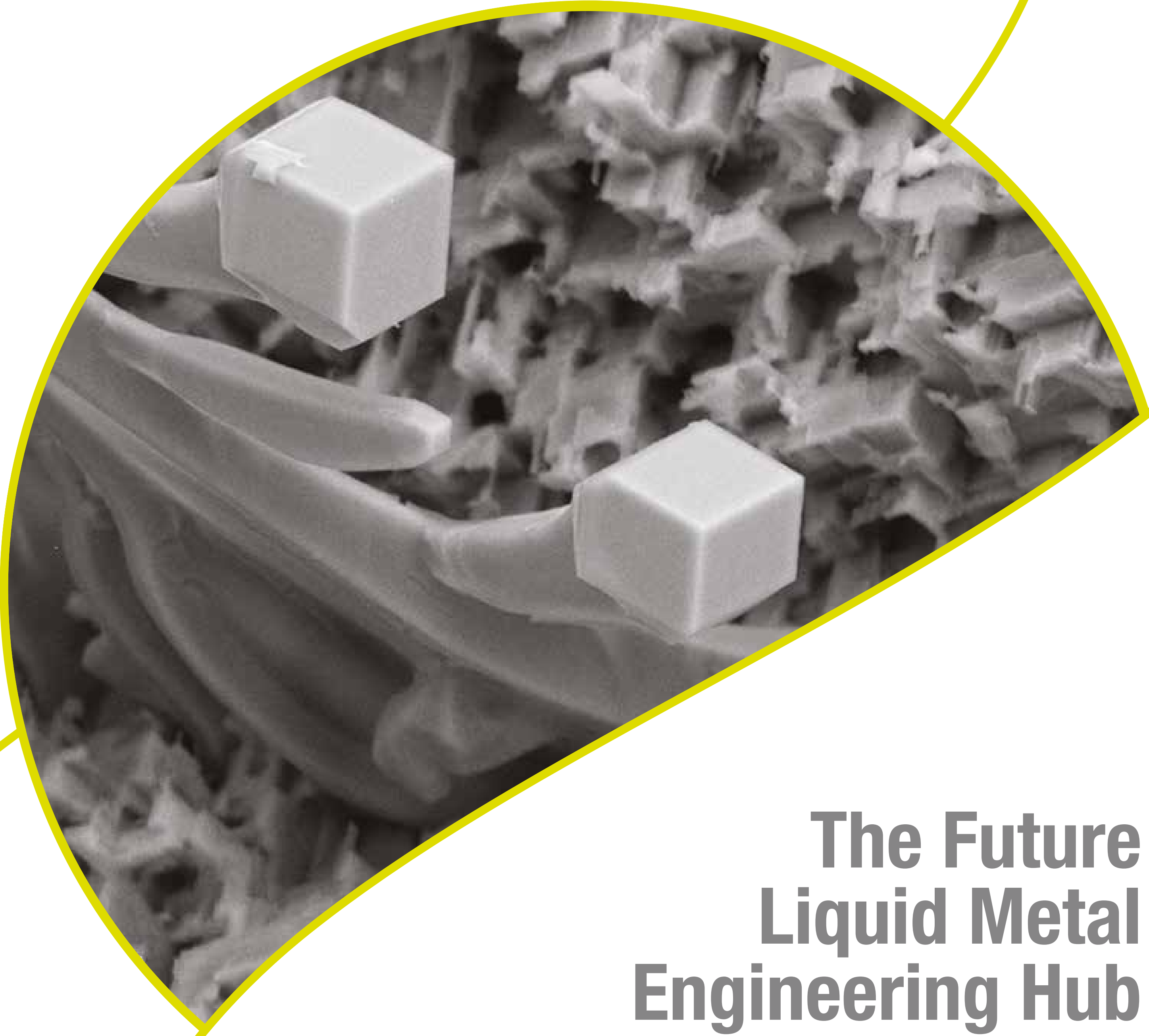
LiME
Liquid Metal Engineering Hub



The Future Liquid Metal Engineering Hub

REPORT 2018

EPSRC
Engineering and Physical Sciences Research Council

Brunel University London

UNIVERSITY OF OXFORD

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The University of Manchester

Welcome

Dear Friends,

It gives me great pleasure to welcome you to the Future LiME Hub 2018 Report.

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 Oxford, Leeds and Manchester universities and Imperial College London.

The past twelve months have been full of activity. The focus for the Future LiME Hub remains centred on our vision of full metal circulation, working to ensure that the fundamental research is not only advancing, but is also transferable to the wider industry, which is highlighted by our extensive and growing connections with our industrial partners. Our focus on building and connecting with our international community remains and since the Hub started we have hosted one international conference, the 6th Decennial Conference on Solidification Processing (SP17) in 2017, and are about to host a second, the 11th International Conference on Magnesium Alloys and Their Applications (Mg2018) in July 2018. The launch of our second Advanced Centre, the Advanced Metal Processing Centre (AMPC), signifies further opportunities and technological developments within the Hub allowing our industrial partners to develop laboratory technologies through to production scale.

We welcome you, as always, to join us from both academic and industrial sectors for national and international collaborations through appropriate mechanisms at all levels. With your support, help and participation, we can continue to work to turn our dream of full metal circulation into a reality for our future generations.

Yours faithfully,

Professor Zhongyun Fan
Director of the Future LiME Hub

LiME
Liquid Metal Engineering Hub

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The Future LiME Hub
Brunel University London
Uxbridge, Middlesex, UB8 3PH

lime@brunel.ac.uk
+44 (0) 1895 267 703

Team Contacts

Professor Zhongyun Fan
Director/Principal Investigator
Brunel University London

E zhongyun.fan@brunel.ac.uk
T +44 (0) 1895 266 406 / 266 413

#metallurgy #solidification #materialsprocessing #heterogeneousnucleation #alloydevelopment

Dr Mark Jones
LiME Manager
Brunel University London

E mark.jones@brunel.ac.uk
T +44 (0) 1895 268 880

#management #technologydevelopment #innovation #industry

Miss Lauren Wigmore
LiME Administrator
Brunel University London

E lauren.wigmore@brunel.ac.uk
T +44 (0) 1895 267 703

#outreach #administration #communications

Professor Geoff Scamans
Co-investigator
Brunel University London

E geoff.scamans@brunel.ac.uk
T +44 (0) 1895 268 571

#recycling #aluminiumalloys #corrosion #oxidation #transport

Professor Patrick Grant
Co-Investigator
University of Oxford

E patrick.grant@materials.ox.ac.uk
T +44 (0) 1865 283 763

#solidification #microstructuralevolution #novelmanufacturing #highentropyalloys

Dr Christopher Gourlay
Co-Investigator
Imperial College London

E c.gourlay@imperial.ac.uk
T +44 (0) 20 7594 8707

#solidificationprocessing #sustainablemanufacturing #industry #intermetalliccrystalgrowth

Professor Xiaorong Zhou
Co-Investigator
University of Manchester

E xiaorong.zhou@manchester.ac.uk
T +44 (0) 161 306 4832

#corrosion #lightalloys #electronmicroscopy

Professor Andrew Mullis
Co-Investigator
University of Leeds

E a.m.mullis@leeds.ac.uk
T +44 (0) 113 343 2568

#crystallisation #metallicmaterials #semisolidprocessing #rapidsolidification #phasefieldmorphologies #intermetallics

Professor Hamid Assadi
Associate Co-Investigator
Brunel University London

E hamid.assadi@brunel.ac.uk
T +44 (0) 1895 268 478

#virtualengineeringcentre #modelling #solidification #simulation

Professor Isaac Chang
Associate Co-Investigator
Brunel University London

E isaac.chang@brunel.ac.uk
T +44 (0) 1895 268 491

#LiMEtrainingcentre #highentropyalloys #industrialapplication

Dr Changming Fang
Associate Co-investigator
Brunel University London

E changming.fang@brunel.ac.uk
T +44 (0) 1895 267 688

#heterogeneousnucleation #atomicmodelling #lightmetals

Dr Shouxun Ji
Co-Investigator
Brunel University London

E shouxun.ji@brunel.ac.uk
T +44 (0) 1895 266 663

#castingtechnologies #aluminiumalloys #magnesiumalloys #highpressurediecasting #castiron

Dr Chamini Mendis

Associate Co-Investigator
Brunel University London

E chamini.mendis@brunel.ac.uk
T +44 (0)1895 268 502

#magnesium #microstructurecharacterisation #thermomechanicalprocessing #phasetransformations #electronmicroscopy

Dr Jayesh Patel

Co-Investigator
Brunel University London

E jayesh.patel@brunel.ac.uk
T +44 (0) 1895 267 105

#technology #innovation #industrialapplication #international

Dr Yun Wang

Co-Investigator
Brunel University London

E yun.wang@brunel.ac.uk
T +44 (0) 1895 268 536

#fundamental #solidificationprocessing #heterogeneousnucleation #lightmetals #highresolutiontransmissionelectronmicroscopy

Professor Dmitry Eskin

Co-Investigator
Brunel University London

E dmitry.eskin@brunel.ac.uk
T +44 (0) 1895 265 317

#moltenlightalloys #ultrasonicprocessing #directchillcasting #aluminium

Professor Alain Jacot

Associate Co-Investigator
Brunel University London

E alain.jacot@brunel.ac.uk
T +44 (0) 1895 265 358

#modelling #solidification #microstructuresimulation

Dr Hari Babu-Nadendla

Co-Investigator
Brunel University London

E hari-babu.nadendla@brunel.ac.uk
T +44 (0) 1895 265 466

#grainrefinement #crystalgrowth #nanostructure #superconducting

Dr Yan Huang

Co-Investigator
Brunel University London

E yan.huang@brunel.ac.uk
T +44 (0) 1895 266 976

#thermomechanicalprocessing #aluminium #thermodynamics #combinedsolidification #lightalloys

Dr Brian McKay

Co-Investigator
Brunel University London

E brian.mckay@brunel.ac.uk
T +44 (0) 1895 266 409

#heterogeneousnucleation #grainrefinement #electronmicroscopy #composites

Professor Peter Jimack

Co-Investigator
University of Leeds

E p.k.jimack@leeds.ac.uk
T +44 (0) 113 343 2002

#fluiddynamics #algorithms #scientificcomputing

Dr Simon Butler

Head of AMCC and AMPC
Brunel University London

E simon.butler@brunel.ac.uk
T +44 (0) 1895 268 561

#casting #processing #industry

Professor Luiz Wrobel

Co-Investigator
Brunel University London

E luiz.wrobel@brunel.ac.uk
T +44 (0) 1895 266 696

The Future LiME Hub

Brunel University London
Uxbridge
Middlesex
UB8 3PH

E lime@brunel.ac.uk

Introduction

Metallic materials are the backbone of the manufacturing industry and metal casting, and play a pivotal role in fuelling economic growth. Metal castings are used in over 90 % of all manufactured goods and in nearly all manufacturing machinery. The UK metal casting industry adds 2.6 bn/year to the UK economy, employs 30,000 people and produces 1.14 MT of metal castings. It underpins the competitive position of every sector of UK manufacturing across automotive, aerospace, defence, energy and general engineering. However, the industry faces severe challenges, including having been "hollowed-out" over the past 30 years, increasing energy and material costs, tightening environmental regulations, a shortage of skilled people and fierce competition from the emerging economies.

Therefore, we established the Future Liquid Metal Engineering Hub (Future LiME Hub) to address these challenges. The core Hub activities are based within BCAST at Brunel University London and are strongly supported by the complementary expertise of our academic spokes at Oxford, Leeds and Manchester universities and Imperial College London. We have identified closed-loop recycling of metallic materials as the single greatest challenge and opportunity facing the global manufacturing industry, formulating our dynamic Future LiME Hub research programme in combination with our ever-expanding industrial partners.

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 with further 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.

Vision

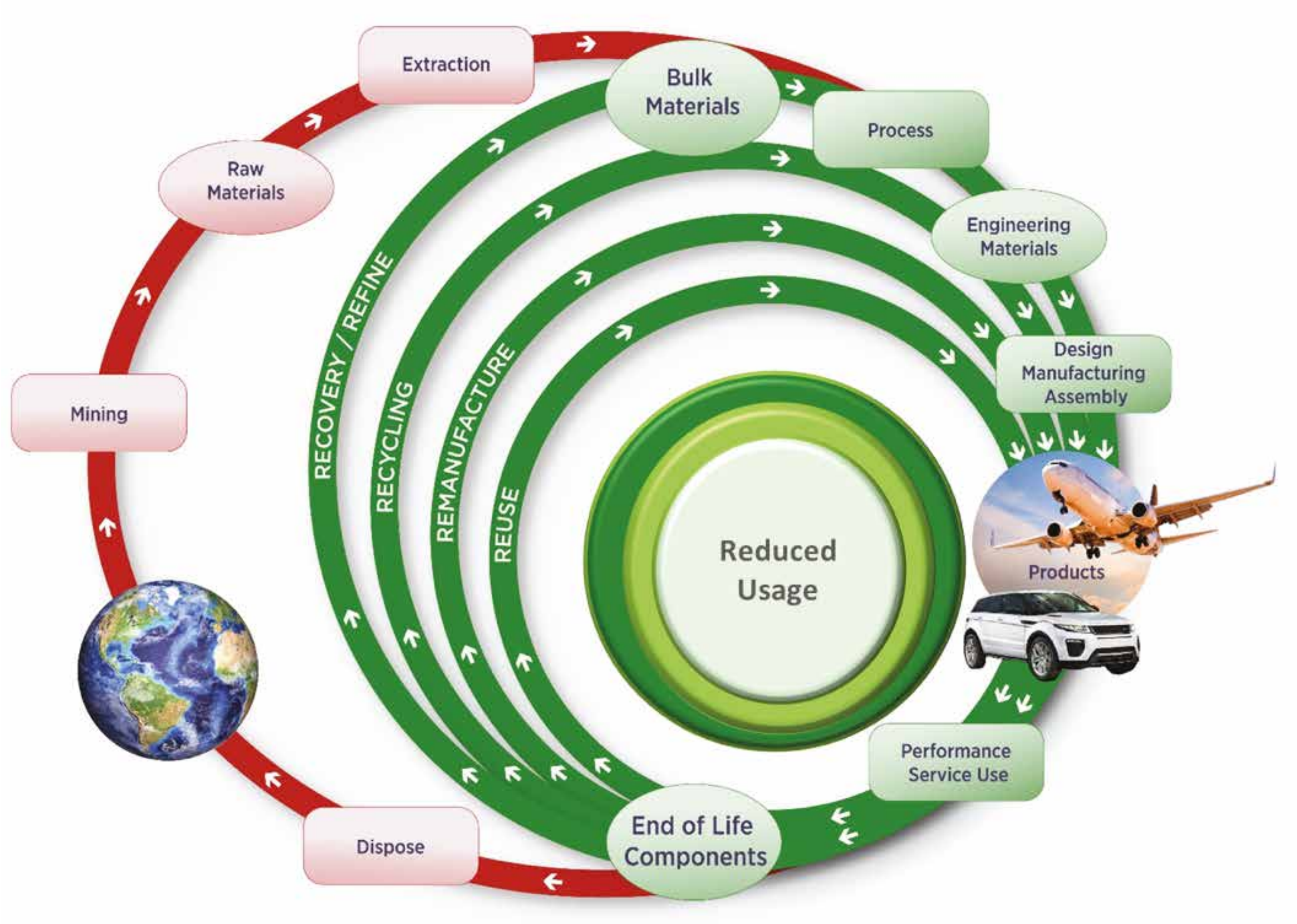


FIGURE 1: Schematic illustration of the Future LiME Hub full metal circulation vision.

The long-term vision of the Future LiME Hub is full metal circulation, in which the global demand for metallic materials is met by a full circulation of secondary metals (with only limited addition of primary metals each year) through reduced usage, reuse, remanufacture, closed-loop recycling and effective recovery and refining of secondary metals, illustrated in Figure 1.

This vision represents a paradigm shift for metallurgical science, manufacturing technology and the industrial landscape. This vision is shared by both our academic spokes and our continually expanding group of industrial collaborators. The Future LiME Hub is laying down a solid foundation for the full metal circulation concept.

Objectives

The Future LiME Hub aims to establish the scientific basis, technological approach and industrial strategy for full metal circulation demonstrated through closed-loop recycling of light metals (Figure 1). More specifically, the following objectives have been set for the programme:

- Remain an international leader of liquid metal engineering in fundamental research, technology development and industrial applications.
- Create, deliver, disseminate and exploit a high quality and multidisciplinary research programme co-created with users to address the closed-loop recycling of metallic materials.
- Be a key source for recycling-friendly advanced metallic materials, sustainable metal processing technologies and innovative industrial applications for the UK manufacturing industry and its supply chain.
- Train future leaders in liquid metal engineering.
- To further nurture both national and international collaborations in fundamental solidification research and industrial applications.
- Continue to drive forward an extensive outreach programme to engage with further stakeholders to deliver the widest impact of the Hub's research.
- Continue to develop a growing number of academic and industrial collaborators and further establish the Future LiME Hub as the leading UK resource for solidification research and technological development.

Management

The Future LiME Hub continues with the same management structure presented in the 2017 Future LiME Hub report, proven to be very effective since the start of the programme. Within this management structure Professor Zhongyun Fan (right of picture) works directly with Dr Mark Jones (left of picture) to drive forward the Future LiME Hub vision and deliver the research programme's aim and objectives.

Professor Fan is also supported by the Hub Administrator (Lauren Wigmore) and the Hub Management Group (team shown below), and is advised by an International Advisory Board (IAB) and an Industrial Steering Panel (ISP), each detailed in the following pages. It has been a very positive year for the Hub management team, showcased by the successful development and application of the research, validated by the most recent IAB and ISP meetings. Furthermore, at the IAB meeting, the panel members agreed that the Hub management team was functioning very effectively and the operation, structure and governance should in no doubt remain going forward.

International Advisory Board

The International Advisory Board (IAB) members stand as experts in the areas of the Future LiME Hub's research. They advise the LiME Hub Management Group on strategic research directions and opportunities in solidification and casting research, benchmark the quality and progress of the Hub's research against the international stage and participate in the Hub's international activities. The members come from a number of renowned institutions from across the globe and have many years of experience within the field.

Professor Lorenz Ratke
Chairman
German Aerospace Centre (DLR), Germany

Current members of the IAB are pictured above. From the left: Professor Zhongyun Fan, BCAST, UK; Professor Wilfried Kurz, Swiss Federal Institute of Technology Lausanne (EPFL), Switzerland; Professor Lorenz Ratke (Chairman), German Aerospace Centre (DLR), Germany; Professor Lindsay Greer, University of Cambridge, UK; Professor John Perepezko, University of Wisconsin-Madison, USA; Professor David StJohn, University of Queensland, Australia; Professor Lars Arnberg, Norwegian University of Science and Technology (NTNU), Norway and Professor Karl Kainer, Helmholtz-Zentrum Geesthacht, Germany.

The IAB meets with the LiME Hub Management Group and researchers annually to receive and review updates on the Hub's research and operational progress. The board have the opportunity to discuss developments and make suggestions for the future direction of research and industrial engagement.

The first IAB meeting with the LiME Hub team was held on 8 April 2016, coinciding with the official launch of the Advanced Metal Casting Centre (AMCC) on 7 April 2017. The second IAB meeting was held prior to the 6th Decennial Conference on Solidification Processing (SP17) on 24 July 2017, hosted by BCAST, with members joining this prestigious conference for the remainder of the week. At this most recent meeting, the board concluded that the Future LiME Hub's international reputation had advanced since the previous meeting, and based on the quality of publications and citations, it was deemed to be very strong. The board was also impressed with the breadth and depth of the Hub's research, particularly its extensive collaboration with a diverse industry portfolio, other academic institutions and the variety of funding organisations, extending beyond the UK landscape.

The next IAB meeting will be held prior to the 11th International Conference on Magnesium Alloys and Their Applications (Mg2018) in July 2018, which will also be hosted by BCAST, with full details provided later in this report.

Industrial Steering Panel

The Industrial Steering Panel (ISP) represents the key strategic interests of the current and potential end-users of the research carried out within the Future LiME Hub. The members of the panel represent a wide array of contributors from casting and metallic processing industries to the manufacturers and users of the end products. They advise on the potential future opportunities for the Hub's research to be applied to industrial and manufacturing needs and help to ensure the industrial relevance of our applied research.

Mr Martin Jarrett
Chairman
Constellium

The main objective of the ISP is to provide independent advice from an industrial perspective on the progress of the projects and the overall strategic direction and relevance of the Hub's research. ISP membership is reviewed by the Hub Management Group annually to reflect the dynamic nature of the research programme. Many new members joined the panel at the most recent meeting held on 10 January 2018, identifying clear growth and expansion of the Hub's industrial research requirements, leveraged from the continual dissemination and wider sharing of the Hub's state-of-the-art research. The panel were impressed by the advancement in industrial pull since the previous meeting held on 20 January 2017, and were looking forward to seeing many of the technologies and alloy developments currently at TRL3-6 being developed through to full commercialisation, with key examples presented by Constellium and Jaguar Land Rover. Fundamental research highlights were also presented and were well received by the panel. The panel were also very supportive of the new Advanced Metal Processing Centre (AMPC), which will further advance the in-house scale-up facilities at BCAST, providing industry with the capability to scale-up the research within the Hub. The AMPC was officially launched on 13 June 2018 with most of the panel members in attendance. Furthermore a new communications strategy was developed, presented and discussed, with the panel reaching consensus on a final version which will be actioned over the up and coming year.

