeneous plasticity at mesoscale. At large strain, the cracks originating from the Mg phase were found to be arrested in the β-Li grains. Both the homogeneous plasticity and the effective crack blunting of the β-Li phase ensure larger tensile elongation of the Mg-6Li-2Gd alloy than the Mg-2Gd alloy.

Heterogeneous nucleation of Fe-containing intermetallic compounds on native oxides in Al alloys

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Abstract

Effective refinement of intermetallic compounds (IMCs) is currently finite by our limited understanding of their heterogeneous nucleation. In this study, we present our latest advance in the understanding of heterogeneous nucleation of Fe-containing IMCs in Al-alloys. Heterogeneous nucleation of intermetallic compounds (IMCs) is inherently more difficult than that of a pure metal or a solid solution. It requires not only the creation of a crystal structure but also the positioning of 2 or more types of elements in the lattice with specified compositions. We demonstrated that heterogeneous nucleation of IMCs is difficult and requires large nucleation undercooling. The heterogeneous nucleation of multiple types of FIMCs on the native oxides/ inclusions formed in different Al alloys were investigated. Some direct evidences such as the heterogenous nucleation of θ-$Al_{13}Fe_4$ on the native $MgAl_2O_4$ was found and investigated. The mechanism of nucleation difficulties of Fe intermetallic compounds was discussed.

Keywords: Heterogeneous nucleation, intermetallic compounds, nucleation undercooling, oxides

LiME project: The Future LiME Hub was launched in November 2015 with sponsorship from the EPSRC, Industrial companies and the host university, Brunel University London. The Future LiME Hub is a national centre of excellence in liquid metal engineering based at Brunel University London in collaboration with our four spokes of Imperial College London, University of Oxford, University of Leeds and University of Manchester. Within this research programme we are conducting fundamental research to deliver a nucleation centred solidification science to underpin closed-loop recycling; are carrying out applied research to develop recycling-friendly high performance metallic materials and sustainable metal processing technologies to enable closed-loop recycling; operating a comprehensive outreach programme to engage potential stakeholders to ensure the widest possible impact of our research and are embedding a centre for doctoral training in liquid metal engineering to train future leaders to deliver long lasting benefits of closed-loop recycling.

Selected Outcomes:

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The application of X-ray computed tomography in self-piercing rivet joints

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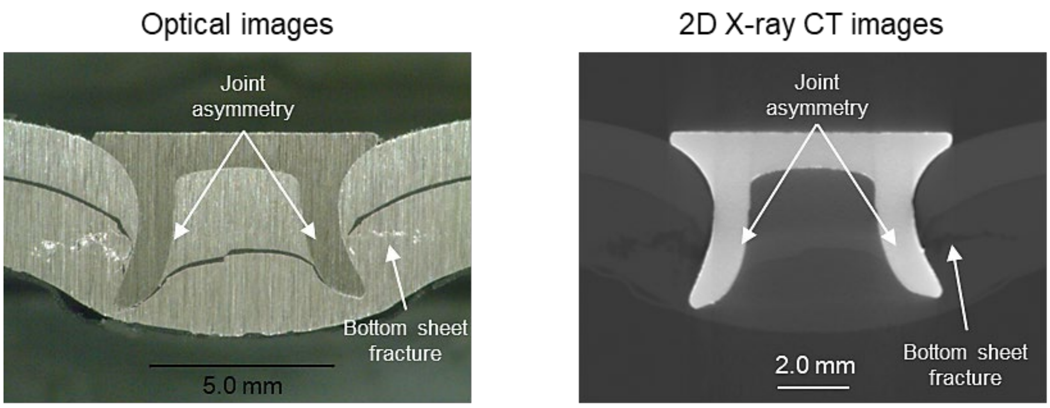
Mixed metals, such as aluminum and steel, are frequently used in the production of electric vehicles. Joining these material combinations using traditional fusion welding techniques is difficult due to the presence of coatings and the propensity to form brittle intermetallics. Self-pierce riveting (SPR) is a high-speed alternative to welding commonly used to join mixed materials in automotive applications. SPR joining offer numerous advantages over welding such as low energy input which aides a lower carbon footprint, compatibility with structural adhesives and the ability to join dissimilar and coated materials.

Successful SPR joining requires a thorough understanding of the development process and requirements. During development, joint quality is typically assessed using destructive optical cross-sections. This approach is limited in that only one section plane can be obtained and analyzed, which may lead to missed critical features. Therefore, there is a desire to be able to quantify the quality of an SPR joint in its entirety and non-destructively.