Current members of the ISP are:

Mr Emmanuel Beslin
Constellium

Mr Paul Blake
Jaguar Land Rover

Mr Keith Denholm
Grainger & Worrall

Mr Henry Dickinson
Norton Aluminium

Mr Anthony Evans
Sarginsons

Mr John Ford
Aeromet

Mr Marcus Henry
Jaguar Land Rover

Mr Craig Jennings
Nissan UK

Professor Graham Machin
National Physical Laboratory

Mr Andrew McNally
Nissan UK

Dr Pam Murrell
Cast Metals Federation

Dr Shyeni Paul
EPSRC

Mr Carl Schubeler
Renault

Dr James Smith
Jaguar Land Rover

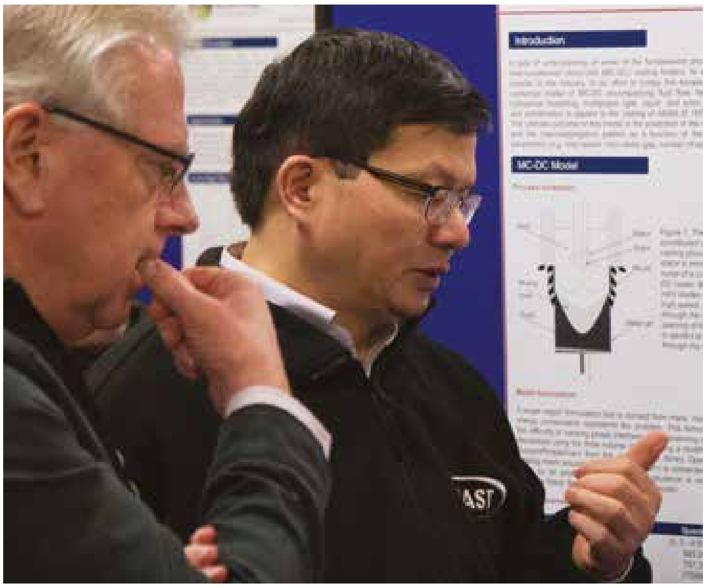
Mr Jack Strong
Grainger & Worrall

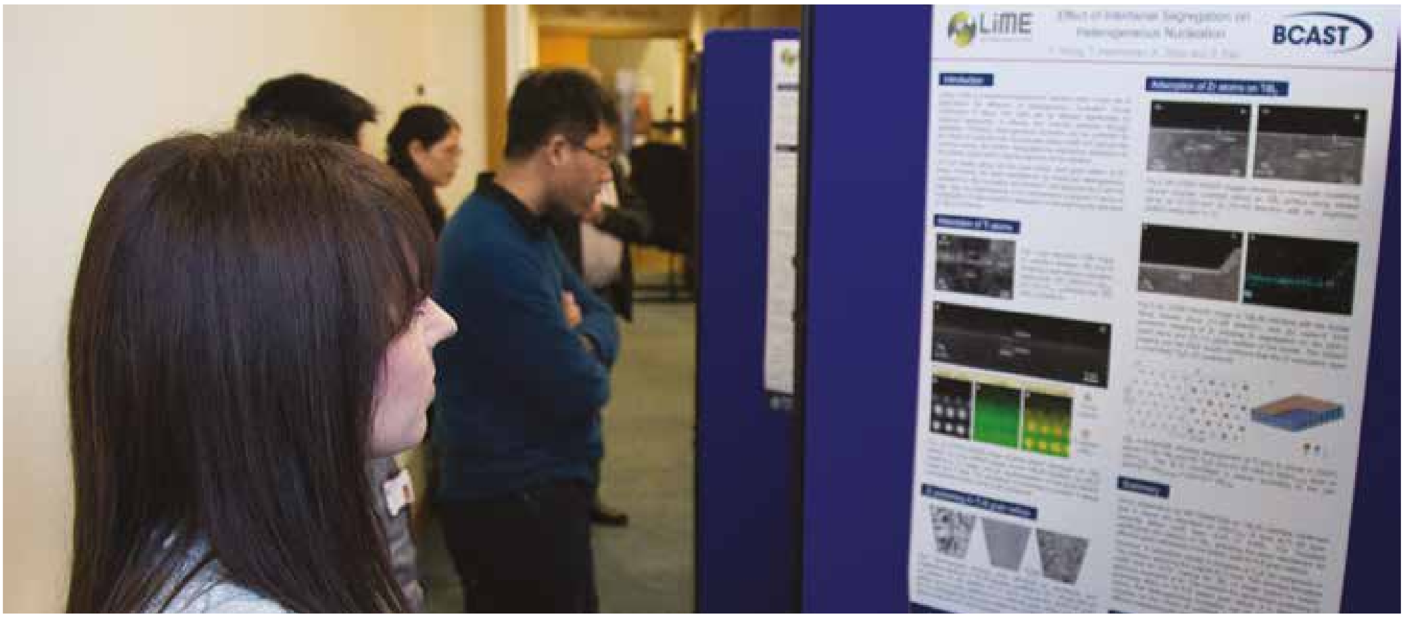
Mr Bill Stott
Aeromet

Mr John Townsend
Stone Foundries

Dr Doug Watson
The Weir Group


BCAST
Morphology of intermetallics-As-cast
Morphology of intermetallics-Homogenised

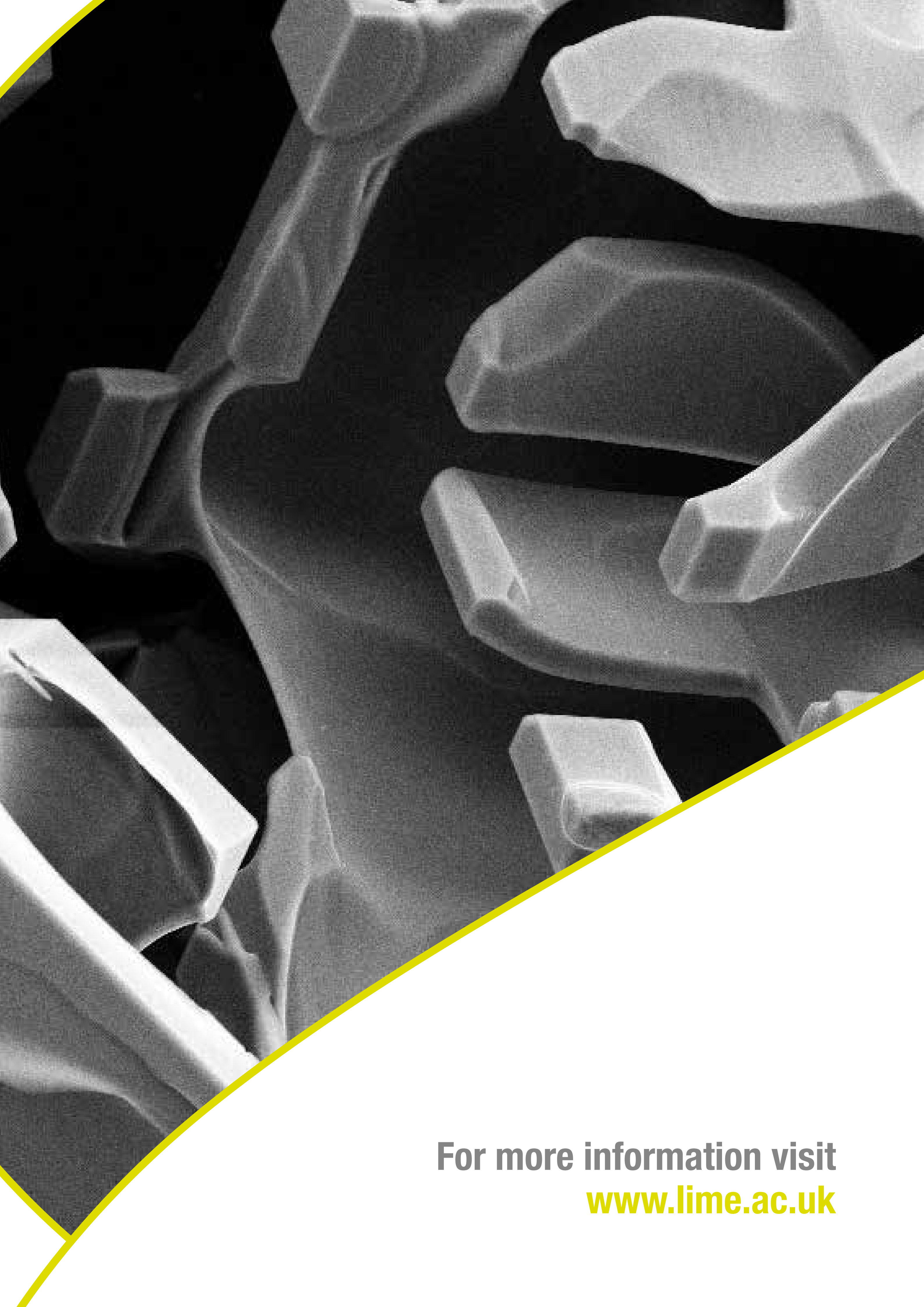

Introduction
MC-DC Model


LiME
BCAST
Introduction

Fundamental Research

The fundamental research theme focusses on three main areas of solidification science. These are: heterogeneous nucleation, the solid/liquid interface during crystal growth and microstructure formation.

The following pages highlight key fundamental research activities.



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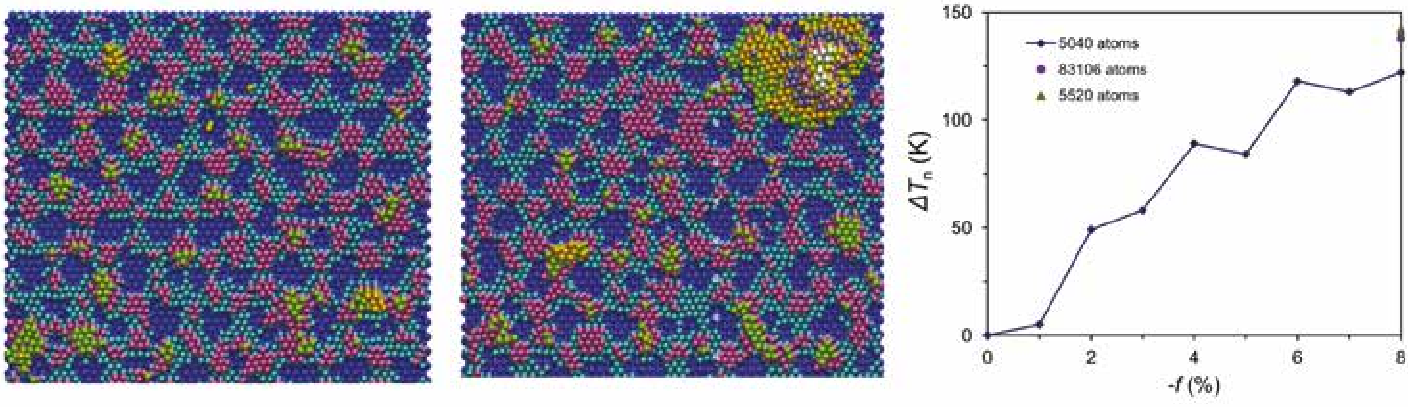
A molecular dynamics study of structural templating during heterogeneous nucleation

H. Men, C.M. Fang and Z. Fan

Heterogeneous nucleation theory is of fundamental importance in understanding solidification processes. However, the effect of physical and chemical properties of the nucleant particle on atomistic mechanisms of heterogeneous nucleation is so far poorly understood.



(a) (b) (c)

FIGURE 1. 2D ordered structures and new phase at (a) t = 200 ps and (b) 300 ps at the interface with a substrate having a lattice misfit f = -8 % at 744 K, and (c) undercooling for heterogeneous nucleation as a function of f. The heterogeneous nucleation proceeds by a structural templating mechanism.

In recent years, it has been realised that atomic ordering in the liquid adjacent to the liquid/substrate interface has significant implication on the heterogeneous nucleation processes [1]. In our previous work [2], we found that two-dimensional (2D) ordered structure formed at the interface even above the liquidus, i.e., prenucleation. The epitaxial nucleation model [3] suggests that prenucleation may provide a mechanism of structural templating for heterogeneous nucleation. In this study, we investigated the structural templating mechanism during heterogeneous nucleation using molecular dynamics (MD) simulation. The MD simulations were conducted for systems of liquid/substrate with varied lattice misfits, and EAM potentials were used to model the interatomic interactions.

In this study, we established an atomistic mechanism of heterogeneous nucleation through structural templating, i.e., a new phase was created by the formation of a 2D ordered structure at the interface. Solid atoms in ordered structure in the 1st layer continue the lattice of the surface layer of the substrate in either fcc or hcp stacking sequence, namely structure templating, at the prenucleation stage (Figure 1a). During the nucleation, ordered regions in the 2nd layer merge together to form the new phase by continuing the lattice of the first layer (Figure 1b). Simultaneously, shockley partial dislocations with predominant screw components were generated between the 1st and 2nd layers in the new phase, leading to a twist of a new phase relative to the substrate. Generation of the partial screw dislocations is largely responsible for nucleation barriers. Further, we found that density of dislocations increases with increasing lattice misfit, as well as undercooling of the nucleation (Figure 1c), i.e., the potency of the substrates degrades with an increase of lattice misfit. Thus, this study reveals the process of heterogeneous nucleation is closely relevant to the property of the substrates.

For the first time we revealed the process of heterogeneous nucleation at an atomic level through a structural templating mechanism, which would be generalised for other materials with varied structures and chemistry. This study has shed new light on the heterogeneous nucleation theory.

Thermodynamics and kinetics of heterogeneous nucleation need to be clarified for an in-depth understanding of the nucleation. Atomistic mechanism of heterogeneous nucleation in the systems of practical interests should be examined in the future to validate the structural templating mechanism.

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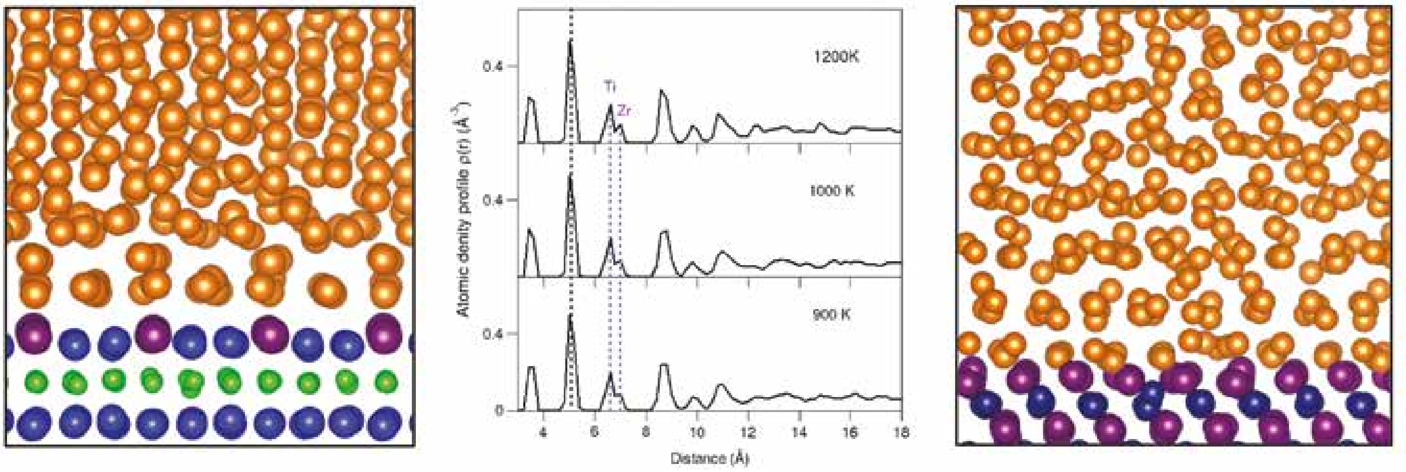
Effect of physical and chemical properties of the substrate on prenucleation

C.M. Fang, B. Jiang, H. Men and Z. Fan

Atomic ordering in the liquid adjacent to a solid substrate (i.e., prenucleation) has recently attracted increasing interest in the solidification research community, due to its implications for heterogeneous nucleation [1].



(a) (b) (c)

FIGURE 1. (a) Snapshot at 1000 K and (b) density profiles of liquid Al/TiB_2(0001) with $ZrTi_2$ 2DC (green, Ti; blue, Ti; purple, Zr), and (c) snapshot of liquid Mg/MgO(111) at 1000 K (dark blue, Mg; purple, O). In both cases the substrate surface becomes atomically rough.

It has been recognised that the atomic ordering is relevant to some properties of the substrate. However, full pictures about effects of its physical and chemical properties on the prenucleation, as well as its origin, are not yet established. In the past, we revealed that the layering at the interface is independent of the lattice misfit, and the in-plane atomic ordering degrades with an increase of the lattice misfit [2]. In this project, we intend to investigate the effect of physical (lattice parameter and surface roughness) and chemical natures of the substrate, and to clarify the interplay between structural and chemical effects of the substrate on atomic ordering. Classical and ab initio molecular dynamics (MD) simulations were carried out for the systems of liquid Al and substrates with varied lattice parameter, chemistry and/or atomic level surface roughness. Further, we analysed atomic ordering, mobility of the atoms, and charge transfer at the interface, using different techniques.

This project revealed the formation of a two-dimensional (2D) ordered structure in the liquid on the substrate surface through a structural templating mechanism, which is dependent on the lattice misfit. We also found that chemistry of the substrate produces noticeable effect on both layering and in-plane atomic ordering at the interface, where an attractive chemical interaction strengthens the atomic ordering, whilst a repulsive interaction weakens it. The enhanced atomic ordering for an attractive chemical interaction is attributed to reducing atomic mobility in the liquid due to a higher electron transfer across the interface. In addition, for the first time we demonstrate that increasing surface roughness of a crystalline substrate reduces both atomic layering and in-plane atomic ordering, and this can be attributed to the increase in atomic mobility. Furthermore, atomic level surface roughness was found in a monolayer of $ZrTi_2$ 2DC on TiB_2 substrate in liquid Al (Figures 1a and 1b) and at the liquid Mg/MgO{111} interface (Figure 1c). Such a rough substrate surface degrades dramatically the atomic ordering in the liquid at the interface, rendering the substrate impotent for heterogeneous nucleation.

This project provides insight on the effect of physical and chemical properties of the substrate on the prenucleation and subsequent heterogeneous nucleation. These are crucial to the development of more effective approaches to grain refinement during solidification through effective manipulation of the interplay between structural and chemical effects of the substrate on atomic ordering.

As part of the future research focus, we will examine the effect of atomic mobility at the interface on both prenucleation and heterogeneous nucleation in more practical systems, such as alloy melts containing native oxides.

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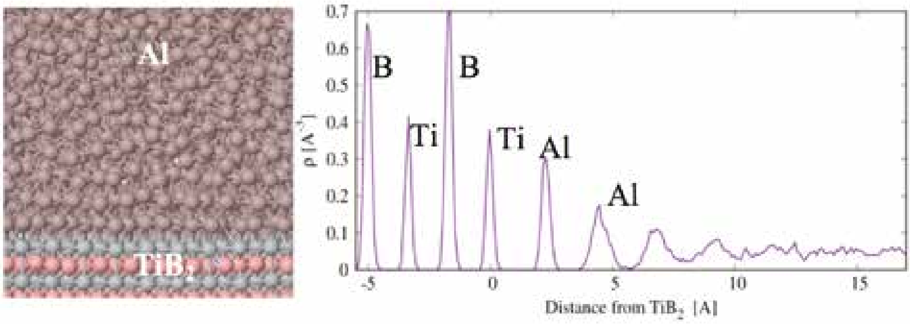
Monte Carlo simulations of solute segregation at the liquid-substrate interface

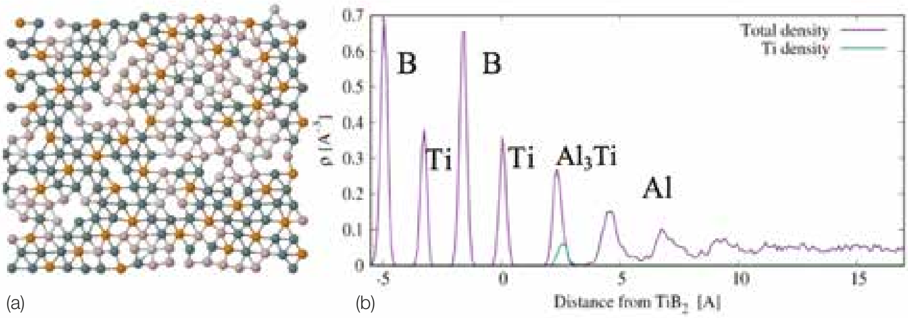
H. Tetlow, C.M. Fang, H. Men and Z. Fan.

Grain refinement facilitates the casting process, reduces cast defects and improves the mechanical performance of the final components. One of the most widely used examples of grain refinement is the addition of Al-Ti-B refiners in aluminium casting.



(a) (b)

FIGURE 1. (a) A snapshot of the MC simulation of TiB_2-Al at 900 K. (b) The density profile of TiB_2-Al perpendicular to the interface.



(a) (b)

FIGURE 2. (a) The Al_3Ti layer at 1400 K as viewed along the z axis. Atoms are coloured as follows: Blue: ordered Al, Orange: ordered Ti, Pink: disordered Al, Grey: disordered Ti. (b) The density profile of Al_3Ti at 1400 K

Experimental studies of this system have revealed that a single Al_3Ti layer is formed at the interface between the solid TiB_2 and liquid Al [1], and that this layer increases the potency of TiB_2 for heterogeneous nucleation of Al [2]. Motivated by the success of the Al-Ti-B refiner we would like to investigate other liquid/substrate systems in which the segregation of solute and/or impurities will occur. This requires the development of a method to simulate the segregation process. However, this is complicated by the fact that the segregation may happen over long time scales and involve solute concentrations which are very dilute. Consequently, long simulations of large systems containing possibly many thousands of atoms are needed. Such simulations are beyond the capabilities of ab-initio and classical molecular dynamics. Therefore, we have focussed on using monte carlo (MC) simulations.

The aim of this work so far has been to perform MC simulations to understand the segregation of Ti to the TiB_2/Al interface, resulting in the formation of Al_3Ti. In doing so we aim to develop a method that will allow further systems to be studied. As no potential currently exists for the Ti-B-Al system, the initial objective was to produce a Lennard Jones (LJ) potential that will accurately represent the system. This was achieved by fitting the LJ parameters to produce the correct lattice constants and formation energies of various materials such as TiB_2, AlB_2 and TiAl. This was then tested for TiB_2-Al by running a MC simulation of the system at 900 K and comparing the structure to existing ab-initio results [3]. The density profile of the system is shown in Figure 1, which was found to match that produced in [3]. We then determined the stability of an Al_3Ti layer at the interface using this potential. MC simulations were performed at various temperatures and the stability of the Ti atoms in the layer were monitored. We found that the Al_3Ti layer may be stable up to 2000 K. This can be attributed to the fact that the first 3 layers are semi-solid at these temperatures, and there is very little movement of atoms between these layers (Figure 2). However, over longer time scales it may be possible that the Al_3Ti may dissolve.

The next steps are to extend this current method to allow for simulation of larger systems, where low concentrations of the solute can be used in order to reproduce segregation conditions. We also plan to perform MC simulations using the semi-grand canonical ensemble, which allows for compositional changes in the system throughout the simulation. We will then investigate a variety of new systems and determine the ideal conditions for solute segregation.

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Brunel University London

Elemental adsorption at the solid/substrate interface and its effect on heterogeneous nucleation

Y. Wang, T. Hashimoto, Z.P. Que, J. Yu, Z. Fan and X. Zhou

In order to understand elemental adsorption at the liquid/inclusion interface and its effect on heterogeneous nucleation, the solid/substrate interface is investigated using high resolution transmission electron microscopy, with particular focus on the surface of inclusions commonly present in recycled alloys, and the competition for nucleation between different inclusion particles.

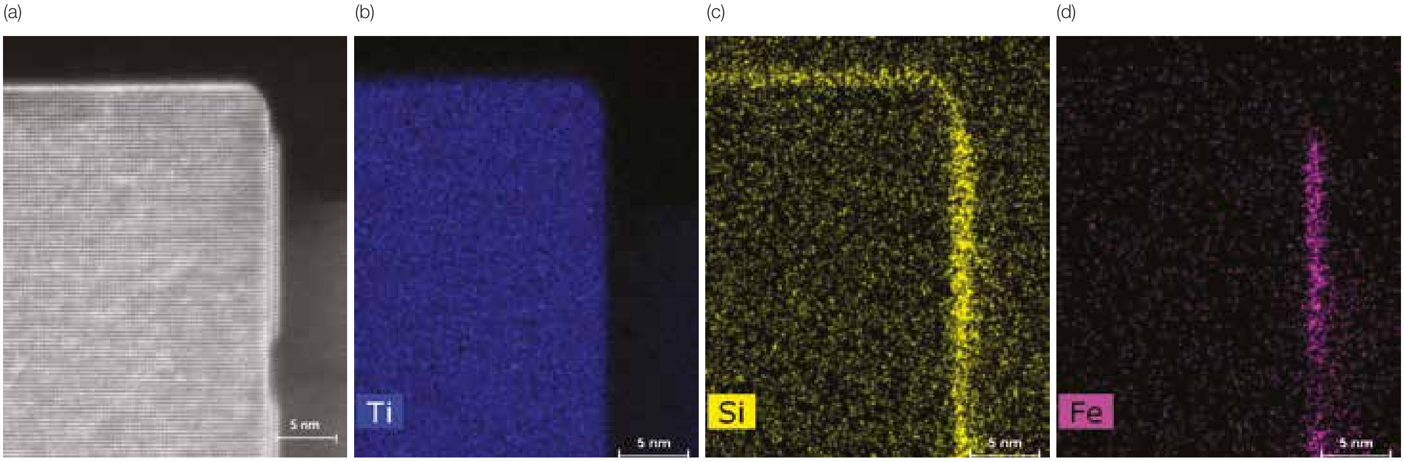

FIGURE 1. (a) HAADF image reveals the atomic arrangement at the surfaces of TiB_2 particle. (b) to (d) EDS maps reveal atomic adsorption layers at the surfaces of TiB_2 particle and that the adsorption layers are Fe-rich and Si-rich, with Fe atoms on prismatic planes and Si on both basal and prismatic planes.

The knowledge created will advance the understanding of the heterogeneous nucleation mechanism, which will be exploited for high performance alloy development for closed-loop recycling and resource efficient manufacturing technologies.

An example is the investigation on the adsorption on the surface of a novel grain refiner based on Al-3TiB_2 master alloy system with the addition of silicon and iron, developed at Brunel University London, and the investigation into the mechanism of grain refinement. The interface between α-aluminium and TiB_2 grain refiner modified by the addition of silicon and iron is characterised using HRTEM and high spatial resolution EDS in order to determine the distribution of Fe and Si (Figure 1). It is found that the adsorption of Fe and Si atoms on the surface of TiB_2 particles occurs, in the form of atomic layers.

Si atoms segregate on TiB_2 surfaces, including both basal and prismatic planes. Fe atoms are adsorbed only on the surface of prismatic plane of the boride particles. Fe adsorption at prismatic plane extends to double atomic layers, which have a larger d-spacing than that of (10-10) TiB_2.

Future research will focus on correlating the segregation with the heterogeneous nucleation and grain refinement mechanisms.

New progress on the understanding of heterogeneous nucleation and phase transformation of Fe-containing intermetallics in Al alloys

Z.P. Que, Y. Wang and Z. Fan

Fe, as an inevitable impurity element, has limited solubility in Al. Coarse Fe-containing intermetallic compounds (Fe-IMCs) usually form during the casting process. The control of Fe-IMC formation to improve the properties of recycled Al alloys is of both scientific and technological interest [1].

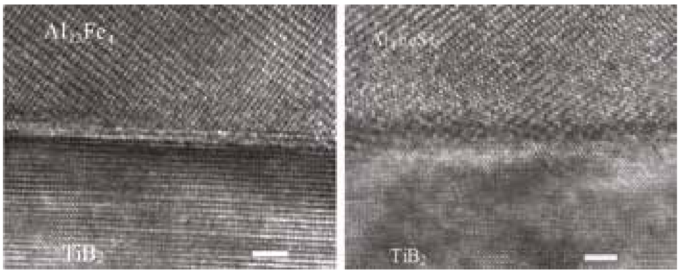

FIGURE 1. High resolution TEM images showing the direct evidence of Fe-IMCs nucleated on the modified TiB_2 particles (a) $Al_{13}Fe_4$//TiB_2, and (b) δ-Al_4FeSi_2//TiB_2.

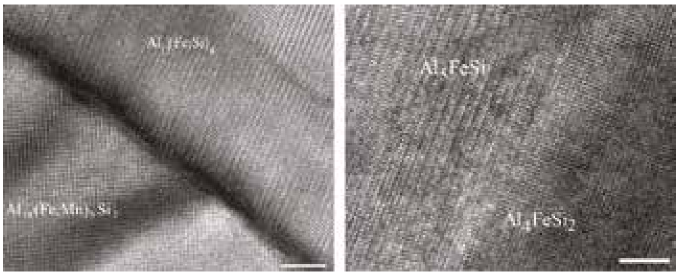

FIGURE 2. High resolution TEM images showing the direct evidence of phase transformation between (a) $Al_{13}(FeSi)_4$//α-$Al_{15}Fe_3Si_2$ (b) Al_5FeSi//δ-Al_4FeSi_2.

So far there is no effective method for refining Fe-IMCs during casting. One of the approaches to overcome the detrimental effect of Fe-IMCs in some Al alloys is heat treatment. For example, the β-AlFeSi with a plate-like morphology was transformed into smaller particles by solid solution treatment. However, understanding of the mechanisms of phase transformation among different Fe-IMCs remains a challenge. As reported in the literature, more than 20 types of Fe-IMCs may exist in different Al alloys. These Fe-IMCs may be easily confused with one another in the as-cast microstructure (phase identification) or after heat treatment (phase transformation). Based on the recent advances in the understanding of pre-nucleation and interfacial segregation [2-3], this research aims to develop an effective approach to refine Fe-IMCs through better understanding of heterogeneous nucleation during solidification and phase transformation during heat treatment.

The major advances on heterogeneous nucleation and phase transformation can be summarised as follows:

(1) Technology development: In the 2017 LiME Report, we reported the significant refinement of α-$Al_{15}(Fe,Mn)_3Si_2$ phase by adding TiB_2 particles with Fe segregation on their surface. In this report, we report the refinement of $Al_{13}Fe_4$, β-$A_{l5}FeSi$, δ-Al_4FeSi_2, $Al_6(Fe,Mn)$ by the modified TiB_2. Direct evidence for nucleation of Fe-IMCs on the modified TiB_2 was found (Figure 1). Based on this advance, a new grain refiner was developed.

(2) Theoretical advance: the conception of composition templating for the heterogeneous nucleation of compounds were developed [3].

(3) A serial phase reactions such as β-Al_5FeSi→δ-Al_4FeSi_2+Al, β-Al_5FeSi→α-$Al_{15}Fe_3Si_2$+Al, $Al_{13}Fe_4$→$Al_{15}Fe_3Si_2$+Al were identified and investigated on atomic level by HRTEM (Figure 2). The direct evidence for heterogeneous nucleation was observed and the high resolution interfaces were observed by TEM. The mechanisms of phase transformations were firstly explained, and the α-$Al_{15}Fe_3Si_2$ phase with new crystal structure generated during the phase transformation were observed and identified.

(4) Heterogeneous nucleation of Fe-IMCs on natural in-situ oxides were investigated. We found direct evidence for heterogeneous nucleation of long plate-like in-situ $MgAl_2O_4$ particles in Al-Mg-Si alloys.

Future work will focus on:

(1) Further refinement of the Fe-IMCs to achieve the desirable size. For example, refine the size of the β-Al_5FeSi to less than 5 μm and the size of α-$Al_{15}(Fe,Mn)_3Si_2$ to less than 2 μm.

(2) Further study on the mechanisms of phase transformation variation under different solidification conditions (e.g., cooling rate and temperature). For example, the eutectoid reaction of primary $Al_{13}Fe_4$→$Al_{15}Fe_3Si_2$+Al only happens at the very slow cooling rate (0.01K/s), and the peritectic reaction of primary $Al_{13}Fe_4$ +L→$Al_{15}Fe_3Si_2$ is unsteady at a faster cooling rate (3.5K/s), and no phase transformation happens on the primary $Al_{13}Fe_4$ when the cooling rate is increased to 1000K/s.

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Nucleation and growth crystallography of Mn-bearing intermetallics in magnesium alloys

G. Zeng, J.W. Xian and C.M. Gourlay

Most automotive magnesium alloys contain a small manganese addition to combat impurity iron. For AZ91 (Mg-9Al-0.7Zn in wt%), sufficient Mn is added to give an Fe:Mn ratio less than 0.032 which gives the alloys acceptable corrosion resistance for most automotive applications.

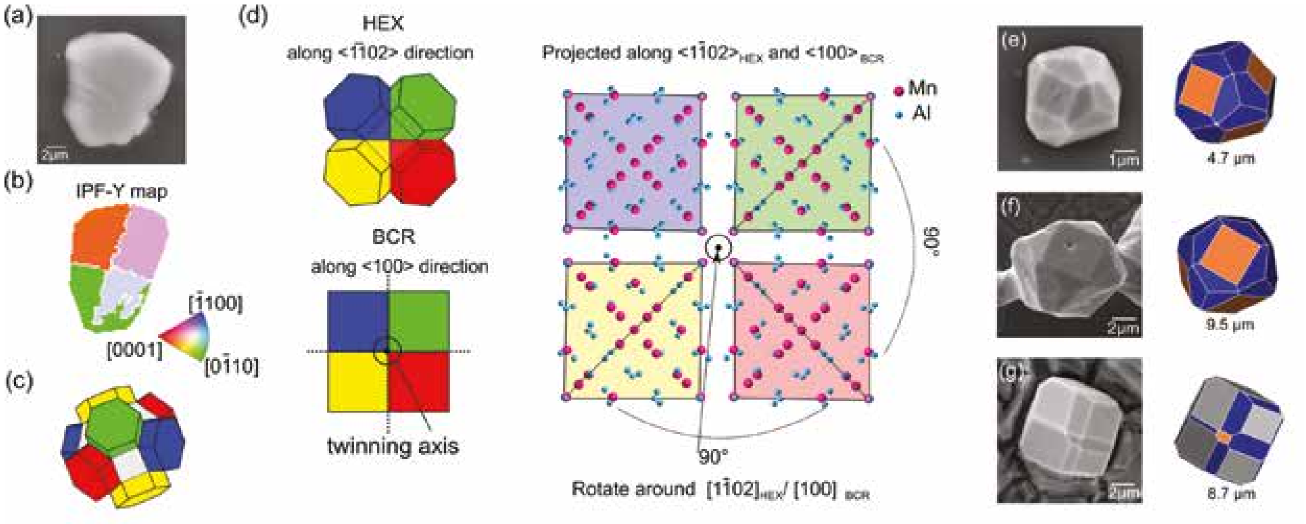

FIGURE 1. (a) to (c) a typical Al_8Mn_5 particle containing four orientations; (a) SE-SEM image of a cross section; (b) EBSD orientation map with colour key of the particle in (a); (c) graphical representation of the orientation relationship between the four orientations in (b) using a RGBY colour scheme. (d) Four-fold cyclic twinning model of particles similar to (a) to (c). (e) to (g) SE-SEM images of extracted Al_8Mn_5 particles and polyhedron models based on {100}-orange, {110}-grey and {112}-blue facets using a pseudo-cubic Al_8Mn_5 cell [1].

Both Mn and Fe are almost insoluble in α-Mg, do not form intermetallic compounds (IMCs) with Mg, and instead react with solutal Al to form $Al_x(Mn,Fe)_y$ IMCs. The main Mn-bearing IMC in AZ91 after gravity casting or high-pressure die casting is Al_8Mn_5, which can dissolve some Fe as $Al_8(Mn,Fe)_5$. At typical Mn and Fe levels, Al_8Mn_5 begins to form above the α-Mg liquidus temperature as a primary phase and can be removed to some extent by gravitational sedimentation which gives some control of the Fe content of melts. However, $Al_x(Mn,Fe)_y$ particle settling also creates sludge in die casting pots and can block filters in the launders of direct chill (DC) casting units. For a given IMC density, the size and shape of the primary IMCs determines their settling behaviour as well as their packing and clumping behaviour.

This work is being conducted to understand the nucleation and growth crystallography of Al_8Mn_5 and to use this understanding to control the size and shape of primary IMCs in Mg-Al-based alloys.

Electron backscatter diffraction (EBSD), focussed ion beam (FIB) tomography, and selective etching techniques are being combined with thermodynamic calculations and polyhedron models to extract new insights into IMC nucleation and growth crystallography.

It has been found that Al_8Mn_5 often nucleates on Fe-rich B2-Al(Mn,Fe) particles and an incomplete peritectic transformation results in a B2-Al(Mn,Fe) core enveloped by a low-Fe Al_8Mn_5 shell. A reproducible orientation relationship (OR) is measured that is linked to the group-subgroup relationship between these phases [1].

As shown in Figure 1a to d, it has been found that most rhombohedral Al_8Mn_5 particles are cyclic twinned, consisting of four orientations related by ~90° rotations around three common <1102 >, which are the pseudo-cubic <100> axes of the Al_8Mn_5 rhombohedral gamma brass when considered with a body-centred rhombohedral (BCR) cell. The three twin planes are $\{2\text{-}201\}_{Hex}$ or $\{100\}_{BCR}$ and the twin obliquity is ω=0.9.

Primary Al_8Mn_5 particles grow with an equaiaxed polyhedral habit that has been measured by combining EBSD with FIB-tomography. Figure 1e to g show that Al_8Mn_5 crystal growth can be explained by polyhedron models based on {100}, {110} and {112} facets of the pseudo-cubic Al_8Mn_5 cell.

The results indicate that, at low Fe:Mn ratio, most impurity Fe is dissolved in B2 particles that are encapsulated by low-Fe Al_8Mn_5 which may be important for corrosion resistance.

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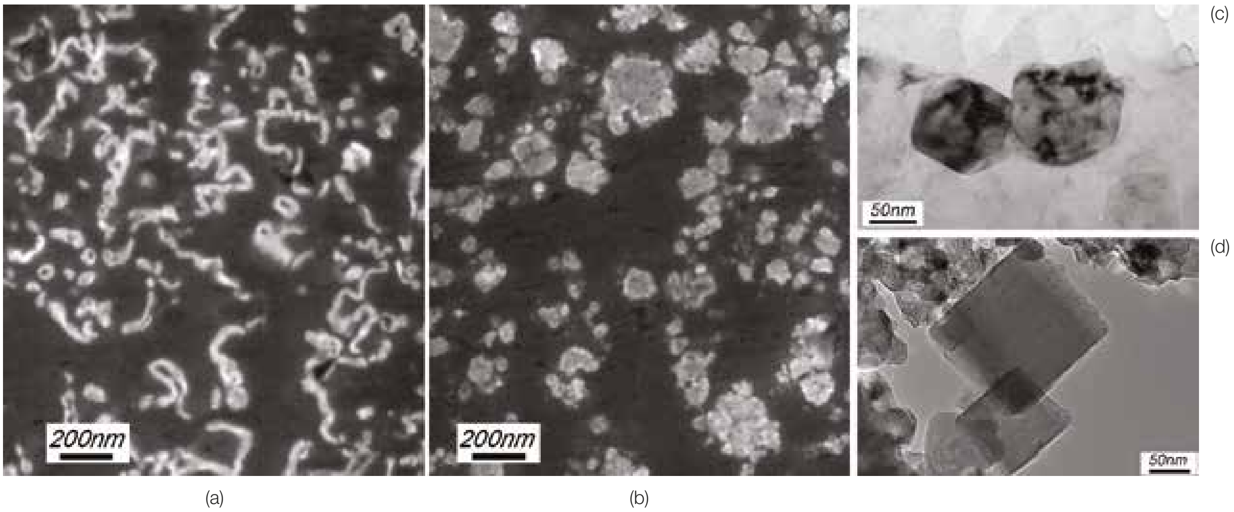
The nature of native oxides in Mg with various alloying elements

S. Wang, Y. Wang and Z. Fan

Minimising and even eliminating the detrimental effects caused by native oxide inclusions is one of the major tasks in recycling of Mg alloys. Our current research demonstrates that native oxide particles formed in-situ in Mg alloy melts can be harnessed for promoting heterogeneous nucleation, resulting in grain refinement.



(a) (b)

FIGURE 1. SEM and TEM images showing the diverse morphology of the native MgO particles formed in Mg and Mg-9Al alloy with (a) string-like, (b) cauliflower-like, (c) decahedral, and (d) cubic.

However, commercial Mg alloys usually contain many alloying elements which are essential to promote the performance of the alloys. Addition of such elements are expected to affect the nature of the in-situ oxides, and in turn the potency for heterogeneous nucleation and finally the effectiveness of grain refinement for Mg alloys. Therefore, there is a need to comprehensively understand the formation mechanism and growth behaviour of oxides in Mg alloy melt as well as the effect of alloying elements.

Controlled oxidation experiments were carried out with the native oxide films/particles being collected using pressurised melt filtration technology. The state-of-the-art electron microscopy was carried out to examine the oxides at atomic scale. Figure 1 shows the diverse morphology of the MgO particles collected from commercial purity Mg and Mg-9Al alloy melts. The morphology can be classified as decahedral, cubic, string-like and cauliflower-like, with the average size being 65 nm and 82 nm for pure Mg and the alloy respectively. The cubic {100} faceted MgO was formed because of burning at high temperature, indicating the minimum surface energy on its {1 0 0} crystal planes. However, the majority of MgO particles in AZ91D (Mg-Al based) alloy is {1 1 1} faceted. It is also revealed that the cauliflower shaped MgO was attributed to the effect of nitrogen and fluorine from the protection atmosphere during processing. 0.5 wt% addition of yttrium to commercial purity Mg resulted in the formation of oxide films consisting of both MgO and Y_2O_3 particles, with their morphology being cubic and decahedral as well. The oxide particles in the rare-earth element containing Mg melts show a larger size, about 120 nm in average, although some smaller (~50 nm in size) particles were also observed. With MgO and Y_2O_3 particles being frequently associated each other, high resolution TEM revealed that there is specific relationships between them, i.e., {1 1 1}MgO and {0 0 1}Y_2O_3.

It has demonstrated that formation and growth behaviour of native oxide particles in Mg and its alloys are significantly affected by alloying elements and the protection atmosphere during processing of the melts. When the oxide particles are harnessed to act as heterogeneous nucleation sites, such diversity in the morphology and size will significantly affect the nucleation process, resulting in advanced effectiveness for grain refinement of Mg alloys.

A comprehensive study is being performed to understand the mechanisms underlying the effect of the important alloying elements in Mg alloys, including Al, Zn, Ca, Sn as well as a small amount of rare earth elements. Any segregation of the elements on the surfaces of the oxides is to be studied. Further investigations will be focused on the effect of the native oxide particles on heterogeneous nucleation. This will include diverse morphology and size distribution for the oxides.

Grain initiation maps

B. Jiang and Z. Fan

Grain initiation is a crucial step towards microstructure formation during solidification. A better understanding of grain initiation can help us to control the solidification processes for grain refinement and property enhancement.

FIGURE 1. Schematic illustration of the explosive grain initiation during solidification of Mg-0.3Al alloy containing native MgO particles.

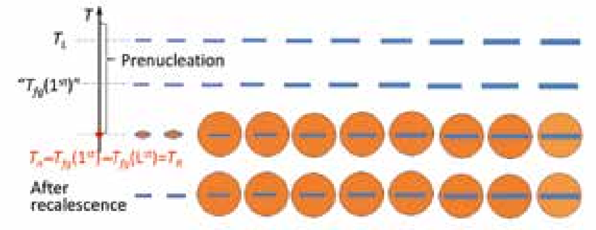
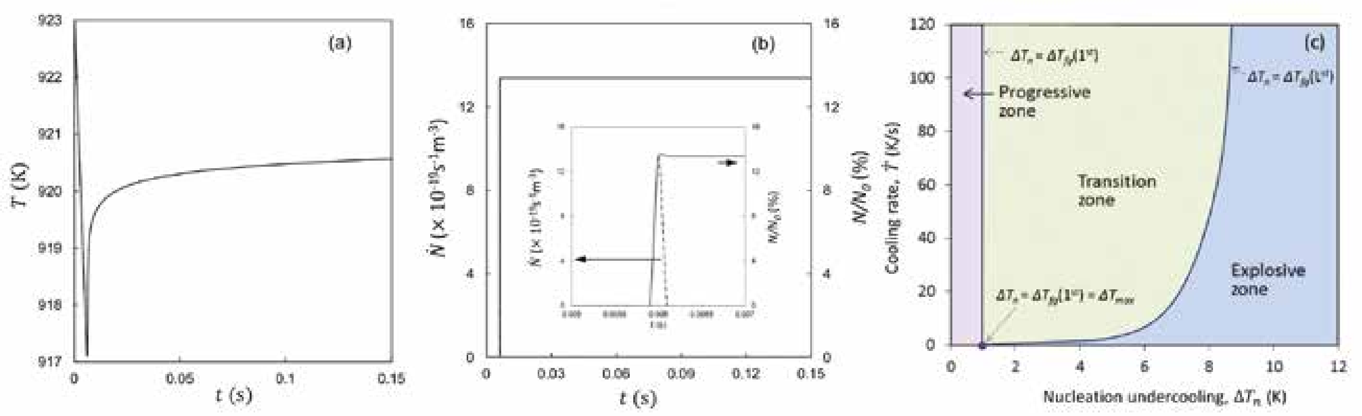


FIGURE 2. (a) Calculated cooling curve and (b) the instantaneous grain initiation rate (N) and accumulative grain initiation events per unit volume (N) normalised by the total number density of MgO particles (N_0), showing the explosive grain initiation behaviour during solidification of Mg-0.3Al alloy containing native MgO particles. (c) Calculated grain initiation map for Mg-10Al alloy inoculated by nucleant particles which have varying nucleation potency but the same Log-normal size distribution and the same particle number density ($N_0 = 10^{12} m^{-3}$).



This work aims to understand the grain initiation behaviour during isothermal solidification of single phase alloys with an emphasis on the interplay between heterogeneous nucleation and free growth. We used a numerical approach to investigate the grain initiation process during isothermal solidification of single phase alloys. We have identified two distinctive grain initiation modes: progressive grain initiation and explosive grain initiation. Progressive grain initiation starts with the largest particle(s), continues with the progressively smaller ones and finishes at recalescence. In contrast, explosive grain initiation is a process in which solid particles initiate grains almost simultaneously and the latent heat released by both heterogeneous nucleation and the initial free growth can cause immediately recalescence (Figure 1). It occurs during solidification of engineering alloys which contain very impotent nucleant particles (either in-situ or ex-situ), and have no other more potent nucleant particles of significance in the melt (Figure 2).

Such grain initiation behaviour is best presented by a grain initiation map (Figure 2c), which is a plot of cooling rate against the nucleation undercooling showing the conditions for progressive, explosive and transition zones for grain initiation. Further theoretical analysis has shown that explosive grain initiation is favoured by solidification of dilute alloys containing only impotent nucleant particles of a large number density and small particle size under high cooling rate.

Effective grain refinement requires appropriate manipulation of the interplay between heterogeneous nucleation and grain initiation. The traditional wisdom is to enhance heterogeneous nucleation by addition of potent nucleant particles. In this work we have shown both theoretically and experimentally that the most effective grain refinement can be achieved by impeding heterogeneous nucleation with the least potent nucleant particles assuming that no other more potent particles of significance exist in the alloy melt. In addition, we have demonstrated that it is more advantageous to make the best use of native solid particles for effective grain refinement rather than to develop grain refiners for chemical inoculation.

As part of the future work, we will develop this numerical model further to analyse the competition for nucleation between different types of nucleant particles that co-exist in the melt.

Prediction of grain size during solidification

F. Gao and Z. Fan

A fine and equiaxed microstructure not only facilitates the casting process but also improves the performance of final components. Therefore, the prediction of grain size for alloys solidified under varying conditions is of both scientific and technological importance.

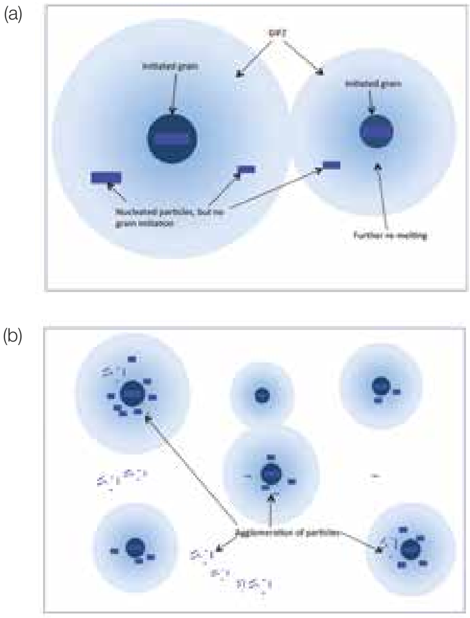


FIGURE 1. Schematic illustration of the mechanisms of grain initiation free zone (GIFZ) and re-melting, which affect microstructure formation.

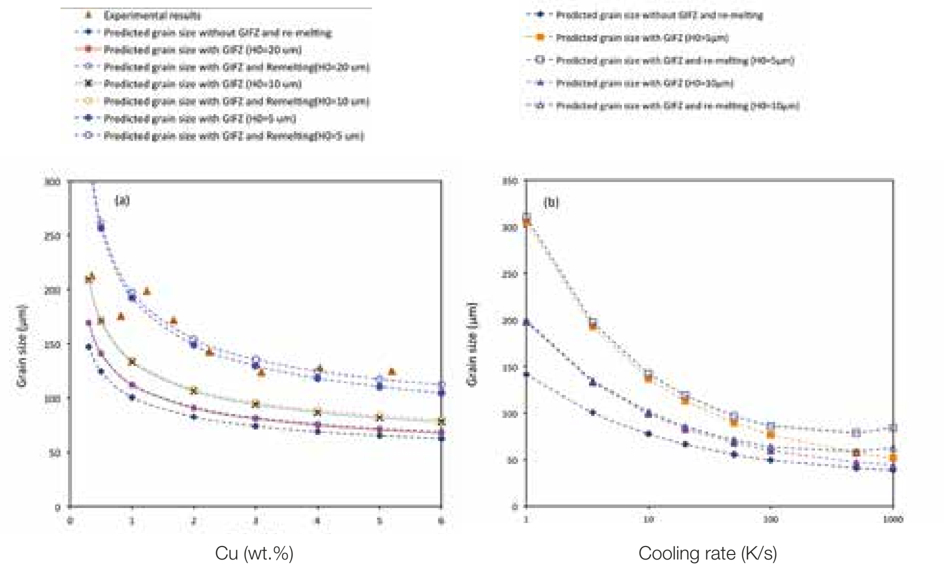


FIGURE 2. The numerically calculated grain size as a function of (a) Cu concentration and (b) cooling rate for Al-Cu alloys showing the agglomeration, from H_0=10 μm to H_0=5 μm, strongly affects the grain size.

However, current models for predicting grain size for isothermal solidification have a limitation in that their predicted grain size is much less than the experimental results. This work aims to develop a numerical model for isothermal solidification to predict grain size more accurately by incorporation of the underlining mechanisms of grain formation.

The free growth criterion [x] specifies which nuclei can initiate grains and contribute to the solidified microstructure. However, we found that not every initiated grain can survive during solidification. Theoretical analysis shows that an initiated grain according to the free growth criterion will not survive under the following two circumstances (Figure 1): (a) a nuclei located in the solute field of a growing solid particle will not initiate a grain albeit it satisfies free growth criterion, we name this solute field as grain initiation free zone (GIFZ); and (b) an initiated grain will re-melt if its solute field overlaps with the solute field of a larger grain, and this is named the re-melting mechanism. By assuming a log-normal spacing distribution for nuclei and a normal spacing distribution for initiated grains, we have developed a numerical model to predict grain size of solidified microstructure.