X-ray computed tomography (CT) is a promising non-destructive evaluation (NDE) tool used in many applications due to the ability to visualize the internal structure of the workpiece. There are only limited studies on the use of X-ray CT to evaluate SPR joint quality. This work demonstrates the use of X-ray CT on such joints. This NDE method can capture various joint defects including radial cracking, joint asymmetry, substrate fracture and cracked rivets. X-ray CT can identify key quality characteristics of SPR joints e.g., interlock, gaps and bottom layer thickness.



Comparison between (left) optical and (right) X-ray CT image of the SPR joint with joint asymmetry and sheet fracture.

Some New Insights into Grain Refinement of Light Metals

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Abstract

Grain refinement is a complex phenomenon. Effective grain refinement depends on the interplay between many factors, such as solid particles (nucleation potency, particle size and size distribution), alloy compositions (including both alloying and impurity elements) and solidification conditions (particularly cooling rate). The traditional wisdom for grain refinement has been searching for the most potent nucleating particles (i.e., particles with minimum nucleation undercooling), such as the well-known Al-Ti-B based grain refiners. Here I show that more significant grain refinement can be achieved by using more impotent nucleating particles. In this talk I will present the concept of explosive grain initiation and its consequences on grain refiner development.

Natural ageing mechanisms for pure and commercial Al-Si-Mg-(Xx) 6016 aluminium alloy sheet

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Age-hardenable aluminium alloys are widely used in automotive applications due to their light weight, fuel efficiency, recyclability, acceptable strength, and good corrosion resistance. 6016 aluminium is a 6000 series aluminium alloy with Si and Mg as major alloying elements, used in the automotive industry for body panels. However, during processing of this alloy for automotive applications, sheets may experience significant time spans (where the sheets commonly undergo natural ageing) between solution heat treatment at the aluminium supplier and age hardening upon the final paint bake cycle at the car making factory. Natural ageing even for a duration of only a few minutes may adversely affect material properties. The current study investigates the natural ageing mechanisms between the experimental 6016 aluminium alloy ((Al-1.0Si-0.6Mg-0.2Fe) and commercial type 6016 aluminium alloy (Al-1.0Si-0.6Mg-0.2Fe-Cr-Ti-Cu-Zn-Mn). During processing of the 6016 alloys, alloying elements were added and slabs were cast and machined. Subsequently, the slabs were homogenized, hot rolled to 6mm sheet, subjected to coil cooling simulation, annealed and cold rolled from 6mm to 2mm sheet. Samples were taken from the 2mm sheet and solution treated for 30 minutes at 530 ^{o}C as well as room temperature water quenching followed by natural ageing at room temperature for different durations. The results revealed that the hardness values of both the experimental and commercial 6016 alloys were similar. However, the alloys exhibited different natural ageing mechanisms where the experimental 6016 alloy seems to age by two distinct mechanisms and the commercial 6016 alloy aged by a single mechanism.

Grain Refinement Mechanism of Al Alloys Inoculated with TiB_2

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An essential foundry practice in Al industry is addition of grain refiners prior to casting to achieve grain refinement, with Al-Ti-B master alloy being the most widely used commercial grain refiners. However, the mechanism of grain refinement, including those underlying so-called "poisoning" effect caused by presence of Zr or Si in the alloy melt, is not well understood. In this work, extensive investigations have been carried out using the state-of-the-art HR-STEM and EDS/EELS to reveal the nature of TiB_2/Al interface at atomic scale and to disclose interfacial segregation of alloying elements and consequent effects on grain refinement. The results show that a 2-dimensional Al_3Ti compound (2DC) formed on the TiB_2 surface is responsible for the high nucleation potency of the diboride particles, leading to enhanced nucleation process and thus grain refinement. Zr or Si atoms in an alloy melt tend to segregate at the TiB_2/Al interface, resulting in dissolution of the pre-existing Al_3Ti 2DC and formation of Ti_2Zr 2DC or Si-rich 2DS layers, as shown schematically in Fig. 1. This leads to the decrease in nucleation potency of TiB_2 particles and thus the impediment of grain refinement, i.e., the poisoning effect. Significantly, the refining efficiency of commercial Al-3Ti-1B grain refiners has been promoted and stabilized to a level higher than 95% from 60% by optimizing the production (Optifine® of MQP Ltd) based on the findings in this work, which reduces the addition rate of the refiner and the cost by more than 50%.

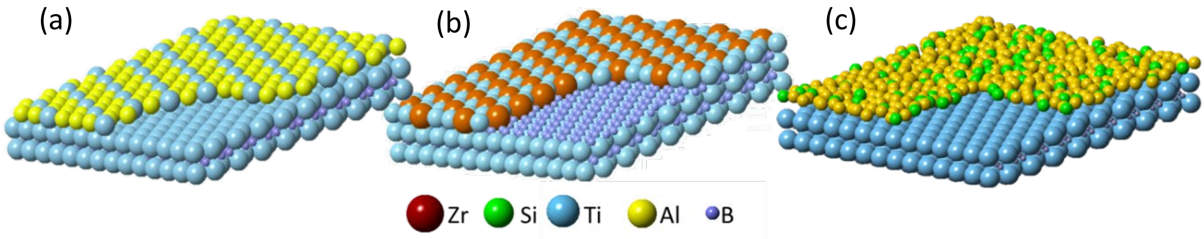

Fig. 1 Schematics showing segregation of (a) Ti, (b) Zr and (c) Si on (1000)TiB_2 surface at the TiB_2/Al interface, demonstrating the mechanisms for promoting grain refinement by (a) 2D Al_3Ti and impeding grain refinement (poisoning effect) by (b) 2D Ti_2Zr and (c) 2D Si-rich solution layers at the interface.

Developments in the multi-purpose high shear melt conditioning technology (HSMC) for processing Al and Mg alloys

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Casting is the first step towards the production of majority of metal products whether the final processing step is casting or other thermomechanical processes such as extrusion or forging. In all casting processes, liquid metal treatment is an essential step in order to produce high quality cast products. A new multi-purpose liquid metal treatment technology has been developed which comprises of a rotor/stator set-up that delivers high shear rate to the liquid metal. It generates macro-flow in a volume of melt for distributive mixing and intensive shearing for dispersive mixing. The high shear device exhibits significantly enhanced kinetics for phase transformations, uniform dispersion, distribution and size reduction of solid particles and gas bubbles, improved homogenisation of chemical composition and temperature fields and also forced wetting of usually difficult-to-wet solid particles in the liquid metal. Melt conditioning by application of intensive melt shearing of Al and Mg alloys has shown that oxide films that naturally exist in melts can be dispersed into individual particles which can act as potent nucleation sites. Due to this enhanced nucleation during solidification, significant grain refinement is achieved without any specific chemical inoculation. Hence, it can benefit various casting processes such as ingot casting, direct chill casting, high pressure die casting and twin roll casting, to produce high quality cast products with refined microstructure and enhanced mechanical properties. Here, we give an overview on the application of the new high shear melt conditioning (HSMC) technology to the processing of Al and Mg alloys.

Keywords: Light alloys, Intensive melt shearing, Casting, Melt conditioning, Grain refinement

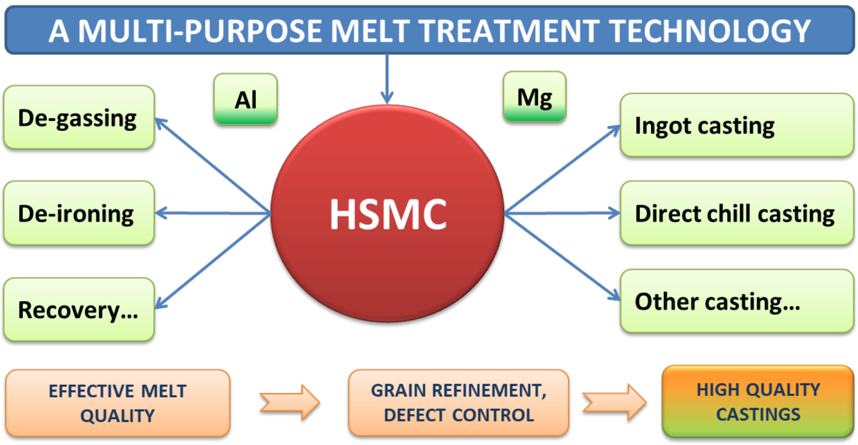

Figure 1: The multi-purpose high shear melt conditioning technology, applicable to conventional casting processes to enhance product quality.