Based on the numerical analysis we found that the GIFZ mechanism has a strong influence on the predicted grain size depending on the extent of nucleant particle agglomeration while the re-melting mechanism has very little impact on grain size (Figure 2a), taking Al-Cu alloys for example, indicate that the agglomeration of nucleated particles strongly affects the grain size. In addition, we found that the effect of GIFZ decreases with cooling rate (Figure 2b).

The implication of this work is that for effective grain refinement it is crucial to disperse the nucleant particles. Nucleant particles, such as TiB_2 introduced by addition the Al-Ti-B grain refiner and native MgO particles in Mg-alloy melts, usually have a submicron or even nanometre size. They have a strong tendency for agglomeration, which reduces their efficiency for grain refinement. We have demonstrated in this work that appropriately dispersed nucleant particles can half the grain size.

Further work will focus on precisely predicting the grain size in practice solidification conditions.

Studying grain refinement in Al alloys using x-ray radiography and machine learning

E. Liotti, A. Lui and P.S. Grant

Although grain refinement by inoculation is the most widespread method to control grain size in Al alloys, its efficiency is low since only 1 % of the added particles nucleate a grain. This project aims to extend our knowledge of the factors controlling inoculant nucleation in order to learn how to manipulate conditions to increase efficiency, enhance grain refinement and to provide a basis for designing better grain refiners.

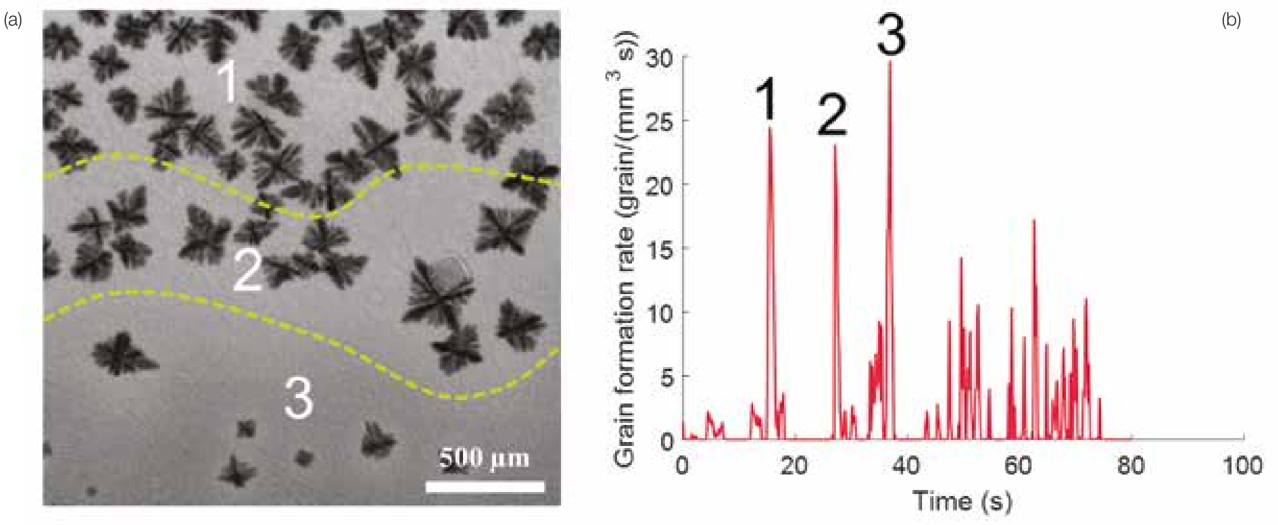


FIGURE 1. (a) Radiographic image of a solidifying Al-25wt%Cu alloy cooled at a constant cooling rate of 0.3 Ks^{-1}. Each equiaxed grain was detected the instant it formed, and then tracked using a machine learning algorithm. (b) Grain formation rate showing the three bursts of nucleation that appear as waves 1, 2 and 3 in (a).

A computer vision algorithm was trained using machine learning to analyse hundreds of thousands of X-ray radiography video frames for the solidification of Al-Cu alloys. The algorithm was capable of detecting every single grain as it appeared during cooling and to quantify its nucleation undercooling. The subsequent growth and movement of thousands of grains as a function of solidification conditions was also recorded. Figure 1a shows a typical frame of a semi-solid Al alloy in which three successive nucleation waves are highlighted. Figure 1b is a plot of the formation rate for the same sequence with peaks corresponding to bursts of nucleation.

The work provides novel, reliable quantitative data to be used to validate long-standing solidification theories as well as unveil new aspects of nucleation. These could lead to new approaches to grain refinement in the metal industry.

The data shows good agreement with the long-standing free growth model of nucleation but reveals new understanding that solute effects lead to both higher nucleation undercoolings and more efficient grain generation by bursts of nucleation.

Future efforts will focus on measuring the potency of different grain refiners and how to exploit solidification conditions to increase the efficiency of existing grain refiners.

Understanding intermetallic compound nucleation and growth using synchrotron x-ray radiography

S. Feng, E. Liotti, A. Lui and P.S. Grant

Controlling the morphology and size of intermetallic compounds (IMCs) is a challenge in the Al industry since IMCs can have a strong effect on the mechanical performance, especially the ductility and toughness, of final components.

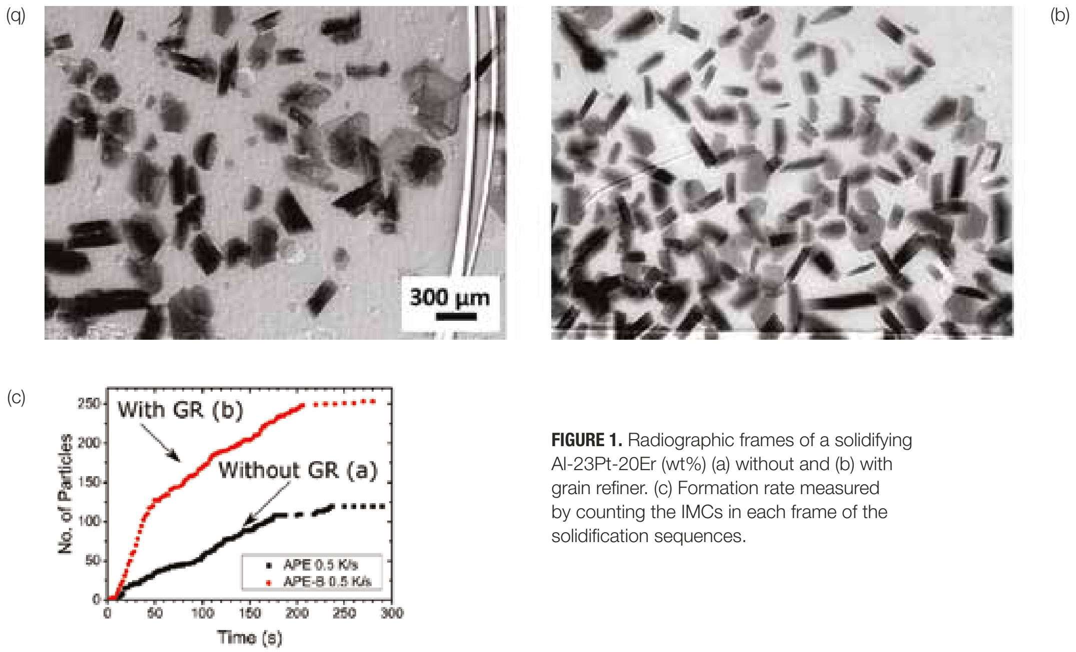


FIGURE 1. Radiographic frames of a solidifying Al-23Pt-20Er (wt%) (a) without and (b) with grain refiner. (c) Formation rate measured by counting the IMCs in each frame of the solidification sequences.

This research aims to deepen the fundamental understanding of how IMCs form (nucleation) and thus how to manipulate solidification and alloy conditions to contrive less harmful IMCs.

The effect of grain refiners and cooling rate on the nucleation of primary IMCs in a model Al-Pt-Er alloy (which is an analogue to the IMCs in commercial Al-Si-Fe and designed to enhance imaging contrast) was studied by X-ray radiography at the ESRF synchrotron. Figure 1a-b are two frames showing IMC density in two samples (a) without and (b) with grain refiner (TiB_2). The count of the number of IMCs in each frame for the two solidification sequences shows that grain refiners, usually added to promote equiaxed α-Al grains, also favour the nucleation of the IMCs.

Understanding the fundamental aspects of IMC formation could help to eliminate or reduce current costly post-solidification heat treatments that are used to manipulate IMC populations and morphology. The same understanding may also be helpful in improving Al alloy recyclability by suggesting approaches to increase the tolerance of alloys to tramp elements such as Fe and Si.

Preliminary synchrotron X-ray radiography results suggests that TiB_2 is an effective nucleation site for the same type of IMCs that are commonly found, and are potentially embrittling, in Al alloys.

Further synchrotron experiments aim to measure nucleation undercooling as well as nucleation rates in more industry standard Fe containing Al alloys.

The morphology and distribution of Al_8Mn_5 in high pressure die cast AZ91

G. Zeng, X. Zhu, S. Ji and C.M. Gourlay

Automotive magnesium components are typically produced by high pressure die casting (HPDC). When conducted with an optimised vacuum system, die and process parameters, HPDC can generate microstructures with fine αMg grains (5-20 μm), a sub-micrometre intermetallic lengthscale, and acceptable porosity.

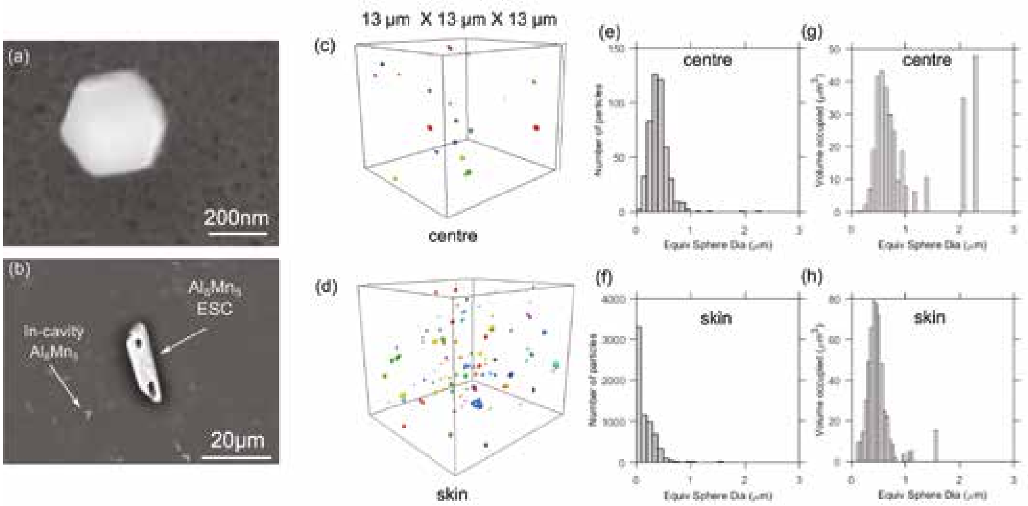


FIGURE 1. (a) to (b) typical Al_8Mn_5 particles in HPDC AZ91D. Most particles are similar to (a). A small number of much larger externally solidified Al_8Mn_5 (ESCs) such as (b) are also present. (c) to (d) rendered images of Al_8Mn_5 in 13x13x13 μm volumes based on focused ion beam tomography. (c) The centre of the cross-section; (d) 10μm from the surface. (e) to (h) Al_8Mn_5 particle size distributions in the centre and skin regions.

However, in many cases, these potential benefits are over-ridden by casting defects including porosity. A feature of Mg HPDC is partial solidification in the shot chamber that leads to large αMg externally solidified crystals (ESCs) being injected into the cavity that reduce Hall-Petch strengthening and can inhibit filling and feeding. Most Mg-Al-based alloys contain sufficient Al and Mn that Al_8Mn_5 forms before αMg during solidification. A consequence of this in HPDC is that Al_8Mn_5 can form and settle in the holding pot (enhanced by Fe pick-up from the pot), leading to die casting sludge. Furthermore, since Al_8Mn_5 forms at higher temperature than αMg, it might be expected that Al_8Mn_5 begins to form in the shot chamber prior to injection as Al_8Mn_5 externally solidified crystals (ESCs) analogous to the Mg ESCs that are widespread in HPDC Mg components.

Work is being conducted to understand the nucleation and growth of Al_8Mn_5 in the shot chamber and die cavity, and how this determines the size and distribution of Al_8Mn_5 particles in HPDC components.

Electron backscatter diffraction (EBSD), selective etching, and focussed ion beam (FIB) tomography are being combined to quantify the three dimensional distribution and morphology of Al_8Mn_5 at different locations in high pressure die cast AZ91D.

It has been found that primary Al_8Mn_5 particles take a wide range of sizes and morphologies within the same HPDC component spanning from faceted polyhedra to weakly-faceted equiaxed dendrites. In low magnification images, some Al_8Mn_5 particles can be seen that have much larger size than most Al_8Mn_5. Figure 1b is a particularly large Al_8Mn_5 particle that is ~20 μm long and has a faceted morphology. Adjacent, is a smaller particle (~1 μm across) with a similar composition. The large Al_8Mn_5 particles (e.g. Figure 1b) are similar to those in samples solidified at low cooling rate (1-3 K/s), suggesting that the larger polyhedral particles are externally solidified crystals (ESCs) that nucleated and grew in the shot chamber analogous to αMg ESCs. Al_8Mn_5 ESCs are a small population of 5-20 μm equiaxed-faceted crystals that are significantly larger than the in-cavity solidified Al_8Mn_5.

The great majority of primary Al_8Mn_5 particles are sub-micrometre, similar to Figure 1a. These are being studied using focused ion beam (FIB) tomography as overviewed in Figure 1c-d and quantified in Figure 1e-h. It can be seen that there is a significant difference in the Al_8Mn_5 particle size and number density in the centre compared with the HPDC skin. The skin region has a mean Al_8Mn_5 particle size (equivalent sphere diameter) of ~160 nm, whereas the centre has a mean Al_8Mn_5 size of 430 nm, excluding ESCs and a wider interparticle spacing.

HPDC of AZ91D can generate numerous Al_8Mn_5 particles with diameter 100-400 nm and a small interparticle spacing. However, partial solidification in the shot sleeve ties up Mn in larger Al_8Mn_5 ESCs, similar to the widely reported αMg ESCs.

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An anti-trapping current for use in phase-field simulation with arbitrary (CALPHAD) thermodynamics

A.M. Mullis and P.C. Bollada

Work on the development of a general anti-trapping current for use in phase-field models with arbitrary CALPHAD type thermodynamics, including the sub-lattice models used for non-stoichiometric intermetallics, is now complete and the model published [1, 2].

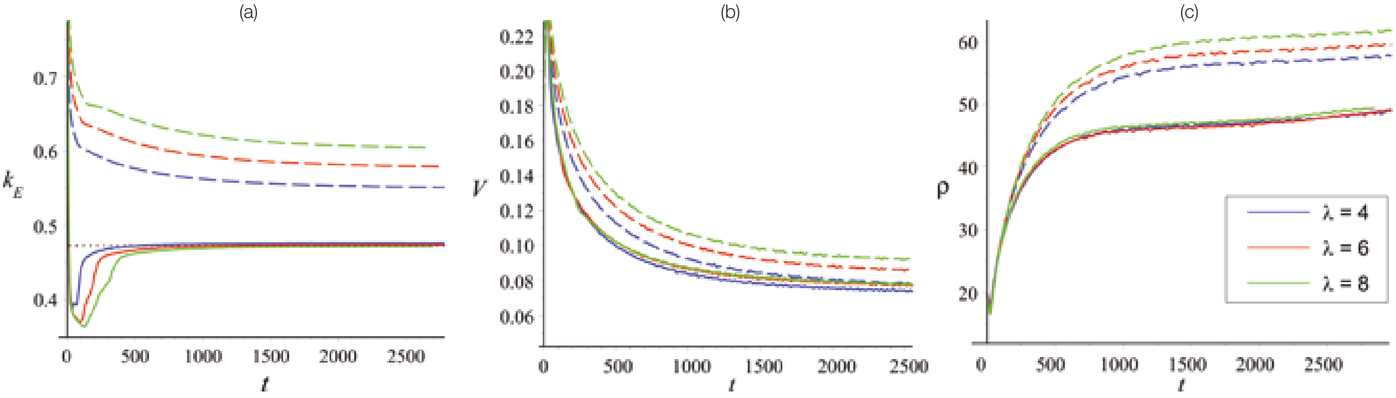

FIGURE 1. Values for (a) the partition coefficient, (b) the crystal growth rate and (c) the dendrite tip radius obtained from phase field simulations with interface widths of 4 (blue), 6 (red) and 8 (green) both with (solid lines) and without (dashed lines) the use of an anti-trapping current.

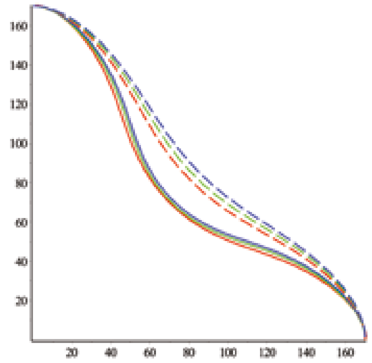

FIGURE 2. Morphology of a dendritic crystal with (solid) and without (dashed) anti-trapping.

Such anti-trapping currents are required to compensate for artificial solute trapping introduced by the diffuse interface used in phase-field simulations but are generally limited to simple thermodynamics in the dilute solution limit. As such, this development is applicable to all fields in which phase-field simulation is used with complex engineering alloys.

The new anti-trapping current is remarkably successful, not only in mitigating the effects of model induced solute trapping, but also in rendering the solution fully independent of interface width effects. This is illustrated in Figure 1 in which we compare the measured partition coefficient, *kE*, the crystal growth velocity, *V*, and the dendrite tip radius, *ρ*, in phase-field simulations for three values of the interface width, *λ*, with (solid lines) and without (dashed line) the anti-trapping current. It is clear from Figure 1a that with the new anti-trapping current the equilibrium partitioning coefficient (dotted) is recovered exactly in all simulations, whereas without the current strong interface width dependence is observed. However, as can be seen from Figures 1b-1c, the new current also renders the velocity and dendrite tip radius independent of the interface width, allowing fully quantitative simulation. Due to the success of the new current, it is now routinely used in all of our phase-field simulations.

However, the inclusion of anti-trapping currents also qualitatively changes the simulation, in that the morphology of the predicted crystals is changed. This point has previously received little attention with it generally being claimed that even non-quantitative phase-field simulations have some qualitative value. The effect can be seen in Figure 2, in which we plot out the outer envelope of a dendritic crystal, again for three values of the interface width, λ, with (solid lines) and without (dashed line) the anti-trapping current. The effect can be understood by realising that different parts of the dendrite are growing at different rates and that therefore, in the absence of an anti-trapping current, will be subject to differing levels of solute trapping. The effect is to make the simulation without the anti-trapping current closer to the equilibrium Wulff shape. Consequently, the model incorporating the new anti trapping current is better suited to non-equilibrium simulation.

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Phase field simulation of needle crystal growth

A.M. Mullis and P.C. Bollada

Following on from our development of a phase-field model for faceted crystal growth [1], we are now extending this to the growth of needle-like crystals. Needle like morphologies are typical of Al-based intermetallics such as $Al_{13}Fe_4$ (θ-phase, also sometimes denoted as Al_3Fe) and can produce severe detrimental effects on properties such as ductility and corrosion resistance.

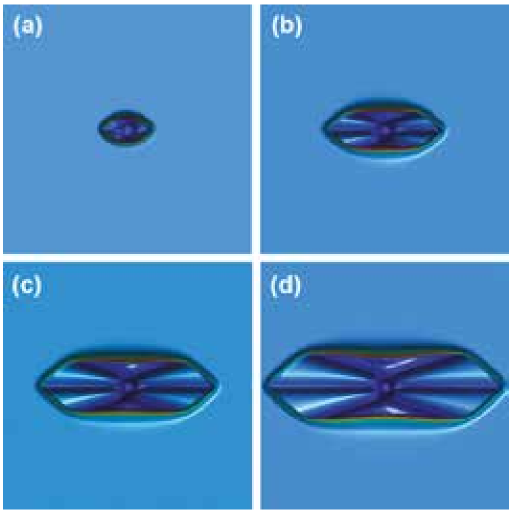

FIGURE 1. Simulated evolution of an $Al_{13}Fe_4$ needle crystal at four different times.

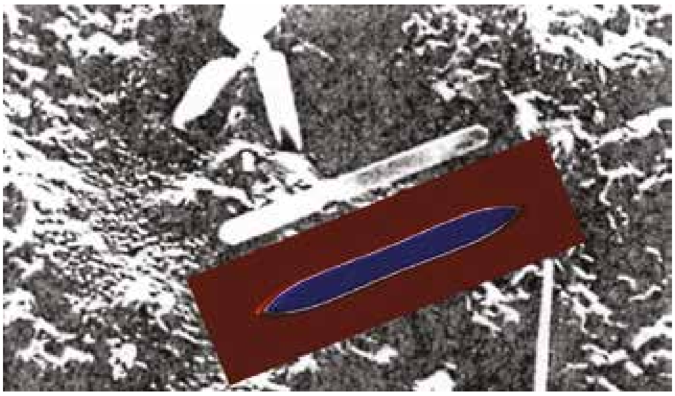

FIGURE 2. Comparison of the morphology of $Al_{13}Fe_4$ needle crystals. Experimental micrograph is for such needles growing in an Al matrix from Ref [2]. Inset is the simulation using the methodology reported here.

Therefore, understanding and controlling the formation of such morphologies is important in high value manufacturing sectors such as automotive and aerospace.

The needle morphology is in fact modelled as a modification of a faceted hexagonal crystal. For a regular hexagonal crystal with faceted sides the required anisotropy functional is:

$$\mathbf{A} = \frac{1}{2}\left\{1+\varepsilon\sqrt{\frac{\left(\phi_x^3-3\phi_x\phi_y\right)^2+q^6}{\left(\phi_x^2+\phi_y^2+q^2\right)^3}}\right\}\mathbf{n}$$

Here ϕ is the phase variable (1 in the solid and 0 in the liquid), ε is the anisotropy strength, **n** is the outward pointing unit normal and subscripts denote differentiation. q is a small parameter that regularizes the sharp corners permitting differentiation of the shape.

Plotting the gradient of $\mathbf{A}$, $[A_x, A_y]$ as a function of φ ($x = \cos(\varphi)$, $y = \sin(\varphi)$) gives the familiar Wulff shape for the crystal. To modify the normal hexagonal morphology to a needle we transform the function $A(x, y)$ to $A(R.x, y)$, where R is an aspect ratio in the anisotropy. However, because growth is strongly preferred along the easy directions of the anisotropy, an aspect ratio of R in the anisotropy leads to a much higher aspect ratio in the resulting crystal. This is illustrated in Figure 1, which shows four snapshots of the growth of a needle crystal. The parameters used in the simulations are $\varepsilon = 0.2$, $q = 0.1$, $R = 2$. The initial seed was a regular hexagon, wherein the initial aspect ratio is $2/\sqrt{3} = 1.15$. This increases with time to 2.33, 3.15, 3.76 and 4.37 for frames (a)-(d) respectively. In fact, we find that, to a first approximation, the length, a, grows linearly with time, t, while the width, b, grows as $\sqrt{t}$, wherein the aspect ratio increases continuously with time. In Figure 2 we make a morphological comparison between simulation and the micrograph of $Al_{13}Fe_4$ needles given in the classic review paper by Allen [2]. In both cases the aspect ratio is around 12 although currently the methodology does not correctly reproduce the angles at the crystal tip. This is being corrected by applying the aspect ratio factor R on a hexagonal basis function, rather than an orthogonal Cartesian basis.

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The critical factor for the iron tolerance limit in magnesium

L. Yang, T. Hashimoto, J. Yu, X. Zhou, G.E. Thompson, G.M. Scamans and Z. Fan

For magnesium and its alloys, a major deficiency is its inadequate corrosion resistance under service conditions, particularly when Fe, Ni, Cu, or Co is present, since their low over-potential (or high exchange current density) for hydrogen evolution has detrimental effects on the corrosion resistance due to increase in the hydrogen reduction rate.