Processing and characteristics of Mg microtubes for bioresorbable stent applications

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Magnesium (Mg) alloys have attracted increasing attention as potential metallic biomaterials for temporary biodegradable implants in orthopedic and vascular applications due to their mechanical, electrochemical and biological properties. However, Mg scaffolds still have some difficulties such as high degradation rate, low mechanical properties, difficult fabrication method, and some biocompatibility issues. In particular, the plasticity is crucial for biodegradable vascular stents that need to crimp on a balloon and then expand with large deformation during implantation. Processing and alloying are key approaches to improving the comprehensive properties of Mg alloys for biomedical applications.
This study investigates the microstructure, texture and mechanical properties of Mg-based microtubes fabricated by double extrusion for bioresorbable stents. Mg microtubes are manufactured by direct double extrusion at high temperatures. After double extrusion, the mechanical behavior of Mg microtubes is analyzed with respect to changes in microstructure and texture. Grain boundary strengthening and texture weakening enhance the plasticity of as-extruded microtubes.

Transformations, Recrystallization, Microtexture and Plasticity in Titanium Alloys; An Emerging View

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Engineering titanium alloys used in the aerospace industry offer unique examples of relatively coarse 2-phase microstructures in which the constituent phases, α(hcp) and β (bcc), are ductile, but elastically and plastically anisotropic. Our understanding of mechanical behaviour of such systems in relation to the scale, morphology and distribution of these phases coupled with their microtexture continues to evolve, even as highly successful, critical applications of the last 20 years have been largely guided by enlightened empiricism.

We describe different facets of the β to α transformation in titanium alloys. A dominant transgranular grouping of α variants with a common close-packed direction characterizes transformation patterns across the entire range of β stabilizer content. We find two distinct recrystallization processes during thermomechanical processing. The first is the well-known α globularisation process. A dynamic recrystallization process is also described in which newly recrystallized α and β grains form with the Burgers orientation relationship with each other. We call this process epitaxial recrystallization. We then present the role of transformation and recrystallisation texture on the development of plasticity in the α phase and on slip transfer between the α and β phases. Against this background, we examine some facets of dwell fatigue behaviour in titanium alloys, a topic that has been of considerable interest recently in the aeroengine community.

This work has been supported by Pratt and Whitney, USA, and the Asian Office of Aerospace Research and Development, USA. The support of the Indian National Science Academy with a fellowship is gratefully acknowledged.

Rapid hardening response of ultra-hard Ti-6Al-2Sn-4Zr-6Mo alloy produced by laser powder bed fusion

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Abstract

Post-heat treatment is critical for additively manufactured alloys to eliminate residual stress. It can significantly affect the microstructure and the mechanical performance. This study systematically investigated the hardening response of a Ti-6Al-2Sn-4Zr-6Mo alloy processed by laser powder bed fusion (LPBF) to a one-step heat treatment. The results revealed significant hardening at both 500°C and 650°C. Most notably, an ultrahigh peak-hardness of 563VHN was achieved within 5 mins of heat treatment at 650°C due to a unique martensite- decomposed α + β microstructure consisting of alternating long β laths that are ~5nm thick and α laths that are ~35nm thick, and within the α laths are also short β laths that are ~2nm thick with an ~11nm inter-spacing. The influence of both types of β laths on the α lath thickness was established and related to the ultrahigh hardness observed, which provides new insight for the design of new metastable LPBF-processed Ti alloys.

Keywords: Laser powder bed fusion, β-Ti alloy, age-hardening, Martensite

The Effects of Additive Manufactured TI-6AL-4V Surfaces on Biological Reactions of Fibroblast

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Rapid tissue integration of cardiovascular devices is of critical importance to reduce the high risk of bleeding at the surgical site and thrombosis at exposed surfaces, however, conventional manufacturing of titanium implants limits blood- and tissue-contacting surfaces to smooth or sintered exteriors. This study investigated the impact of 3D printed Ti-6Al-4V topographies by laser bed powder fusion (LBPF) process on mammalian and human fibroblast cell attachment and morphology.

Substrates were manufactured under different laser scanning speeds that created surfaces with various roughness. Inspired by 3D scaffolds, textures were applied on substrates which generated a much larger surface area for cell attachment. All samples were sand-blasted to minimise the risk of residual loose powders. The morphologies of LBPF substrates were assessed through scanning electron microscopy (SEM). Fibroblast cells were seeded on the printed substrates, and cell viability, attachment and morphology assessed at 48 hours post cell seeding.

SEM revealed powder particles were visible on the final surfaces even after sand-blasting owing to partial sintering; these mimic current sintered cardiovascular devices used in the clinical practice. MTS cell viability assays indicated the substrates were not cytotoxic, with cell viability similar to tissue culture polystyrene (TCPS) and polished titanium substrate controls. However, rougher substrates corresponding with higher scanning speed, showed increased cell adhesion than the polished control groups. Textured substrates showed reduced cell coverage compared to non-textured polished controls at 48 hours post cell seeding, suggesting longer culture periods may be required to achieve cell coverage across the larger surface area of the textured samples. The LBPF-produced textures show promising results in 2D cell culture experiments; however, we expect the main benefits to include mechanical interlocking of tissue in 3D-culture and implantation experiments. These techniques may be used for personalisation of devices with better tissue integration and fewer adverse events.