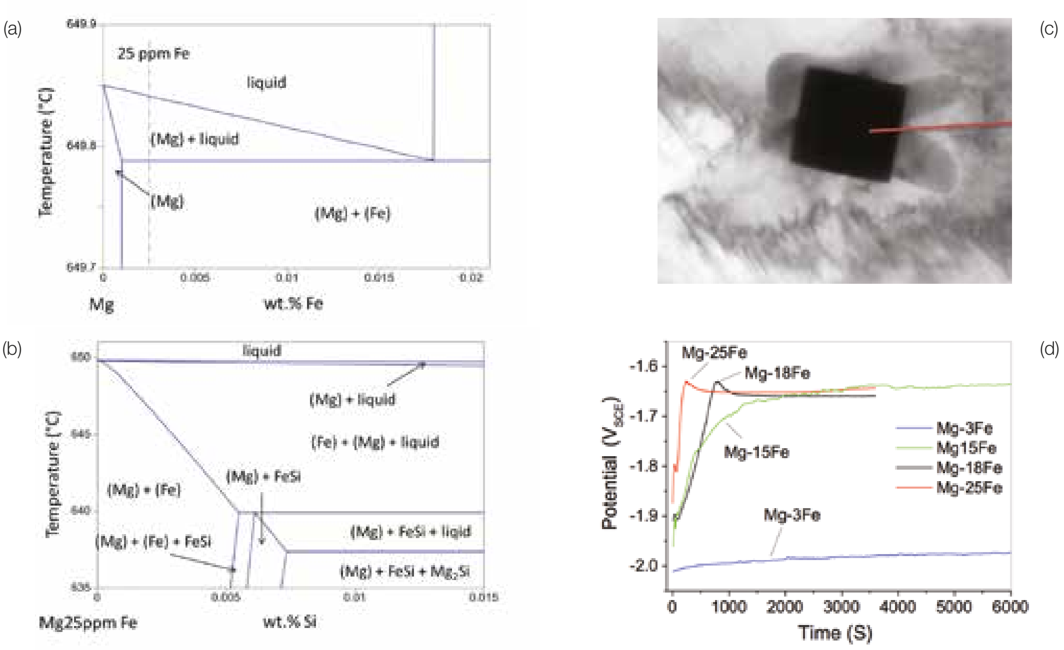


FIGURE 1. (a) The solidification interval of Mg-Fe phase diagram, (b) the ternary Mg-Fe-Si phase diagram at constant 25 ppm Fe showing an enlarged solidification interval, (c) TEM images of a typical Fe-rich particle and (d) open circuit potential as a function of immersion time, revealing the surface film breakdown potential that is controlled by the cathodic reaction at Fe-rich particle.

Iron is one of the most common impurities, which are introduced during alloy production, particularly for recycled alloys. The corrosion rate of Mg is usually insignificant (< 1 mm/year) if the content of Fe is below a critical value, whereas the corrosion rate substantially increases when the Fe content exceeds the critical value. This critical value is referred to as iron tolerance limit. However, significantly different values of iron tolerance limit have been reported. This presented study is focused on determining the critical factors that control iron tolerance limit in magnesium, with a particular focus on the solidification behaviour of Fe-rich phases.

It is found that the critical factor for the tolerance limit of iron in magnesium is corrosion potential, which is determined by the cathodic and anodic reactions and their kinetics that are controlled by the size and population of Fe-rich particles. Further, the iron tolerance limit is significantly affected by the presence of other alloying elements or impurities. Silicon, a common impurity in magnesium, even at the low ppm level, can significantly influence the solidification behaviour of the (Fe) phase in Mg-Fe alloys through introducing a solidification interval and, consequently, promoting the formation and growth of (Fe) particles that contain silicon. This reduces the corrosion tolerance limit of Fe in magnesium.

In summary, the critical factor for iron tolerance limit in magnesium is corrosion potential, which can be controlled by the distribution of iron. The iron tolerance limit in magnesium can be increased by controlling the formation of Fe-rich particles.

Future research will focus on how to promote the formation of iron-rich particles that have relatively high over-potential and low exchange current for hydrogen reduction so that the iron tolerance limit in magnesium can be increased.

Academic Leadership Contacts

For further information or to collaborate with us on our fundamental research please contact

lime@brunel.ac.uk
+44 (0) 1895 267 703

Professor Zhongyun Fan
Director/Principal Investigator
Brunel University London

E zhongyun.fan@brunel.ac.uk
T +44 (0) 1895 266 406 / 266 413

Professor Xiaorong Zhou
Co-Investigator
University of Manchester

E xiaorong.zhou@manchester.ac.uk
T +44 (0) 161 306 4832

Professor Patrick Grant
Co-Investigator
University of Oxford

E patrick.grant@materials.ox.ac.uk
T +44 (0) 1865 283 763

Dr Christopher Gourlay
Co-Investigator
Imperial College London

E c.gourlay@imperial.ac.uk
T +44 (0) 20 7594 8707

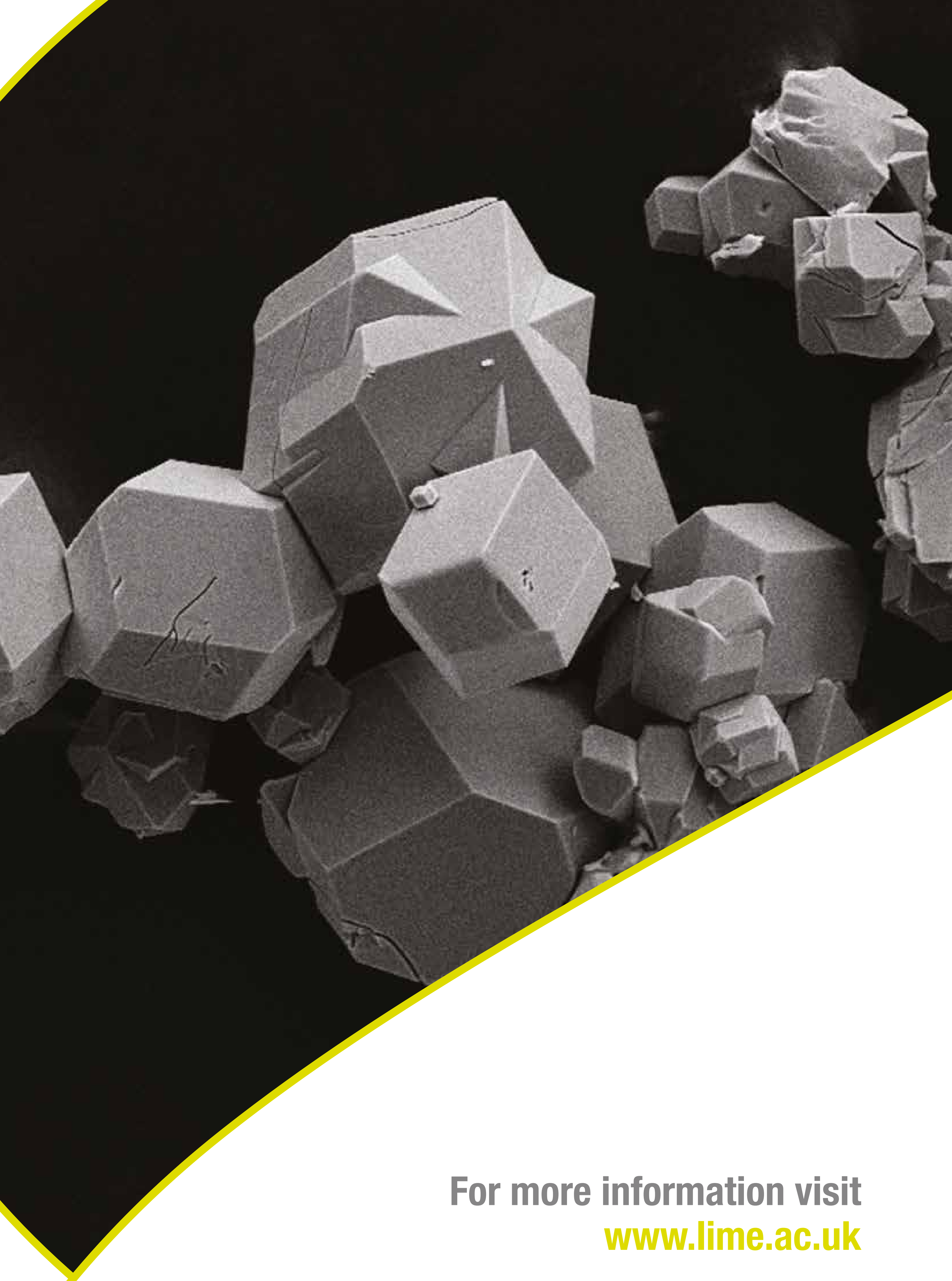
Professor Andrew Mullis
Co-Investigator
University of Leeds

E a.m.mullis@leeds.ac.uk
T +44 (0) 113 343 2568

Alloy Development

Alloy development research concentrates on the design of optimum microstructure in lightweight aluminium and magnesium based alloys to deliver maximum performance, by using a combination of experimental and theoretical approaches. These are used to achieve the required physical properties including strength, ductility and conductivity.

Alloy development research highlights are exhibited in the following summaries.



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Development of high strength multicomponent aluminium based die casting alloys

I.T.H. Chang, Q. Cai and Z. Fan

There is an increasing demand for lightweight vehicles in the automotive industry to reduce fuel consumption and lower emissions. This has led to a rapid growth in the use of aluminium parts produced by high pressure die casting (HPDC). Currently, existing aluminium die casting alloy compositions are based on binary Al-Si or Al-Mg systems with additions of minor alloying elements.

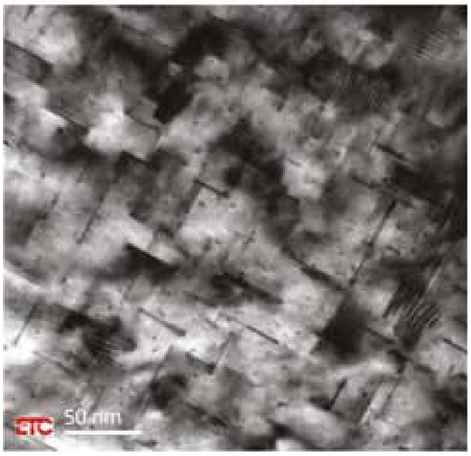

FIGURE 1. Ultrafine precipitates in the α-Al matrix of HPDC Al-Cu-Si-Mg-Mn-Fe alloy heat treated at peak aged condition.

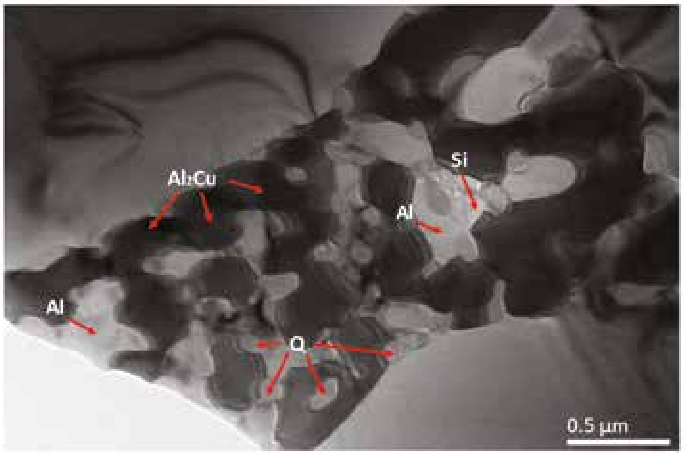

FIGURE 2. Nanocrystalline eutectic mixture in as-cast HPDC Al-Cu-Si-Mg-Mn-Fe alloy

However, their yield strength and ultimate tensile strength are limited to 120-250 MPa and 250-330 MPa. Hence, there is an urgent need to develop HPDC aluminum alloys with strength properties beyond those currently available for the ever-demanding automotive engineering components.

Recently, near-eutectic ternary Al-Cu-Si [1] alloys have received increasing attention due to a combination of ultrahigh strength and good plasticity, which are attributed to the nano/ultrafine structure composites containing either micron-sized dendrites embedded in ultrafine eutectic matrix or multi-scale bimodal eutectic microstructure. However, there are very limited studies on the use of high-order multicomponent eutectic aluminium alloy systems for the design of high strength casting aluminum alloys.

The aim of this project is to develop high strength multicomponent aluminium die casting alloys that offer a combination of various strengthening mechanisms (e.g. grain boundary, second phase or precipitate hardening) with reasonable ductility and good fluidity via low melting point of liquid phase. The objective is to design a series of hypoeutectic compositions in Al-Cu-Si-Mg-Mn-Fe multicomponent eutectic systems for high pressure die casting, to exploit the high hardness of nanocrystaline eutectic mixture and the soft α-Al dendrites to yield a combination of high strength and good ductility properties.

It has been demonstrated that the yield strength and ductility can be tailored according to alloy composition. The yield strength increases from 219 MPa to 267 MPa, while the ductility decreases from 7.7 % to 3.1 % with increasing amount of nanocrystalline eutectic mixture from 13 % to 24 % respectively. Upon peak ageing heat treatment of these casting alloys, their yield strength increase at the expense of the ductility. This research work has demonstrated that the yield strength of 395 MPa and ductility of 1.8 % can be achieved in the peak aged HPDC Al-Cu-Si-Mg-Mn-Fe hypoeutectic alloy with 24 % nanocrystalline eutectic mixture. Such exceptional high strength in this material is attributed to a combination of nanoscaled precipitates in the α-Al matrix and hard intermetallic phases in the eutectic mixture, as shown in Figures 1 and 2. Future work is to explore the high-order multicomponent eutectic concept in the development of high strength copper-free aluminium die casting alloys.

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Progress in the development of new Mg alloys for the low force TRC process

C.L. Mendis, U. Amin, X.L. Yang and Z. Fan

Magnesium (Mg) is the lightest of the structural metals and is widely available. This makes alloys based on Mg ideal for applications where lightweighting is of high importance, such as automotive. Many of the desired weight savings for automotive could be achieved using Mg alloys for sheet applications, for example in potential application to body panels.

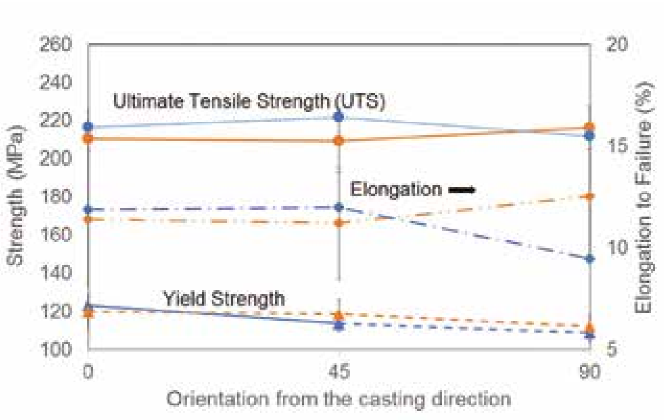

FIGURE 1. Mechanical properties of TRC processed ZASM1100 alloy in the as-cast and homogenised conditions.

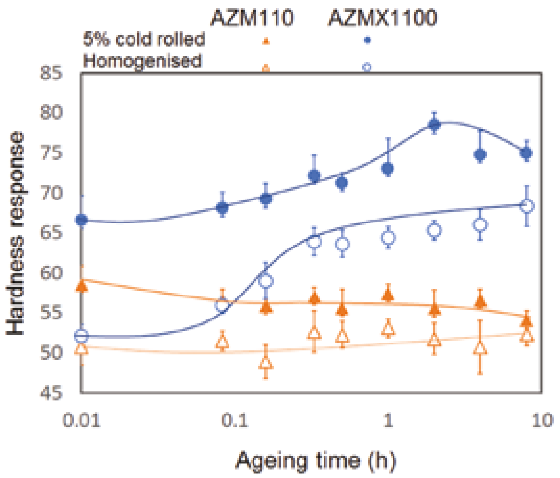

FIGURE 2. Age hardening response of AZM110 and AZXM1100 following thermomechanical processing.

Conventional twin roll casting (TRC) has shown some promise as a pathway to producing Mg sheet products, although this conventional TRC process can only be used to produce very dilute alloys, due to centre line segregation defects, which requires subsequent rolling passes to achieve the sheet thicknesses required for automotive and personnel electronics applications. At present, a majority of the research on TRC of Mg alloys concentrates on AZ31 (Mg-3Al-1Zn) alloy or other dilute Mg-based alloys that cannot be thermomechanically processed further to allow strength enhancement. Conventional TRC sheets show large anisotropies in strength both in and out of the sheet plane and in the case of AZ31, a strong basal texture that does not allow for subsequent forming operations without subjecting to elevated temperature, leading to the loss of mechanical properties.

Hence, there is a need to develop Mg alloys suited for the TRC process that may be subsequently strengthened through solute segregation or precipitation hardening to allow production of a high strength final product, while imparting a high level of ductility during processing. The low force TRC process developed within BCAST (currently optimised) allows for faster processing of TRC strip with a thinner gauge which does not require subsequent rolling steps to reduce the thickness of the sheet via rolling. ZASM1100 (Mg-1Zn-1Al-0.2Si-0.4Mn) alloy was developed as a dilute TRC alloy while AZMX1100 (Mg-1Al-1Zn-0.5Mn-0.3Ca) was developed as a possible heat treatable alloy based on previous investigations of Mg-Al-Ca system [1]. The low force TRC process combined with alloy development is used to investigate the mechanical property evolution of the ZASM1100 alloy, while the role of thermo-mechanical processing such as heat treatment in the homogenised AZMX1100 alloy is investigated.

The TRC ZASM1100 alloy showed a fine scaled microstructure (not shown here) in the as-cast and the homogenised conditions, while the mechanical properties remained similar between the two conditions, as shown in Figure 1. This alloy exhibits relatively isotropic mechanical properties in the plane of the TRC sheet both in the as-cast and the homogenised conditions which would allow for homogeneous deformation during any subsequent mechanical processing. The yield strength and ultimate tensile strength (UTS) could be further improved to ~240 MPa and ~260 MPa, respectively, following a 25 % cold rolling reduction (not shown in Figure 1). The AZM110 did not show any appreciable hardening response following homogenisation (to mimic the final structure achieved after twin roll casting and homogenisation) nor following a 5 % cold rolling reduction (pinch rolling reduction or forming operation), while the AZMX1100 alloy with 0.5wt% Ca shows an appreciable hardening response following both processing paths, as shown in Figure 2. Further investigations on the modified thermomechanical processing schedules as well as microstructure evolution and mechanical property evaluations will be conducted in the future to establish the processing/microstructure/properties relationships for this newly developed Mg-Al-Zn-Mn-Ca alloy system.

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Strength improvement in high pressure die castings for automotive components

X. Zhu, S. Ji and Z. Fan

This project is sponsored by Jaguar Land Rover to develop and commercialise the next generation of high strength cast aluminium alloys produced by high pressure die casting (HPDC) for light duty engines and other structural components.

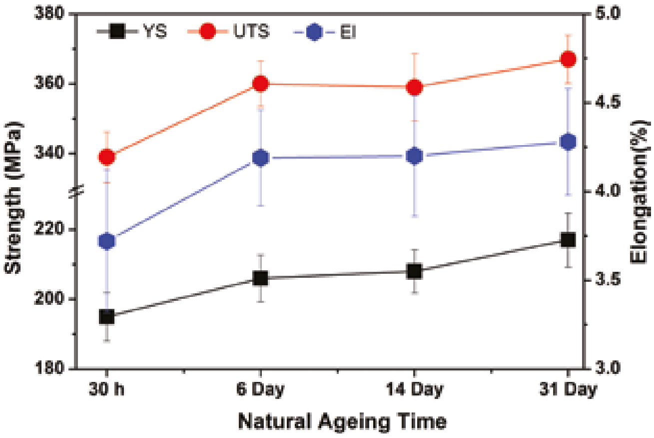

FIGURE 1. The effect of natural ageing on the mechanical properties of the newly developed alloy.

Mechanical properties	YS (MPa)	UTS (MPa)	El (%)
Current alloy	145	329	5.17
Developed alloy	217	367	4.25

TABLE 1. The mechanical properties of the current and developed alloys.

As lightweighting automotive structures are always required for transport manufacturing, the mechanical properties of existing commercial aluminium alloys for the HPDC process does not meet industry requirements. Therefore, the development of new high strength aluminium alloys for HPDC is necessary for automotive OEMs. In this project, a cam carrier is selected for this case study. The current commercially available aluminium alloy is EN AC-46000, which has a yield strength (YS) of 145 MPa, ultimate tensile strength (UTS) of 329 MPa and elongation of 5.1 %. The new high strength HPDC aluminium alloy has to meet the required properties of UTS>300 MPa, YS>200 MPa, El>2 % in casting body and >4 % in 6.35 mm Ø die-cast tensile samples at room temperature. Such requirements must be met only in the as-cast condition without any heat treatment.

Generally, the increase of strength is obtained at the sacrifice of elongation. Therefore, the biggest challenge of this project is to maintain the elongation at an acceptable level (>4 %) as the strength is increased by 38 %. In Al-Si-Cu-Mg alloys, the two main strengthening phases are Q-$Al_5Cu_2Mg_8Si_6$ and θ-Al_2Cu intermetallic compounds. The θ-Al_2Cu phase exists in the form of (1) large individual blocks, or (2) fine Al-Al_2Cu lamellar eutectics along the boundaries of α-Al grains; while Q-$Al_5Cu_2Mg_8Si_6$ only exists within the eutectic mixture. The experimental results reveal that the addition of Cu (Cu< 3%) increases the elongation, but a further increase in the level of Cu induces a decrease in elongation. A series of alloying additions, including Si, Cu, Mg, Zn, and other elements of Zr, Ni, Ti were studied to determine the optimum combination of alloying elements and final composition. The Fe level should be limited to no more than 1wt.% to avoid the formation of large α-AlFeMnSi phase and needle-like β-AlFeSi phase. It was also found that too much modifying or refining elements (Mn, Ti and Sr) are deleterious to the properties.

The natural ageing of the developed alloy can simultaneously improve the YS, UTS and elongation. It is believed that the high cooling rate during the HPDC process induced a degree of solid solution of solute-atoms and then the natural ageing leads to the precipitation of fine Q-$Al_5Cu_2Mg_8Si_6$ phase within α-Al grains. It has been confirmed that fine Q-$Al_5Cu_2Mg_8Si_6$ precipitates are distributed within α-Al matrix, which are responsible for both strength and elongation improvement. After a few day's natural ageing, the developed alloy has the stable properties: YS >210MPa, UTS >350MPa and El >4.0 %. The tensile property of the developed alloy has good repeatability.

In the future, trial castings of the developed alloy with a shape off box will be produced and the Weibull statistical model will be used to analyse reliability of the castings. This will then allow for the developed alloy to be fully implemented within industry.

Aluminium alloys for engine components working at elevated temperatures

M. Rahimian, S. Ji and Z. Fan

Improvement in performance of the internal combustion (IC) engine for reduction of fuel consumption and CO_2 emissions is highly competitive, and requires an increase in the combustion pressure and temperature within the engines.

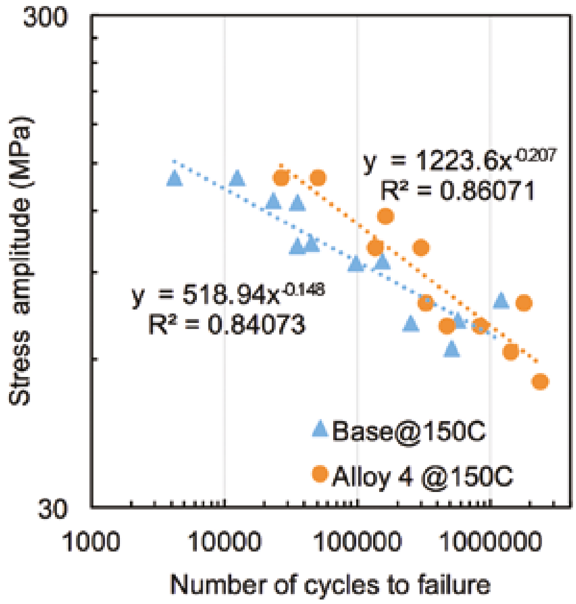

FIGURE 1. Stress amplitude versus the number of cycles to failure obtained from the fatigue tests of the alloy 4 and baseline alloy at 150 °C.

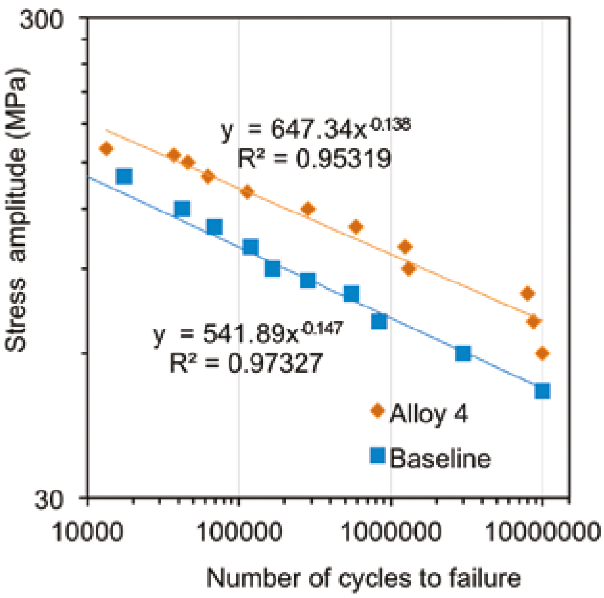

FIGURE 2. Stress amplitude versus the number of cycles to failure for the alloy 4 and baseline alloy conducted at 200 °C.