Three-dimensional Shape and Stress Field of a Deformation Twin in Magnesium

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Abstract

While the three-dimensional (3D) shape and stress field of a twin in hexagonal close-packed (HCP) metals have attracted considerable interest in recent years due to their substantial impact on internal stress and mechanical properties, a detailed understanding of their variation with twin size is still lacking. An analytical model that is not restricted by spatial scale is developed in this work by considering the effects of anisotropic boundary energy, elastic strain energy and plastic relaxation to predict the 3D shape with the minimum energy, and the stress field, of an isolated ellipsoidal twin of different sizes. The model is applied to Mg with a focus on the $\{10\bar{1}2\}$ twin type. The analytical results show that the nucleation of the nano-sized twin embryos is facilitated by the stress field near structural defects such as dislocations. During the expansion of this nano-sized twin embryo, the interplay between the elastic strain energy and interfacial energy changes the length of the twin along the twin shear (forward) direction from being shorter to longer than that along the lateral direction. In contrast to the current understandings, the maximum shear stress on the twin plane along the twin shear direction occurs at the lateral, rather than the forward, side of the twin. At the forward side, the maximum shear stress occurs at a distance ahead of the twin tip and this distance increases with increasing twin thickness.

Towards Fast, High-Fidelity Simulation in Metal Manufacturing Operations

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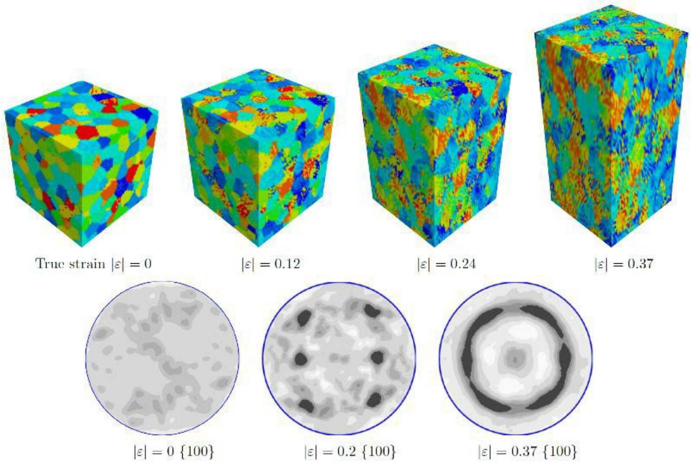
Accurate simulation of metal manufacturing operations has always required pushing the boundaries of what is practical with computing hardware. Metal manufacturing simulations are almost always more challenging than general structural simulations because of the multiple sources of non-linear behaviour with regard to the continuum mechanics being modelled and the potential for coupled physics to come into play. Examples of non-linear behaviour include stiffness changes due to deformation (geometric non-linearity), contact between various tooling and the workpiece (boundary non-linearity) and material non-linearity. Arguably material non-linearity is the most complex of these as material behaviours occurs at multiple length scales and a valid constitutive model must bridge across these length scales in order to provide an accurate solution across all possible material states being considered. Certain states encountered in a manufacturing operation may even require consideration of phase change in the material and subsequent tracking of multiple phases of material throughout a simulation (e.g. additive manufacturing, welding, casting), adding a further layer of complexity into the model. Other manufacturing operations, such as machining and trimming, require accurate prediction of failure in the workpiece material because failure is an integral part of that specific process. In forming processes failure is to be avoided but the accumulation of plastic strain is typically strongly impacted by the residual texture in the blank sheet material due to rolling. This necessitates consideration of anisotropic yield behaviour into account when modelling plasticity. Still further examples of material complexity include the activation and de-activation of additional slip planes in HCP materials such as Magnesium and Titanium alloys (twinning).

This keynote will discuss some of the challenges of accurate computational modelling across various metal manufacturing operations as well as present some solutions, both in terms of numerical approaches and hardware acceleration. The talk will also discuss collaborations with our university partners as well as our own internal development work with regards to developing high speed multi-scale GPU based finite element solvers. The talk will present examples of fast and high-fidelity metal manufacturing simulation including improvement of the incremental sheet forming process through virtual prototyping of the manufacturing operations.


True strain $|\varepsilon| = 0$
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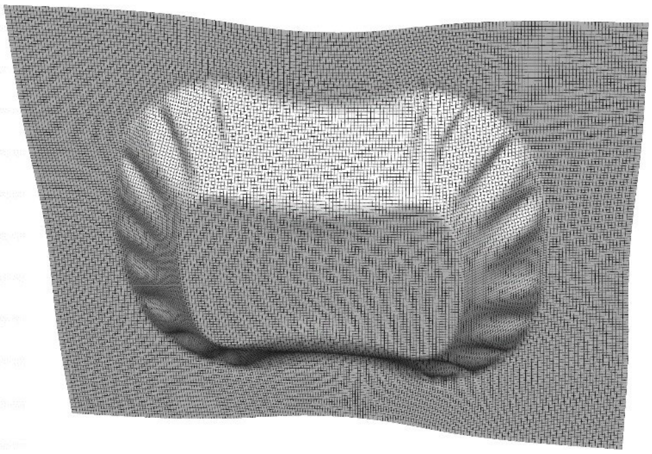

Simulation of Stress Development and Hot Tearing Formation of Aluminium Alloys during Casting Process

Gui Wang, Damian McGuckin, Matthew Dargusch, Jinyan Liu

Abstract

Hot tearing and cold cracking continue to be a major problem in both Direct Chill (DC) and large shape casting of aluminium alloys attributed their high thermal expansion value. To attain the materials performance needed in critical applications of the use of wrought aluminium alloys for aerospace structures, alloys are being developed with higher alloying content and an increasing ingot size. These tendencies lead to serious tearing/cracking defects during DC casting. Through both laboratory testing and numerical simulation, this paper looks at the development of a better understanding of the formation of defects and it relationship with the cast grain structure. Casting experiments were conducted using an experimental rig on Al-Zn and Al-Cu alloys to match the DC casting cooling condition. Data from the experiments was used to validate DC casting simulation models.

Keywords: Hot tearing, Solidification, Aluminium.

Novel Bainitic Ti Alloys Designed for Additive Manufacturing

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A novel bainitic titanium alloy system has been designed specifically for additive manufacturing (AM). The Ti-xCu-yFe alloys take advantage of constitutional supercooling to suppress the growth of large columnar grains usually associated with AM Ti alloys. The bainitic microstructure show refined α-phase within a matrix of β-phase. The intermetallic Ti_2Cu forms prevalently on the edge of the α-phase and within the β matrix. The high strength of these materials in the as-built condition is attributed to the high prevalence of fine α-phase and Ti_2Cu particle as well as significant solid solution hardening. This work demonstrates a viable way to fabricate structural; components with unique and excellent properties using low-cost elemental powders with AM.

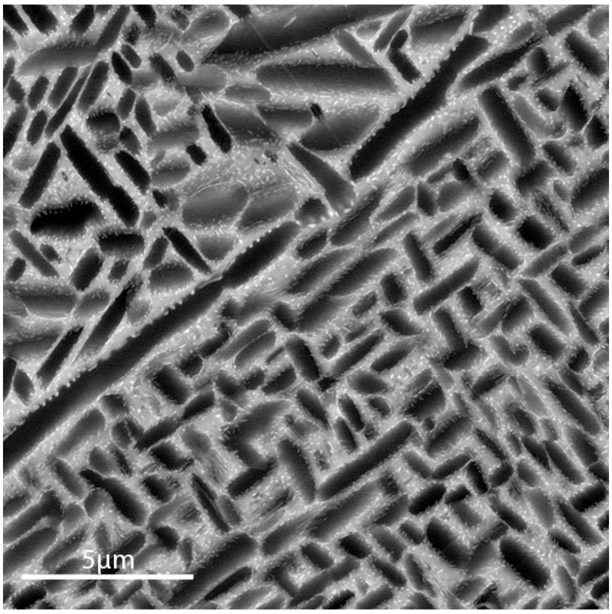

Figure 1: Typical bainitic microstructure of Ti-4Cu-4Fe(wt%) with α-phase forming within retained β-phase. The intermetallic Ti_2Cu forms between the α- and β-phase and throughout the retained β-phase.

X-ray imaging of Al alloy solidification: intermetallic compounds and defects

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X-ray imaging techniques have been increasingly used to study metal solidification in real-time. Thanks to advances in X-ray sources and detector technology, images can now be obtained with spatio-temporal resolutions sufficient to robustly extract quantitative information. This poster presents an overview of *in situ* radiographic studies of Al alloy solidification at Oxford University, focusing on the formation dynamics of ***intermetallic compounds (IMCs)*** and ***solidification defects***. The thrust is to understand how to control as-cast microstructure as a means to facilitate downstream processing and to promote greater alloy recirculation.