Therefore, the development of aluminium alloys for improved mechanical performance at elevated temperatures is essential for manufacturing future IC engine parts.

The present project aims to increase the working temperature of aluminium alloys by matching the mechanical properties of the baseline alloy (EN-AC-42000) at 150 °C, with the new alloy at 200 °C. To achieve the defined targets, minor elements including Zr, Mo, Nb, Ni, Hf, Si, Mn, Fe Sc, Cu, V, Ti, RE and others were studied and the new alloy has been developed for industrial applications. For the EN AC-42000 alloy, the yield strength and ultimate tensile strength are 218 and 272 MPa respectively and elongation is 4.86 % at ambient temperature. The yield strength and ultimate tensile strength are 160 and 173 MPa respectively, after exposing the alloy at 200 °C for 40 minutes whilst elongation is increased to 6.6 %. For the newly developed alloy, the yield and ultimate tensile strength and elongation at ambient temperature are 293 MPa, 374 MPa and 5.31 % respectively. The yield and ultimate tensile strength decrease to 232 and 256 MPa and the elongation increases to 6.15 % at 200 °C. More importantly, the fatigue properties at 150 °C and 200 °C are tested and the results are shown in Figures 1 and 2. Clearly, the improvement in tensile strength and fatigue properties for the newly developed alloy are significant. At 200 °C, the fatigue property of the new alloy is 10 times better than the baseline alloy when the stress is fixed at the same level. Meanwhile, for the given cycles, the stress level of the new alloy is 30 MPa higher than the baseline alloy.

The investigation on the strengthening mechanism has shown that the new phases formed at the elevated temperature exhibit minimal coarsening and provide an effective strengthening behaviour to resist deformation at elevated temperatures.

The developed materials have been validated in the small scale testing from the tensile and fatigue properties at room temperature and at elevated temperatures. The demonstration components will then be made and tested in line with industrial partners for application to the cylinder heads of internal combustion engines. The plan for future work will include testing of the alloys for other applications at elevated temperatures.

High modulus aluminium-based materials for automotive applications

S. Amirkhanlou, S. Ji and Z. Fan

The design of automotive structural components made from lightweight aluminium shape castings are usually based on either yield strength or stiffness (Young's modulus) requirements. Although aluminium alloys have reasonably acceptable yield strength, their Young's modulus is undesirably low. Therefore, the development of aluminium-based materials with improved Young's modulus becomes essential for lightweighting structures.

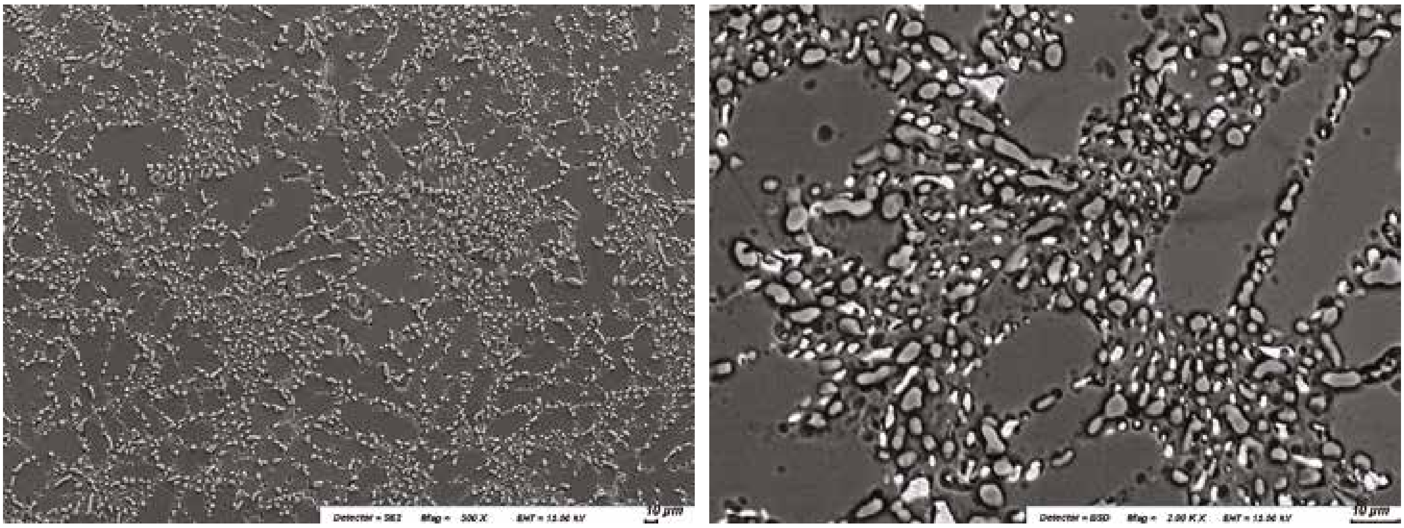

FIGURE 1. Typical microstructures of gravity cast Al-Si-Ni-Mg alloys developed for a high Young's modulus property, taken at low (left) and high (right) magnifications.

The target of this project is to improve the Young's modulus of cast aluminium-based materials from 70 GPa to greater than 85 GPa. The only possible option is to introduce high modulus phases in the microstructure of aluminium alloys, which can be achieved through alloying elements, insoluble metallic or non-metallic components. Therefore, three approaches were considered to improve the stiffness of aluminium alloys. The first approach was to achieve high modulus materials through in-situ formation of TiB_2 phases within aluminium matrix, which can improve the Young's modulus up to 95 GPa within an acceptable level of making sound castings through conventional sand casting or gravity casting routes. The second approach was the fabrication of steel wire reinforced aluminium matrix to form Al/Fe composites, using a combination of sand casting, gravity casting and squeeze casting routes. The third approach was to study the effect of alloy chemistry on the Young's modulus of cast aluminium alloys. It was found that the influence of alloying elements on the Young's modulus depends on the microstructure. If the alloying elements form a solid solution phase, the magnitude of the Young's modulus increment is determined by the nature of the atomic interactions. If the alloying elements form second phases, the magnitude of the Young's modulus increment is determined by the volume fraction and the intrinsic modulus of the second phase. Among the alloying elements (e.g. Si, Cu, Mn and Ni) studied, Si and Ni are favourite candidates to enhance the Young's modulus of cast aluminium alloys. After optimising the heat treatment process, the studies showed that the Al-Si-Ni-Mg alloy could provide a Young's modulus of ~84 GPa, with a yield strength in excess of 200 MPa and a total elongation of 4.6 %, which has fully satisfied the requirement of the project. In addition, the composition of Al-Si-Ni-Mg alloy could be modified to give even higher Young's modulus, reaching ~94 GPa with the yield strength over 200 MPa and 1.2 % total elongation. The ultra-high Young's modulus property in Al-Si-Ni-Mg alloy is mainly attributed to the presence of α-Al, Si, Al_3Ni and $AlNi_3$ phases in the resultant microstructure.

The key concerns for the Al-Si-Ni-Mg alloy with increased stiffness are the relatively low elongation. However, they have been overcome by optimising the alloy chemistry and heat treatment conditions. Figure 1 shows typical microstructures of gravity cast Al-Si-Ni-Mg alloys with exceptionally high modulus.

For further information or to collaborate with us on our alloy development research please contact

lime@brunel.ac.uk
+44 (0) 1895 267 703

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Overview of high shear melt conditioning (HSMC) technology for processing Al and Mg alloys

J.B. Patel, Y. Zhang and Z. Fan

Light alloys of Al and Mg are used in many industrial applications where lightweighting is of paramount interest. Lightweighting has become more important for increased fuel efficiencies, with the increase in the mass of cars as a result of the weight of the batteries or fuel cells associated with electric vehicles.

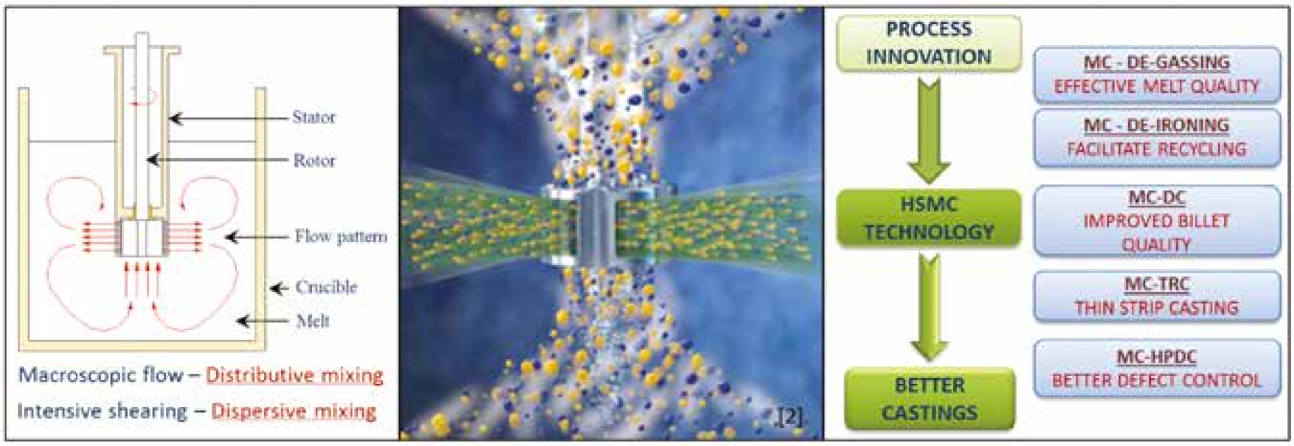

FIGURE 1. Schematic illustrations of the high shear melt conditioning (HSMC) technology and its potential applications.

The development of high strength alloys and composites requires a refined microstructure with a reduced defect distribution together with a homogeneous composition profile in the final product. Solidification and casting is essential for processing metallic materials, regardless of whether the final product is used in the cast or wrought form. The quality of the casting and in turn the quality of the melt is crucial in determining the final properties. Oxides, gas and other inclusions usually deteriorate the quality of the melt, and in turn the properties and quality of the castings. The reduction in defect density and the resultant increase in strength would contribute to the lighter parts, and this may be achieved through melt conditioning, especially with intensive melt shearing.

There are numerous existing methods including electromagnetic stirring, mechanical stirring with an impeller, melt filtering, and rotary degassing, which are used to treat the liquid metals. The rotor–stator device developed within BCAST provides intensive melt shearing, dispersing inclusions into finer scale particles that enhance the number of nucleation sites [1].

The HSMC technology uses a simple rotor-stator arrangement to provide intensive melt shearing. It comprises of a set of rotor and stator attached to an electrical motor with a speed control. The HSMC technique provides macro-flow in a volume of melt for distributive mixing and intensive shearing near the tip of the device for dispersive mixing. Hence, the HSMC technology can be used for; physical grain refinement by dispersing naturally occurring oxides, for degassing of melts, for the preparation of metal matrix composites and also for preparation of semi-solid slurries. In turn, these characteristics can be applied to benefit various conventional casting processes such as direct chill casting, twin roll casting and high pressure die casting, in order to improve the quality of cast products. Currently, grain refinement of Al and Mg alloys is usually achieved by enhancing heterogeneous nucleation by means of chemical inoculation methods. However, in the case of application of intensive melt shearing, which is termed as a physical treatment as supposed to chemical treatment, previous research has demonstrated that naturally occurring oxides and other inclusions present in Al and Mg alloy melts are amenable to physical manipulation by intensive melt shearing. The dispersed oxide particles can act as potential nucleating agents for the primary (α) phase in both Al and Mg alloys.

The concept of high shear melt conditioning in Al and Mg melts has been extensively studied and well understood in terms of solidification and application to industrial casting processes to solve some commonly associated fundamental problems. It has also proven to be applicable to different casting processes making it a 'multi-purpose' liquid metal treatment technology, which can be easily integrated to benefit various industrial casting processes. One of the key features is that it can be easily applied in-line to an existing launder system in large scale operations requiring very little size scale-up of the HSMC equipment.

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Numerical modelling of high shear melt conditioning (HSMC)

B. Lebon, J.B. Patel, H. Assadi and Z. Fan

High-shear melt conditioning (HSMC) results in grain size reduction without the addition of grain refiners. In high shear processing, a rotor-stator mechanism (the high shear device) is immersed into the bulk liquid.

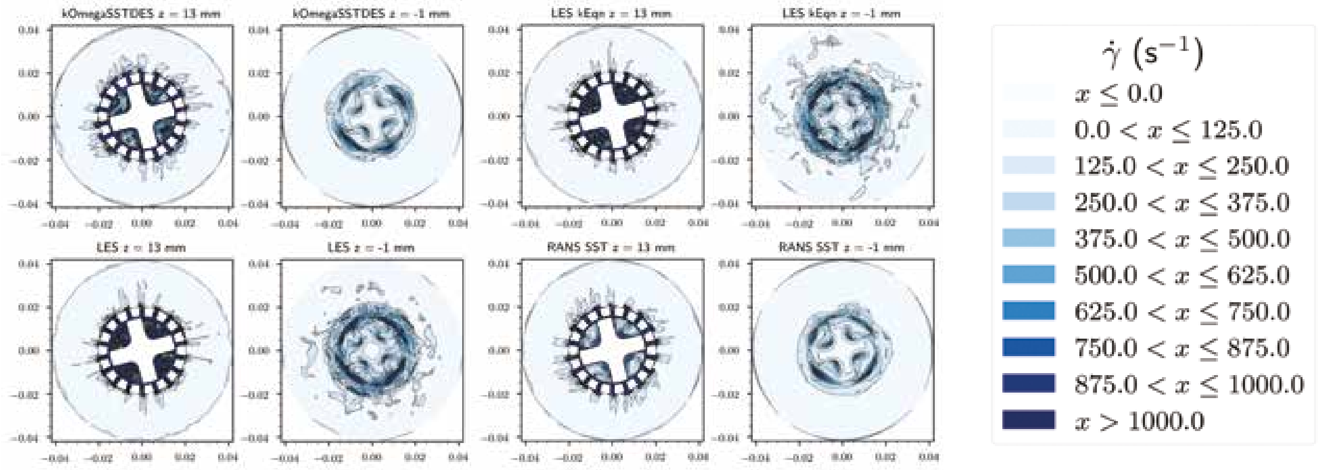

FIGURE 1. Strain rate field in an 80 mm Ø mould with rotor at 1000 RPM. Z planes are along the axis of the rotor.

High shear melt conditioning (HSMC) results in grain size reduction without the addition of grain refiners. In high shear processing, a rotor stator mechanism (the high shear device) is immersed into the liquid bulk. The rotor rotates at high speed inside a cylindrical stator surrounded by a series of small holes. The high shear rate is due to the high speed of the rotor tip and the small gap between the rotor blades and the stator. The resulting break up and dispersion of oxide inclusions can lead to a uniform structure, hence better material properties.

The flow pattern inside the melt bulk is crucial to the mixing and deagglomeration process and affects the efficiency of the mixer. The mixing zone, also known as a pseudo-cavern for shear-thinning liquids, is of paramount interest. However, the flow around the mixer is complex, thus making optimisation of the process challenging. While the literature has different recent examples of numerical studies of rotor stators, all of them to date treat turbulence using the Reynolds-Averages Navier-Stokes (RANS) approach. RANS can predict flow features around the mixer; however, they severely under-predict the global turbulent energy dissipation rate ε. The flow pattern around mixers is rich in non-uniform and inherently transient structures, thereby necessitating the use of better turbulence models.

In this work, a turbulence model is used to predict flow in a rotor-stator device, shearing A6060 melt at 1000 RPM, in an 80 mm Ø mould. The average torque around the rotor is around 0.08 Nm, corresponding to an average power of 35 W and power number of 2.0. The flow equations, solved using the interDyMFoam solver of OpenFOAM, are closed by using two Large Eddy Simulation (LES) models: the Smagorinsky [1] and Yoshizawa [2] subgrid scale models, a Detached Eddy Simulation (DES) model (k-ω SST) [3] and the RANS k-ω SST model [3].

Both LES models yield similar predictions, with similar order of magnitudes for strain rate and similar complex flow structures below the mixer. Large strain rate values are confined to the mixer volume, implying deagglomeration can occur only within the mixer volume. Turbulent mixing is prominent throughout the bulk region within the height of the stator rows. In this region, any inclusions are expected to be evenly distributed. Through the stator holes, the jet is always generated at the leading edges and recirculations at the trailing edge, regardless of the rotor position, with the largest flow rates occurring at the top rows.

However, the RANS and DES models both underestimate the strain rate both inside and under the mixer. This discrepancy will lead to inaccurate evaluation of deagglomeration rates when coupling flow to a deagglomeration model, should these turbulence closures be used. Moreover, the LES model evaluations were tractable on the BCAST high-performance computing facility, yielding results for the 80 mm Ø mould within two weeks. This paves the way for optimisation studies of the flow pattern and deagglomeration rate around the rotor-stator mixer.

HSMC will be focussed on in the future and studied numerically using an LES model and an uncertainty quantification framework to determine the optimum rotation speed and mixer geometry, to maximise the pseudo-cavern around the mixer and the strain rate within the mixer region.

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De-ironing of aluminium scrap by high shear melt conditioning technology

J. Lazaro Nebreda, J.B. Patel, G.M. Scamans, I.T.H. Chang and Z. Fan

Manufacturing primary aluminium ingots requires 20 times more energy and produces 4 times more CO_2 emissions than obtaining ingots from remelted scrap and so aluminium recycling is necessary for a sustainable future.

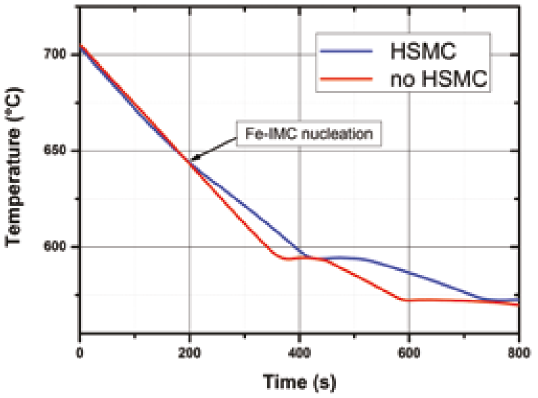
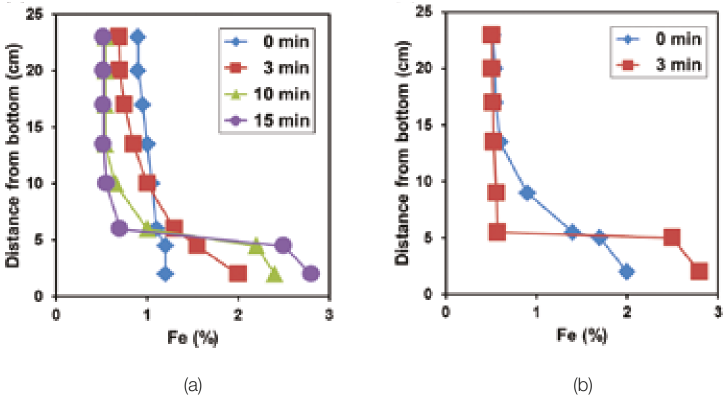


FIGURE 1. Cooling curve of A380-1Fe alloy before and after applying high shear melt conditioning (HSMC) at 700 °C showing the enhanced nucleation of the Fe-rich phase.



(a)

(b)

FIGURE 2. Sedimentation of Fe-rich phase in A380-1Fe alloy after cooling and holding at 600 °C for different times (a) without melt treatment (b) after HSMC.

However, one of the main problems of aluminium recycling is the gradual accumulation of impurities in the molten scrap, in particular iron, due to the presence of high iron containing components (rivets, screws, nuts…) or from the steel tools used during casting processes. A key objective of BCAST has been to develop a technology [1] based on intensive high shear melt conditioning (HSMC), that enables efficient iron removal [2], avoiding the recycled aluminium to be either downgraded into low quality cast products or diluted with primary aluminium.

The aluminium purification method is based on the fact that iron tends to form dense intermetallic compounds (Fe-IMCs) during solidification which can be separated to obtain a low-Fe molten metal [3]. The problem is that these compounds tend to nucleate on the wetted side of the naturally occurring oxide films entrained in the Al-alloy melt and as they are normally agglomerated and not well dispersed within the melt, the nucleation and growth of the Fe-rich IMCs is hindered (Figure 1 red line).

The use of HSMC technology can easily disperse the large oxide films and clusters into very fine and uniformly distributed individual particles [4], in turn enhancing the nucleation of the Fe-IMCs (Figure 1 blue line).

As a consequence of the enhanced nucleation, the separation of Fe-IMCs can be achieved much faster, thus increasing productivity and reducing processing costs. Figure 2 shows an example of this for A380-1Fe melt held at 600 °C (above α-Al formation) in a 25 cm chamber. Without melt treatment (Figure 2a), the Fe-IMCs need some time to nucleate (1-3 min), and even more to effectively grow and settle (10-15min). When using HSMC technology (Figure 2b), the nucleation occurs during the cooling stage and this reduces the time needed for the IMC to fully settle (< 3min).

Currently BCAST is focused on scaling up this innovative technology to apply it in a recycling plant, as well as evaluating its applicability to remove other impurities or inclusions in the melt.

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Towards a short homogenisation process for DC cast billets of wrought Al alloys by MC-DC casting

H.-T. Li, N.S. Barekar, J.B. Patel and Z. Fan

In industrial practice, Al-Ti-B (C) master alloys are commonly used as grain refiners during DC casting of wrought aluminium alloys. However, addition of grain refiners results in more globular grains with a coarse necklace like morphology of second phase particles [1].

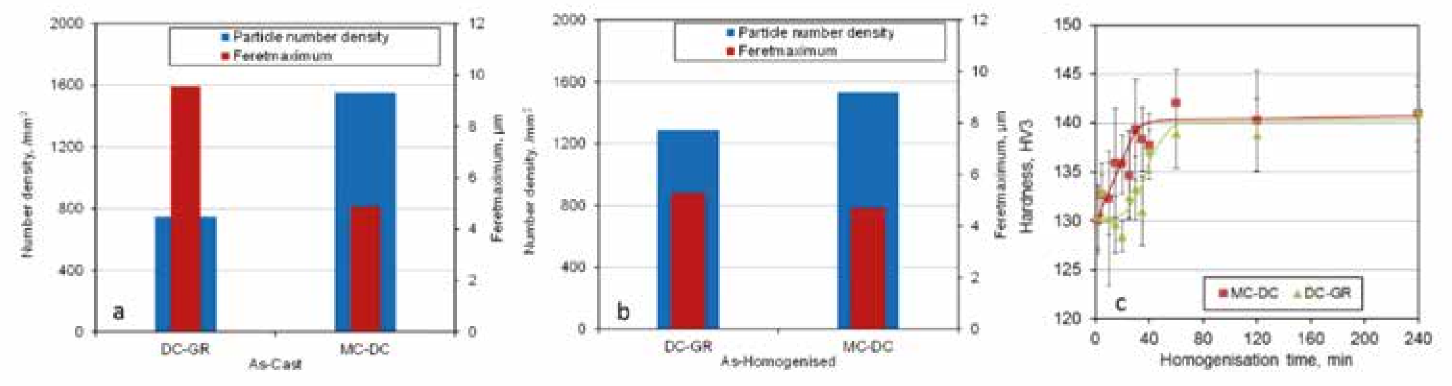

FIGURE 1. Size (feret maximum) and number density of intermetallic particles in an A6xxx alloy of 152 ø mm billets, prepared under different DC casting conditions. (a) As-cast, and (b) after homogenisation, (c) holding time of homogenisation treatment against hardness with the same ageing procedure.

A homogenisation treatment is an indispensable step for the DC cast billet prior to extrusion/rolling to reduce the micro-segregations of Mg and Si and transform the majority of the coarse β-AlFeSi to the finer α-AlFe(Mn)Si phases [2]. This transformation is however a slow and energy-consuming process to facilitate the downstream thermomechanical processing. The time to break up, transform and redistribute these Fe-rich intermetallics is the controlling factor to dictate homogenisation capacity far beyond that necessary to redistribute Mg and Si. By using MC-DC casting technology, fine equiaxed dendritic grains can be formed and thus, second phase particles can be refined and uniformly distributed. As a consequence, a short homogenisation treatment of MC-DC cast billet can be expected.