First, the ***formation and inoculation*** of primary $Al_{13}Fe_4$, a deleterious Fe-rich IMC in commercial Al alloys, were systematically investigated using a model, hypereutectic Al-3wt.%Fe alloy. The study of 4,531 IMCs in 56 experiments, covering a cooling rate range 0.5 Ks^{-1} to 4 Ks^{-1} and thermal gradient range **~**0 Kmm^{-1} to 8 Kmm^{-1}, showed that additions of Al-Ti-B and Al-Ti-C master alloys - normally added to promote α-Al grain formation - consistently increased the number density and formation rate of primary $Al_{13}Fe_4$ IMCs under all conditions. A model for IMC formation was proposed to explain the interplay between nucleants, solute diffusion fields and solidification conditions. Second, we used X-ray radiography to investigate ***fluid flow*** in mushy zones, the evolution of ***hot tears*** and the effect of Fe-rich IMCs on hot tear formation. Hot tearing initiated at lower solid fraction when IMCs were present due to reduced interdendritic flow. The largest, most damaging hot tears formed from many merging events, enhanced by the presence of IMCs.
(250 words)

Enhancing Mechanical Property Predictions in Aluminium Alloys using Data-Driven Class-Based Regressors

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Aluminium (Al) alloys are widely utilised in the transportation, construction, and marine industries due to their favourable mechanical attributes. Studies into the relationship between the structure and properties of Al alloys have been conducted to predict these mechanical properties and aid in designing new alloys. This research introduces a novel classification of aluminium alloys identified through unsupervised learning. The categorisations are subsequently used to introduce an approach to improve the accuracy of mechanical property predictions by using data-driven class-based regressors. Individual random forest regressors are trained for each of these classes. Further, our results demonstrate that these class-based regressors outperform those based solely on domain knowledge.

The effect of heat treatment on the microstructure of additively manufactured Ti-Cu

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Additively manufactured (AM) Ti-Cu alloys have shown promising mechanical properties compared to AM Ti-6Al-4V. Equiaxed grains have been observed in as printed Ti-Cu samples, unlike the columnar grains of as printed Ti-6Al-4V. The hyper-eutectoid samples had a high strength although this was at the cost of a relatively low elongation at failure. One of the methods that can be used to increase elongation is to heat treat or stress relieve the builds.

Before tensile samples were heat treated, the microstructure of smaller cube samples was first investigated. These samples were manufactured using Directed Energy Deposition (DED) and had a composition of Ti-7.5Cu as-built. They were heat treated at 600°C and 700°C for four-time lengths; 5, 10, 20 and 40 minutes. The scale and morphology of the microstructure changes were then observed.

It was found that multiple microstructural phases were present in the samples, and these modified with heat treatment. The initial very fine lamellar pearlite microstructure is seen in Figure 1a. Heat treatment was observed to coarsen and reduce the aspect ratio of the Ti_2Cu lamellae. Additionally, coarser lamellae found along nodule boundaries, also coarsened with higher temperatures, and longer heat treatment times. These microstructural changes will be assessed to determine the advantages or otherwise of the heat treatment on the tensile properties particularly the elongation to failure metric.

This work is completed in collaboration with the Defence Science and Technology Group (DSTG).

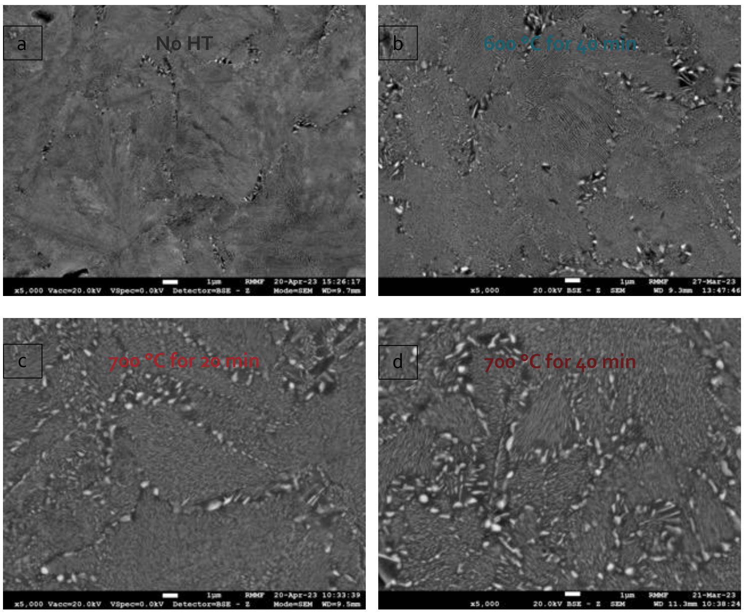

Figure 1: Microstructure of samples with (a) no heat treatment, (b) 600°C for 40 minutes and 700°C for (c) 20 and (d) 40 minutes.