Compared with a DC cast billet of A6082 alloy with Al-Ti-B grain refiner addition (DC-GR), the MC-DC cast billet shows similar grain size but with fine equiaxed dendritic structure. This results in much finer second phase particles with a higher number density in the as-cast microstructure (Figure 1a). After the same homogenisation treatment, the size of second phases in DC-GR samples decreased significantly and the number density increased accordingly. However, the size and number density of MC-DC cast samples show almost no change (Figure 1b). This suggests a short homogenisation treatment might be necessary in the MC-DC cast sample to dissolve the Mg_2Si phase only. To achieve the peak ageing hardness in the MC-DC cast billet, less than 40 min of homogenisation was enough compared with the DC-GR samples in which more than 60 min were needed (Figure 1c).

Fine and uniformly distributed second phase particles facilitate a short homogenisation treatment, which is of significant economic importance, in particular for large-sized DC cast ingots/billets. Further investigations on hot formability after a short homogenisation treatment are necessary in MC-DC cast billets to guide the practice in industry. Further thermomechanical processing and microstructural assessment of MC-DC cast billets will demonstrate the full advantages of this emerging technology.

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Improvement of macrosegregation and second phases in Mg Alloys by MC-DC casting

H.-T. Li, J.B. Patel and Z. Fan

Magnesium alloys offer the potential for weight and related energy savings in both the automotive and aerospace industries because they have the highest strength-to-weight ratio of all structural metals [1]. For wrought magnesium alloys, formation of macrosegregation and coarse second phase particles not only affects the downstream processing but also results in a high scrap rate of cast billets.

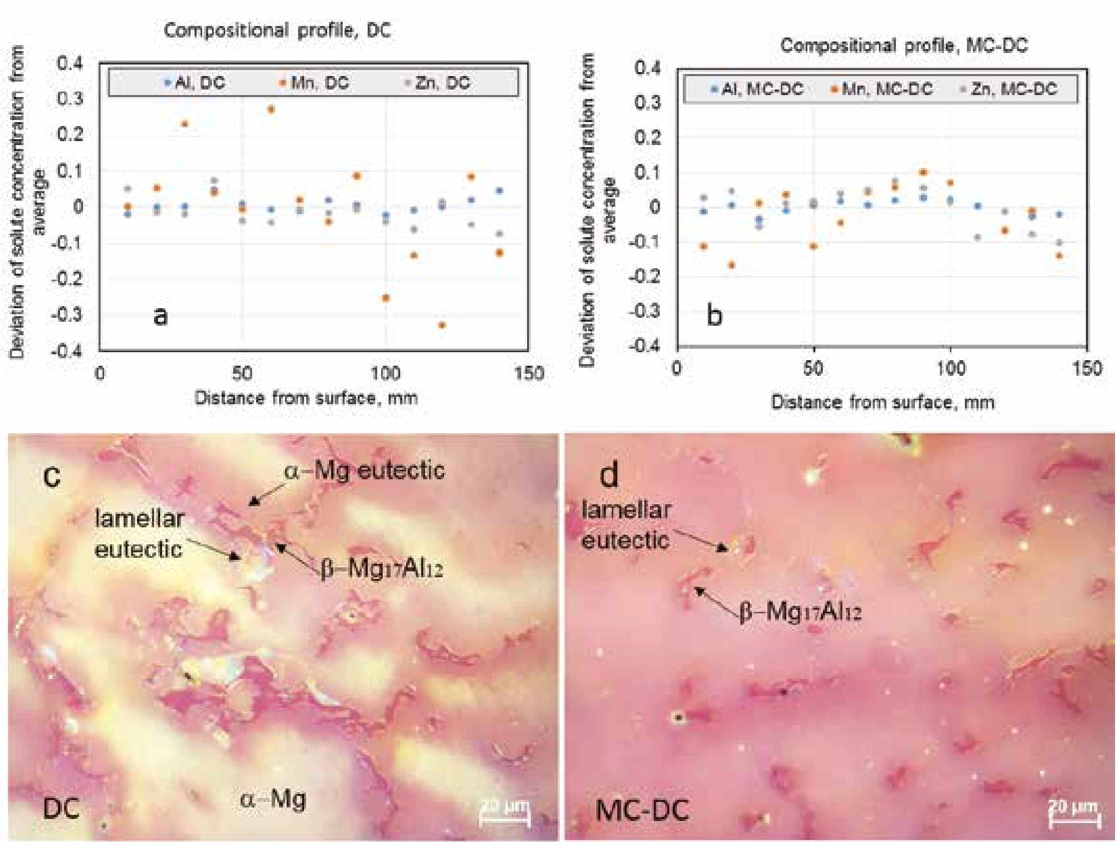

FIGURE 1. Alleviated macrosegregation (a) and (b). Refinement of second phases (c) and (d) in the MC-DC cast billet of a commercial AZ80 alloy with a 300 mm ø.

Melt conditioned direct-chill (MC-DC) casting is an emerging technology to manipulate the solidification process by a rotor-stator high shear mechanism in the sump during the DC casting process [2]. By using MC-DC casting technology, both macrosegregation and second phase particles can be improved in DC cast billets of a commercial Mg alloy. Figure 1 shows the alleviated macrosegregation (Figures 1a and 1b) and refinement of second phase particles (Figures 1c and 1d) in an MC-DC cast AZ80 alloy. These can be ascribed to grain refinement and shallower sump profile achieved by intensive melt shearing.

By manipulating the solidification process in MC-DC casting, the macrosegregation can be alleviated and second phase particles can be refined significantly. Further assessment of the impact on downstream processing is ongoing.

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Numerical modelling of the melt conditioned direct chill (MC-DC) casting process

B. Lebon, H.-T. Li, J.B. Patel, H. Assadi and Z. Fan

Direct-chill (DC) casting is a semi-continuous casting method that produces wrought aluminium and magnesium alloys.

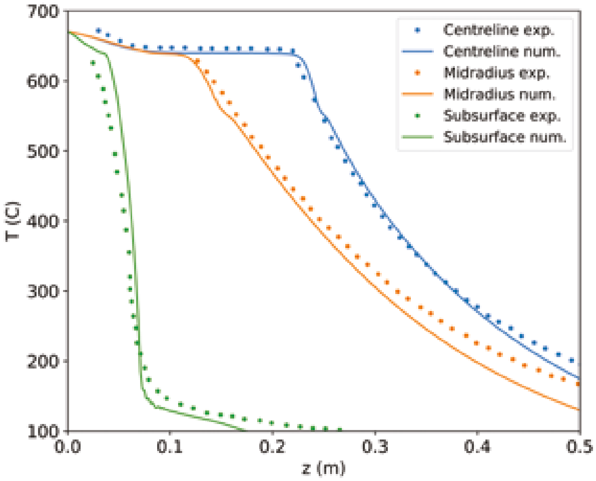

FIGURE 1. Validation of the DC casting model using temperature measurements from Vreeman et al. *Journal of Heat Transfer*, 124 (2002), 947.

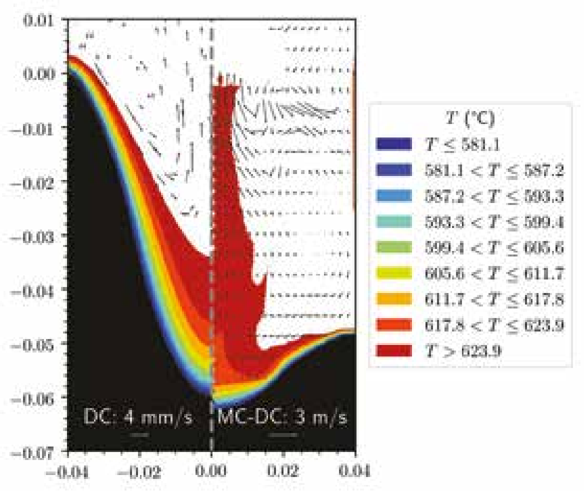

FIGURE 2. Comparison of the sump profile between (left) conventional DC casting and (right) MC-DC. Velocity arrows are of different scales for DC and MC-DC.

A fine and uniform microstructure is desirable for DC cast billets: beneficial effects include enhanced thermo-physical properties and improved extrudability, machinability, and surface finish for downstream processing. Treatment of the melt with high-shear melt conditioning (HSMC) results in grain size reduction without the addition of grain refiners. Numerical modelling can be used to understand this effect, and can be used to optimise the melt conditioned direct chill (MC-DC) casting process for key parameters, such as geometry of the mixer, operating temperature and the speed of rotor. Modelling is also a suitable alternative to costly experiments, which may be neither feasible nor practical in high temperature, opaque and highly reactive melts.

A single-region formulation that is derived from conservation of mass, momentum, energy, and species is used to represent this problem. The formulation is implemented in the open-source library OpenFOAM, by adapting the buoyantPimpleFoam solver to DC casting process, and validated against temperature measurements in a binary Al-Cu alloy cast (Figure 1). Rotation is implemented using the sliding mesh method. While flow in conventional DC casting is laminar, the flow around the mixer is highly turbulent. Reynolds-Averaged Navier-Stokes (RANS) equations can predict the turbulent flow features around the mixer; however, they severely under-predict the global turbulent energy dissipation rate. HSMC simulations therefore necessitate better turbulence models. In this work, the continuum equations are closed by using a Large Eddy Simulation (LES) model, with the Yoshizawa subgrid scale model. This model is applied to the casting of AZ31 in an 80 mm Ø mould, sheared at 4000 RPM using a 42 mm Ø mixer (Figure 2).

While the distribution of shear rate and mass flow rate is highly non-uniform in the sump, the temperature gradient in the presence of high shear is higher across the mushy zone and the sump is shallower than in conventional DC casting. The large flow rate below the mixer draws melt at the liquidus temperature through large recirculations near the mould wall. The shell at the mould near the graphite-hot top interface re-melts, leading to the reduced sump depth. The slurry is sucked towards the mixer, where it is re-melted during the transit. The net effect of these recirculations is a smaller slurry zone and consequently a larger temperature gradient across the sump. The increased heat extraction and the corresponding larger temperature gradient lead to an effectively larger cooling rate, i.e. a smaller local solidification time within the mushy zone for the same casting speed. This can in turn lead to a finer, more uniform grain structure in the resulting billet.

This model is now ready for performing design of experiments to optimise the operating conditions and geometry of the mixer against the desired sump profile. These parametric studies will be run on the BCAST high-performance computing facility using the uncertainty quantification framework Dakota. The model will be further extended to study macrosegregation, by considering the effect of grain motion using a mean-field approach.

Melt conditioned twin roll casting (MC-TRC) process for Mg alloy flat products

X.L. Yang, C.L. Mendis, J.B. Patel and Z. Fan

Flat products (sheet/strip) of Mg alloys are desired for application in the transport sector, due to their high specific strength, low density and excellent damping capacity, to meet fuel efficiency requirements through lightweighting.

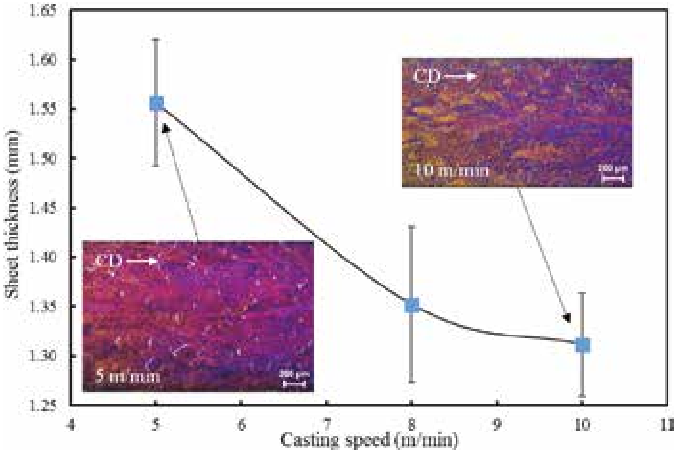

FIGURE 1. The relationship of strip thickness on the different casting speed. Casting direction is indicated as (CD).

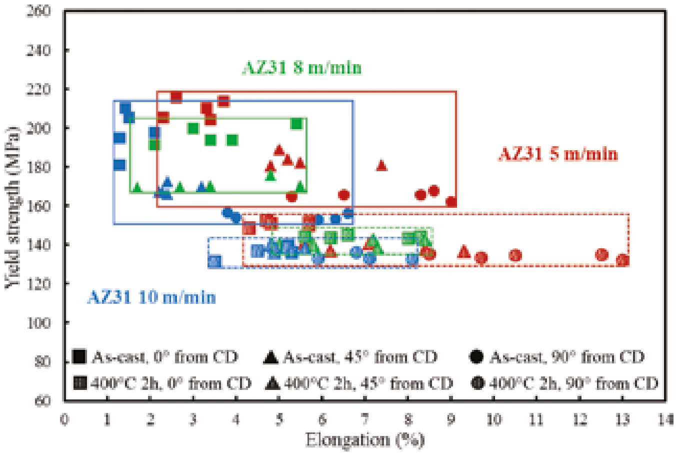

FIGURE 2. The tensile properties of the Mg alloy strip produced with different casting speeds.

The conventional twin roll casting (TRC) process has been used in the Mg industry in the last two decades to replace the initial slab and rolling process to significantly reduce the energy consumption and shorten the processing steps. However, TRC still faces great challenges: coarse and non-uniform microstructure; severe solute segregation (this limits alloy composition to dilute alloys with narrow freezing range); and low productivity. These problems hamper downstream processing, impact the mechanical properties of the final product and prevent its industrial application. Thus, the TRC process developed in house at BCAST aims to produce thin gauge strip with fine and uniform microstructure, no solute segregation (centre-line or inversed), good surface finish, reduced basal texture and isotropic in-plane mechanical properties, which can be used for direct component production with little rolling.

By combining two original technologies developed in BCAST, namely high shear melt conditioning (HSMC) and low force twin roll casting, the MC-TRC process is developed as an alternative approach for Mg alloy sheet/strip production by emphasising the control of solidification in the MC-TRC process compared with the conventional TRC process. By the dispersion of MgO nano-particles entrapped in magnesium oxide films, using MC, the heterogeneous nucleation is enhanced during the solidification, which provides refined equiaxed grain structures and a uniform solute distribution. With the limited load on the twin rolls, the roll surface would act as a metallic mould with high cooling rates. This helps to retain the randomised solidification texture due to limited deformation, reduce the squeeze effect of un-solidified solute rich liquid which eliminates the macro-segregation (centre-line/inversed) through the strip thickness.

The results below present the study of casting speed on the strip profile through the twin roll biting point to reduce the rolling deformation during the MC-TRC process and its impact on the mechanical properties of the as-cast strip.

Continuous reduction in strip thickness with equiaxed grain structure was observed with eliminated macro-segregation with the increased speed. This suggests that the rolling deformation is reduced with increased casting speed, indicating the randomised solidification texture retained during the MC-TRC process. With such microstructural improvement, more isotropic in-plane tensile properties are observed with increased casting speed in comparing the spread of data points obtained under different conditions. This indicates the potential formability of Mg alloy strip produced by the MC-TRC process for direct stamping without prior rolling process.

The next stages of this research will focus on the formability of Mg alloy strip produced by the MC-TRC process, by processing parameter optimisation to improve the isotropy of in-plane mechanical properties and out of plane tests (Erichsen cup tests) to explore the formability potential.

Multiscale modelling of microstructure evolution during twin roll casting

Y. Qiu, H. Assadi and Z. Fan

Twin roll casting (TRC) is an energy efficient way to manufacture near-net shape sheets of light alloys, such as magnesium, for lightweight applications in the automotive and aerospace industry [1].

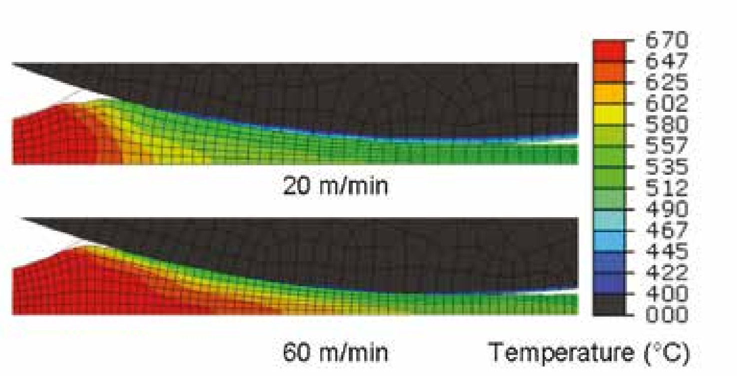

FIGURE 1. Modelled temperature distributions resulted from different casting speeds.

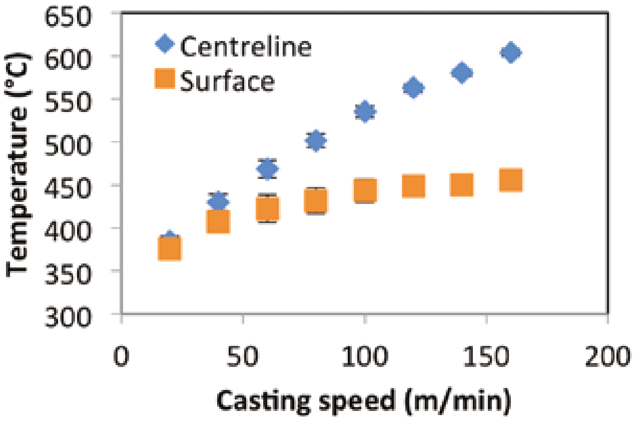

FIGURE 2. The effect of casting speed on the exit temperature on the strip surface and at the centreline, assuming a high gap conductance between the rolls and the strip.

However, challenges remain in eliminating unfavourable microstructural features, such as coarse columnar dendrite grains and centreline segregation, in the as-cast alloy sheets, due to the complex nature of the TRC process [2]. By modelling the effects of melt conditioning, alloy composition, and casting parameters on the microstructure development during TRC, feedback can be provided to optimise the TRC process to develop high performance alloys with improved mechanical properties, tailored for specific applications.

A multiscale model is used to simulate the evolution of microstructure during TRC, in which the process of grain growth in fluid flow is modelled via phase field simulation coupled with lattice Boltzmann model, and a Lagrangian macroscale model is applied for heat transfer and deformation analysis, which provides the boundary conditions for the microscale model. Results from 2D temperature-displacement simulations via ABAQUS show quantitatively the correlation between the casting speed and the depth of melt sump, exit temperature of the strip and the rate of heat transfer, as shown in Figure 1 and 2. The results also show that further decrease of the roll temperature below room temperature has a negligible effect on the modelled temperature profile of the strip. Meanwhile, the depth of melt sump is shown to increase significantly as the assigned gap conductance between the rolls and the strip decreases. The gap conductance is taken as an adjustable parameter, which will be obtained by comparing the modelled strip temperature profiles with the experimentally obtained strip temperature data.

Based on the macroscale modelling results, an upper bound of the casting speed, for which the strip can completely solidify before it exits the rolls, can be deduced for TRC with specific strip thickness, roll dimension, and alloy composition. By casting at higher speeds, manufacturing efficiency can be improved, and the deformation zone can be reduced, which is particularly favourable in TRC of magnesium alloys.

In summary, a multiscale model is proposed to model the evolution of microstructure during TRC, which consists of heat transfer modelling at macroscale, and modelling of solidification with fluid flow at microscale. Results from the macroscale model can be used to deduce the upper bound casting speed.

In the future, the multiscale model will be further developed and tuned to model quantitatively the solidification of more complex, industrially relevant alloy compositions. This will include comparison with the experimental data for Al and Mg alloys, to calibrate the adjustable parameters in the model. The results will be summarised into microstructure selection maps, to help improve process design and manufacturing efficiency for different solidification processes.

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Improved defect control and mechanical property variation in HPDC A380 alloy by HSMC

Y. Zhang, J.B. Patel, J. Lazaro Nebreda and Z. Fan

High pressure die casting (HPDC) is a cost-effective and net-shape manufacturing process for mass production of thin walls and complex shapes. There are three typical advantages of the HPDC process which include high filling, cooling and solidification rates with high intensification pressure.

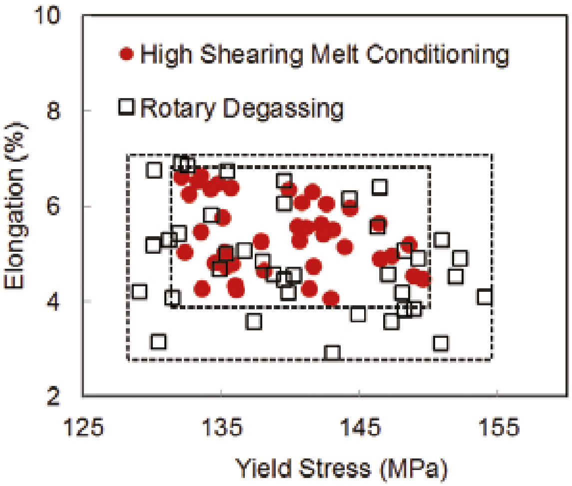


FIGURE 1. A comparison to show the MC-HPDC improvement on yield strength and elongation of the HPDC A380 alloy.

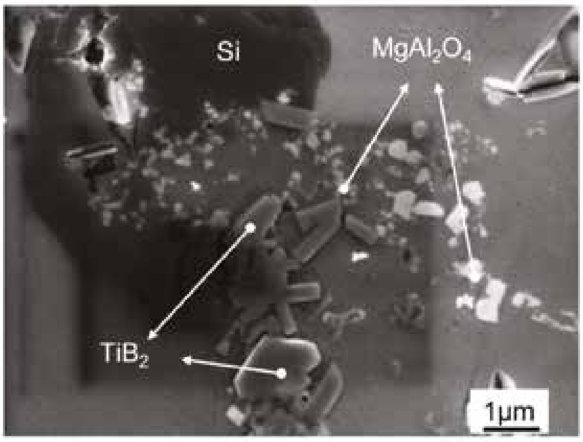


FIGURE 2. Microstructure of the prefil sample showing that $MgAl_2O_4$ and TiB_2 were the key particles in the A380 alloy with high shear melt conditioning.

The characteristic of very high cooling rate can lead to very fine microstructures, resulting in components with excellent surface finish, high dimensional tolerance and excellent fatigue performance. These advantages mean that the automotive industry is further selecting HPDC Al castings, from the demand to meet their ever-increasing lightweighting requirements and to reduce CO_2. However, HPDC does have a disadvantage, as the high filling rate and intensification pressure can create high porosity defects within the castings. Therefore, the traditional HPDC process has unavoidable mechanical property variations.

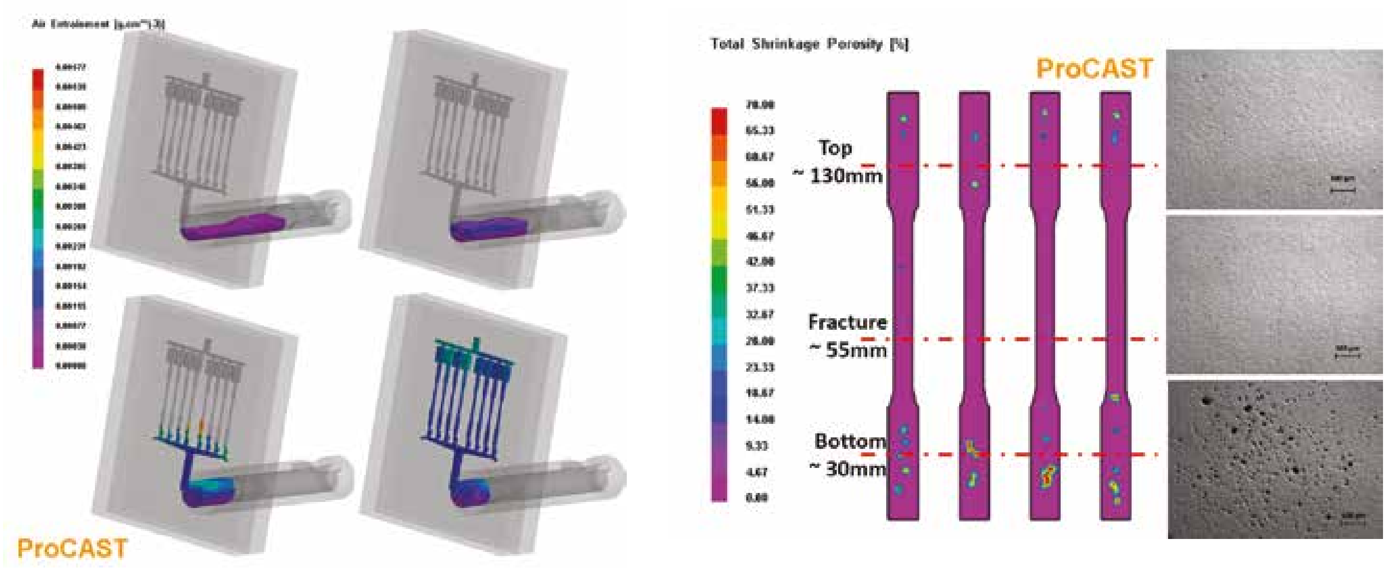
In the past few decades, many efforts have focused on the filling process, solidification and grain refinement, which included increasing the temperature of the shot sleeve and pouring temperature, aiming to minimise the mechanical property variation. Unfortunately, only limited improvement was achieved. Recently, a physical refinement method by high shear melt conditioning (HSMC), patented by BCAST, has been proven to refine Mg and Al alloys via dispersing the existing oxide films into fine particles, to form potential nuclei for Mg, and accelerate the formation of $MgAl_2O_4$ as effective nuclei for Al alloys.