Towards a "Green Aluminum" Paradigm – Processing Pathways for a Closed Loop Circular Economy Model

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Aluminum (Al) castings are widely used for light-weighting applications in the transportation and manufacturing industries to reduce energy consumption and carbon footprint. However, primary production of Al is energy-intensive with extensive CO_2 emission. Re-melting Al scrap only uses ~5% of the energy (and reduced emission) required to produce primary Al from ores. The amount of Al available for recycling is estimated to double by 2050, providing a huge opportunity to have a near closed loop cycle for Al, following circular economy principles. This presentation looks at effective utilization of the ever-expanding global Al scrap stream to develop value added alloys for casting applications. The mechanical properties of secondary (recycled or green) Al alloys are often limited by their high Fe contents, due to the formation of brittle β-Al_5FeSi phase which reduces the alloy's ductility. We address the challenges from two different pathways: ***One*** is to remove the "bad actors" through metallurgical processing methods using external forces: mechanical, gravitational, or electrical (at UCI); whereas the ***second*** approach (at OSU) is to mitigate the effect of the "bad actors" influencing the effects of microalloying (such as Mn, Cr and Sr) and cooling rate on the formation of Fe-containing intermetallic phases in secondary Al-Si-Mg based alloys (Figure 1). For example, a new recycled alloy with high Fe content (about 0.5wt.%) showed comparable mechanical properties to a typical primary die cast alloy (≤ 0.2wt.%) with similar composition. A progress report on these two pathways will be presented and reviewed.

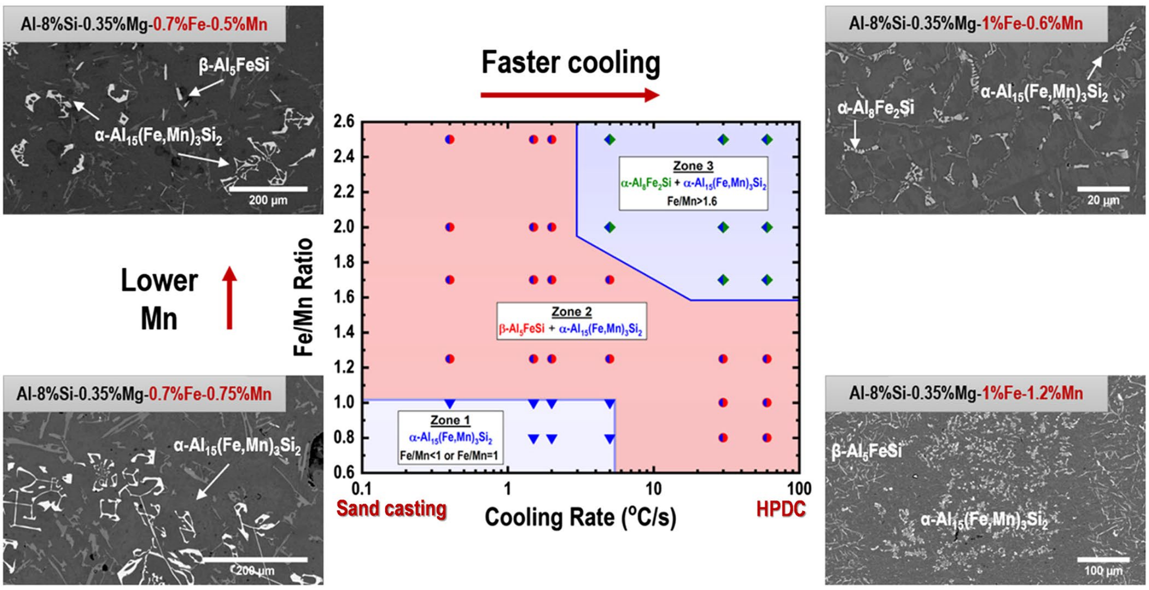

Figure 1. A formation map of Fe-containing intermetallic phases: effects of cooling rate and Fe/Mn ratio on intermetallic phase formation in Al-Si-Mg alloys with high Fe contents.