In this project, HSMC prior to HPDC (melt conditioned-HPDC) was employed to produce A380 alloy components. HSMC includes two steps: the first is degassing with an Ar flow rate of 0.2L/min and shearing 5 minutes at rotor speed of 1500 rpm, and the second is shearing at 1500 rpm for 10 minutes to complete the melt conditioning treatment without introducing Ar. With the application of HSMC, both the yield strength and elongation of the HPDC A380 alloy were improved, as shown in Figure 1. The distribution range of the yield strength and elongation of the A380 alloy with rotary degassing was from 129.1 MPa to 152.9 MPa, and from 2.91 % to 6.88 % respectively. With HSMC, the distribution range of the yield strength and elongation was from 130.7 MPa to 149.9 MPa, and from 3.73 % to 6.62 % respectively. The particles in the A380 alloy were analysed using SEM after collecting via the Prefil®-Footprinter, with the result shown in Figure 2. Figure 2 demonstrates that besides the TiB_2 particles, $MgAl_2O_4$ with bi-modal size distribution were also found in the A380 alloy when applying HSMC. The size of the large $MgAl_2O_4$ particles were approximately 300 nm, and the size of the small particles were approximately 80 nm. The formation of bi-model $MgAl_2O_4$ particles resulted in refinement of the α-Al, with each formed in the shot sleeve and die cavity due to the small misfit of about 1.4 % between the particle and Al. The refined primary α-Al reduces the formation of shrinkage porosities and improves their distribution. Both the refinement and defect control were ascribed to the contribution of mechanical property variation improvement.

Modelling of the high pressure die casting process

K. Dou, A. Jacot, Y. Zhang, E. Lordan and Z. Fan

Numerical simulation is a powerful and cost-effective tool to optimise manufacturing processes and to gain access to quantities that are difficult to obtain experimentally.



(a) (b)

FIGURE 1. Simulation of flow and air entrainment during high pressure die casting of Silafont-36 test samples (a) simulated (centre) and (b) micrographs (right) showing porosity at three locations.

A new approach for the simulation of the high pressure die casting (HPDC) process has been initiated at BCAST to investigate flow and heat transfer, as well as microstructure and defect formation in HPDC parts during manufacturing. The simulations are performed initially to help design experiments. The long-term objective is to understand the variability of mechanical properties in HPDC parts, which is a major concern to achieve weight reduction through lighter designs. The approach is based on a combination of experiments and simulation.

The HPDC of tensile test samples of an aluminium alloy, Silafont-36, has been simulated using the finite element casting software ProCAST. As shown in Figure 1a, during the first stage of injection, when the piston moves at a low speed, a shallow wave is formed at the free surface of the melt. During the second stage, the piston velocity increases and the melt is injected into the die at high speed. The simulation predicts the evolution of different physical quantities such as the melt velocity, temperature and solid fractions. In addition, it provides insight into the distribution of defects. In Figure 1a the colour maps represent the amount of entrapped air. These results were obtained by using the air pressure and flow in the die, including the role of vents. In this case, the air cannot fully escape from the die, and some entrapped air is predicted. Figure 1b shows the predicted amount of shrinkage porosity, which is another type of defect playing a crucial role in the variability of mechanical properties. The predicted shrinkage porosity shows a good agreement with the experimental data.

A simulation approach has been developed to get insight into the melt flow, solidification and defect formation during high pressure die casting of aluminium alloys. The predicted values of shrinkage porosity correlated with the measurements. Further comparisons are needed before simulation can be fully deployed to address variability of mechanical properties.

Industrial Applications

The industrial application research theme provides an industrial steer for all research activities within the Hub. We work with many partners ranging from OEMs to Tier 1, 2 and 3 suppliers within the light metal supply chains. The scope of projects includes new alloy development for OEMs, to the advancement of Tier 1 cast products using our high shear technology for melt conditioning.

Research highlights within the industrial application theme are shown in the following pages.

For more information visit
www.lime.ac.uk

High strength and ductility cast aluminium alloys

X. Dong, S. Ji and Z. Fan

The increasing demand for lightweight structures in automotive and other transport applications has driven the need for thin-walled castings with improved mechanical properties.

FIGURE 1. (a) Industrial tilting gravity casting trial and (b) trial gravity casting component of the developed aluminium alloy.

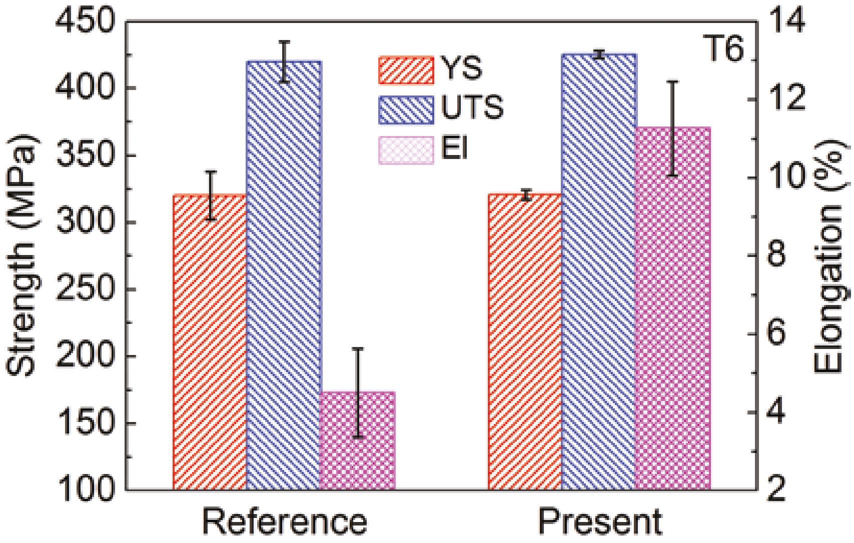


FIGURE 2. Mechanical properties of the developed aluminium alloy produced by high pressure die casting.

Supported by Innovate UK through the LEAAST project, a high strength and ductility aluminium alloy has been developed for gravity casting, low pressure die casting and high pressure die casting manufacturing processes. The industrial gravity casting scale trials (Figure 1) of the newly developed aluminium alloy have successfully demonstrated improvement in strength and ductility properties of the castings.

The gravity castings of the developed aluminium alloy exhibit an excellent combination of strength and ductility, with a yield strength of 310 MPa, an ultimate tensile strength of 365 MPa, and an elongation of 11 % at ambient temperature. The newly developed aluminium alloy outperforms commercially available gravity cast aluminium alloys with 25 % increase in strength and 85 % increase in ductility.

Similarly, the high pressure die castings of the developed aluminium alloy exhibit a yield strength of 320 MPa, an ultimate tensile strength of 425 MPa, and an elongation of 11 %. Although the strengths of the developed aluminium alloy are comparable with the most advanced die cast aluminium alloys, there is a significant increase in ductility, as shown in Figure 2.

Further to the excellent mechanical properties, the developed alloy offers additional benefits such as relatively low material cost, good castability and corrosion resistance. The research work on the development of the high strength and ductility aluminium alloy has been recognised with a CMF 2017 Innovation Award in the UK. Future work will focus on the exploitation of this developed aluminium alloy for lightweight structures in other industrial applications.

Recycled aluminium through innovative technology (REALITY)

K.W. Al-Helal, J.B. Patel and Z. Fan

The REALITY project works towards supporting vehicle manufacture in the UK industry and allows Jaguar Land Rover to demonstrate a competitive leadership in reducing CO_2 emissions at the source of manufacture.

FIGURE 1. DC-GR and MC-DC billets with extrusioned flat bars of BA-6111 and TT-6111.

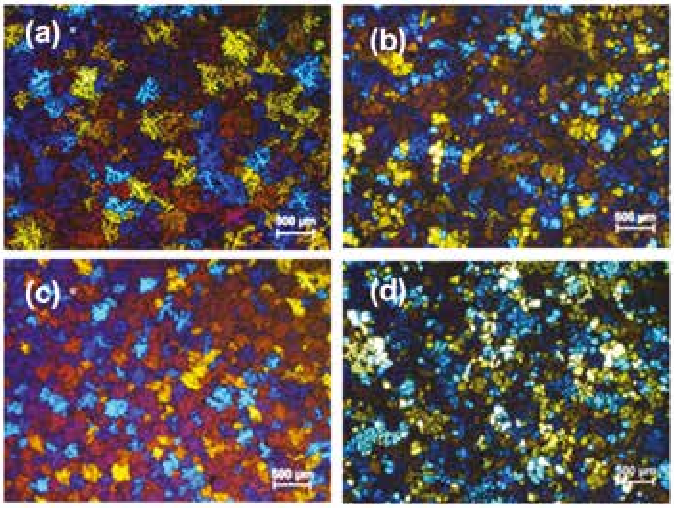


FIGURE 2. Optical micrographs; (a, c) DC-GR and (b, d) MC-DC of BA-6111 and TT-6111 alloys respectively.

Cost effective automated separation processes for shredded scrap will enable the closed-loop recycling of end-of-life vehicles back into high performance product forms for new vehicle body manufacture in the UK, providing significant CO_2 savings using less or no primary metal and generating major cost savings. REALITY is a 36 months project to enable the development and industrial deployment of sensor-based scrap sorting technologies to separate wrought and cast alloys, then to further separate wrought alloys into alloy types, which has never been achieved before. Full scale recycled scrap based sheet and castings will be produced and evaluated. The organisations involved in this project are: Jaguar Land Rover, Axion, Novelis, Norton Aluminium, Innoval Technologies, Brunel University London and the University of Warwick. The UK, the major exporter of more than 1 Mt of aluminium scrap from the EU each year, will be uniquely placed to use, rather than export this precious scrap, which is based on secondary aluminium alloy resource. The source materials are bottom ash 'BA', taint tabor 'TT' and end-of-life vehicle 'ELV' alloys.

The source of recycled aluminium is from Axion ELVs, which is obtained from Jaguar Land Rover ex-engineering and ex-crashed cars. These ELVs will be shredded and automatically sorted using state-of-the-art sensing and sorting technologies. BA is provided by Scanmetals UK Ltd and is the ash aggregate formed when waste is burned in an incinerator. Following combustion, a certain amount of metallic material is left within the ash, which can then be processed and recovered. At BCAST, 300 kg of BA was melted and cast into ingots to produce 180 kg with a AA6111 alloy composition.

BCAST's melt conditioning technology was tested using their scale up facilities, to identify if the technology is capable of tolerating the impurities in these sources, to then be used for either coil production or for the commercial scale shape casting by high pressure vacuum die-casting. Materials evaluation and characterisation will be carried out on both the resultant sheet and cast product forms.

Experiments were also conducted at the AMCC facilities for direct chill grain refined (DC-GR) and melt conditioned direct chill (MC-DC) billets, followed by extrusions into flat bar ~ 118 mm x 4.8 mm of BA-6111 and TT-6111 alloys, as shown in Figure 1. The optical micrographs show equiaxed refined grains with no casting defects for the MC-DC billets of BA and TT alloys, as shown in Figure 2. More work will be performed for MC-DC of the ELV alloy, conventional twin roll casting and melt conditioned twin roll casting of BA-6111 and TT-6111 alloys, with microstructure and tensile property evaluation to follow.

CAAHS (Carbon Aluminium Automotive Hybrid Structures)

M. Ben Tahar, E. Beslin, R. Darlington, G. Scamans, A. Den Bakker, E. Hinton, Z. Li and A. Miranda

The CAAHS project is a 24 month Innovate UK programme in which Brunel University London is directly involved in collaboration with Bentley Motor Company, Constellium, Gordon Murray Design (GMD) and Innoval Technology.

FIGURE 1. Baseline frames (carbon fibre iPanel® + Constellium HSA6^{TM} extrusions) produced in 2017 for dynamic crash testing.

FIGURE 2. Baseline frames produced in 2017 for testing adhesive bonding.

FIGURE 3. CAAHS 3D extruded tubes bent in 2017.

FIGURE 4. CAAHS automotive frame that will be manufactured at scale 1:1 in 2018.

The project is focused on the opportunity to significantly reduce body structure weight by utilising an aluminium frame structure. This will use a novel high strength extrusion alloy based on the Constellium HSA6™ product, in conjunction with advanced composite panels which are based on recycled carbon fibre, whilst maintaining the high volume, low cost benefits of the original iStream® technology. The target is to develop a frame that is 40 % lighter than the incumbent steel frame.

In 2017 the team worked on designing the new frame using aluminium and recycled carbon fibre panels. Aluminium alloys, extrusion shapes, cutting edge joining and manufacturing techniques were trialled at scale in Brunel University London's Advanced Metal Casting Centre (AMCC) and at GMD. Information collected through the first year of the project allowed for development of a new advanced frame that will be manufactured in 2018 within the AMCC and at GMD.

Future work will lead to the completion and manufacture of two new frames. Before this task can be completed, the frame design will be released in early 2018 so extrusion dies can be sourced for the AMCC. Meanwhile, billets will be prepared using the BCAST DC caster, and extrusions will be produced using the BCAST 6" press. Tubes will then be shaped using the BCAST freeform bender, before being assembled together at GMD. One of the two frames will undergo crash tests to assess performance, while the second will be kept intact for showcasing at public events.

High shear melt conditioned direct chill casting: a Constellium case study

N.S. Barekar, H.-T. Li, J.B. Patel, Z.P. Que and Z. Fan

Direct chill (DC) casting of aluminium alloys has been an essential process for feedstock production and further mechanical processing of wrought product forms.

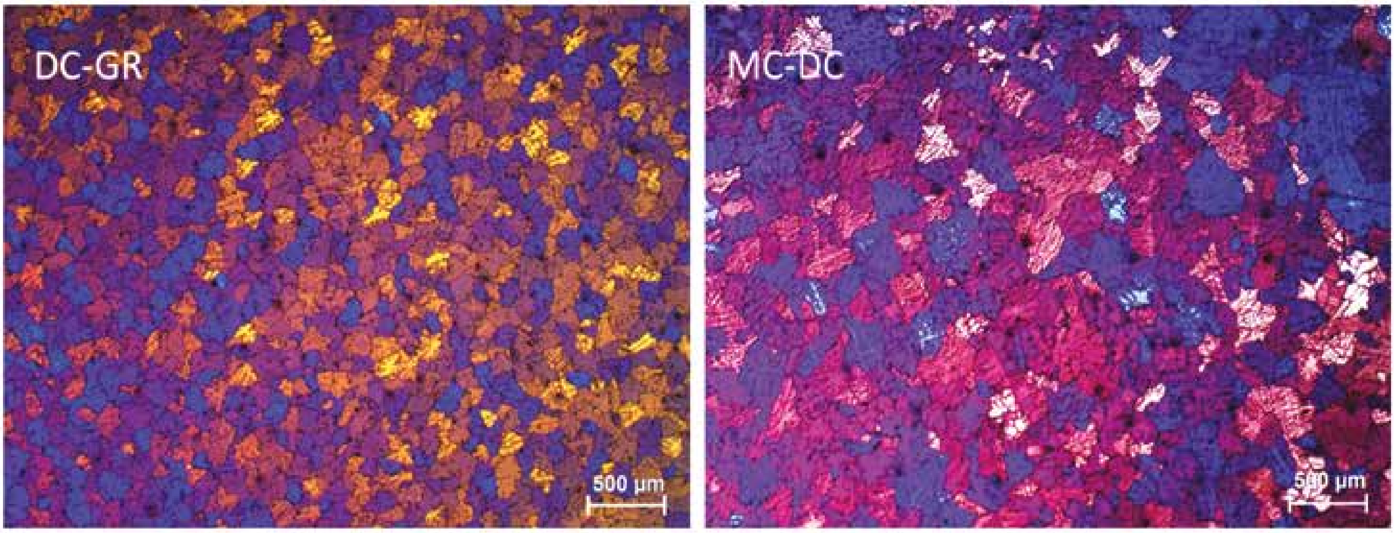


FIGURE 1. Grain structure of A6082 alloy under different DC casting conditions showing globular grain in DC-GR and fine equiaxed dendrites in MC-DC.

Achieving a fine, uniform and defect-free microstructure throughout the billet cross section has been a long standing industrial challenge. DC cast ingots of wrought Al alloys conventionally require the deliberate addition of a grain refiner (DC-GR) to provide a fine equiaxed as-cast microstructure. However, grain refiner additions cannot ensure the uniformity of microstructures and refinement of secondary phases. These problems can be addressed by combining the conventional DC casting with high shear melt conditioning directly in the casting sump. Melt conditioning direct chill casting (MC-DC) is an emerging technology which manipulates the solidification process to control and tailor the microstructure for high quality billet production. To study the potential benefits of melt conditioning, an alloy 6082, one of the major regular production alloys of Constellium was selected for industrial trials. The microstructure of a MC-DC billet was compared with the billet produced using commercial practice with Al-Ti-B grain refiner.

In conventional DC casting with grain refiner, low thermal gradient and high nucleation rate by inoculants favour globular growth resulting coarse dendritic arm spacing. The non-uniform cooling rate across the section of the billet in conventional DC casting results in the variation of grain size. In contrast, the solidification process in MC-DC at a lower speed is characterised by high thermal gradient / high undercooling compared to DC-GR due to enhanced rate of heat extraction by the intensive forced convection. This results in uniform distribution and finer eutectics in MC-DC due to fine dendritic arm spacing, as shown in Figure 1. The grain refinement observed in MC-DC billet is attributed to the effective dispersion and uniform distribution of naturally occurring oxides in the Al melt.

Future research will be focused on investigating the effect of homogenisation on microstructure of MC-DC billets; in particular a detailed characterisation of the secondary phases before and after homogenisation.

Melt conditioned direct chill (MC-DC) casting of 6xxx series Apple Inc. Al-alloys

J.B. Patel, H.-T. Li, N.S. Barekar and P. Lloyd

An investigation was performed on three specially selected Apple Inc. Al-alloys to evaluate the effect of MC-DC casting, and to assess the benefits of not using commercial grain refiner (Al-Ti-B type) during casting. These MC-DC trials were conducted within our Advanced Metal Casting Centre (AMCC) at Brunel University London, to produce billets of 150 mm in diameter and 2 m in length.

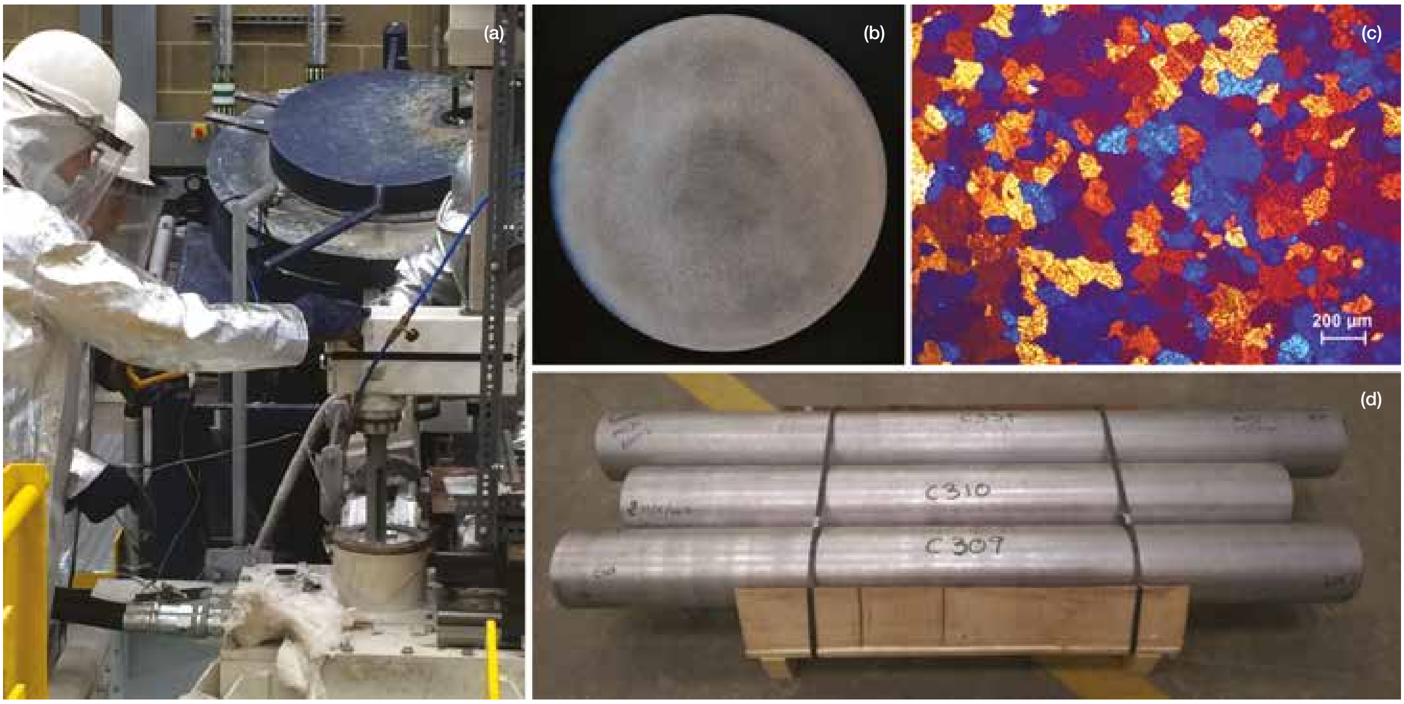


FIGURE 1. (a) MC-DC casting in operation without Al-Ti-B grain refiner. (b) MC-DC billet slice with no-crack in the centre. (c) MC-DC fine equiaxed grain structure. (d) Final manufactured MC-DC billets ready for shipment.

The billets were cast at optimal parameters and shipped to Apple for extrusion into thin profiles for subsequent analysis of their microstructure and chemical segregation integrity. Furthermore, the surface finish was carefully inspected after extrusion, with the ambition of eliminating surface streak marks which are caused by the addition of Al-Ti-B based grain refiners.

Melt conditioned direct chill (MC-DC) casting of large scale 7xxx series Al-alloy at Arconics, USA

J.B. Patel, H.-T. Li, N.S. Barekar and P. Lloyd

An employee from Arconic (formerly known as Alcoa Inc.) first heard a BCAST member presenting on MC-DC casting at the TMS conference in the USA, after which he soon approached BCAST to enquire and learn more about the MC-DC casting technology and to review the status of the technology in terms of readiness for industrial application.

FIGURE 1. Typical large-scale slab casting of aluminium for aerospace applications.

In the past few years, MC-DC casting of Al has had previous large-scale casting opportunities, which meant that our in-house development of the HSMC equipment was almost at technology readiness for the industrial trials at one of Arconic's DC casting facilities. This trial is currently in the process of planning to first ship the HSMC equipment (Model: HSMC-Al-90) to a nominated Arconic facility to perform MC-DC casting of a 7xxx series Al-alloy on a 0.55 m diameter 4-strand table, and secondly, for the first time, perform a MC-DC casting trial on a rectangular single strand table to cast a large slab of 0.61 m thickness, 1.67 m wide and 2.54 m length. The motivation behind these large-scale trials is to reduce the severe chemical segregation that is prominent in this type of casting, where current Al-Ti-B based grainers are not able to control the chemical segregation as required to avoid large crack formation upon final solidification and facilitate the thermomechanical processing generated with extrusion and forging.

Melt conditioned twin-roll casting (MC-TRC) of an Al-Sn bearing alloy at Federal Mogul Powertrain, USA

J.B. Patel, Y. Zhang, X.L. Yang and K.W Al-Helal

This interest was sparked from a published journal paper available online which focussed on MC-TRC of Al-alloys. Federal Mogul Powertrain is in the business of manufacturing lightweight bearings for automotive applications.

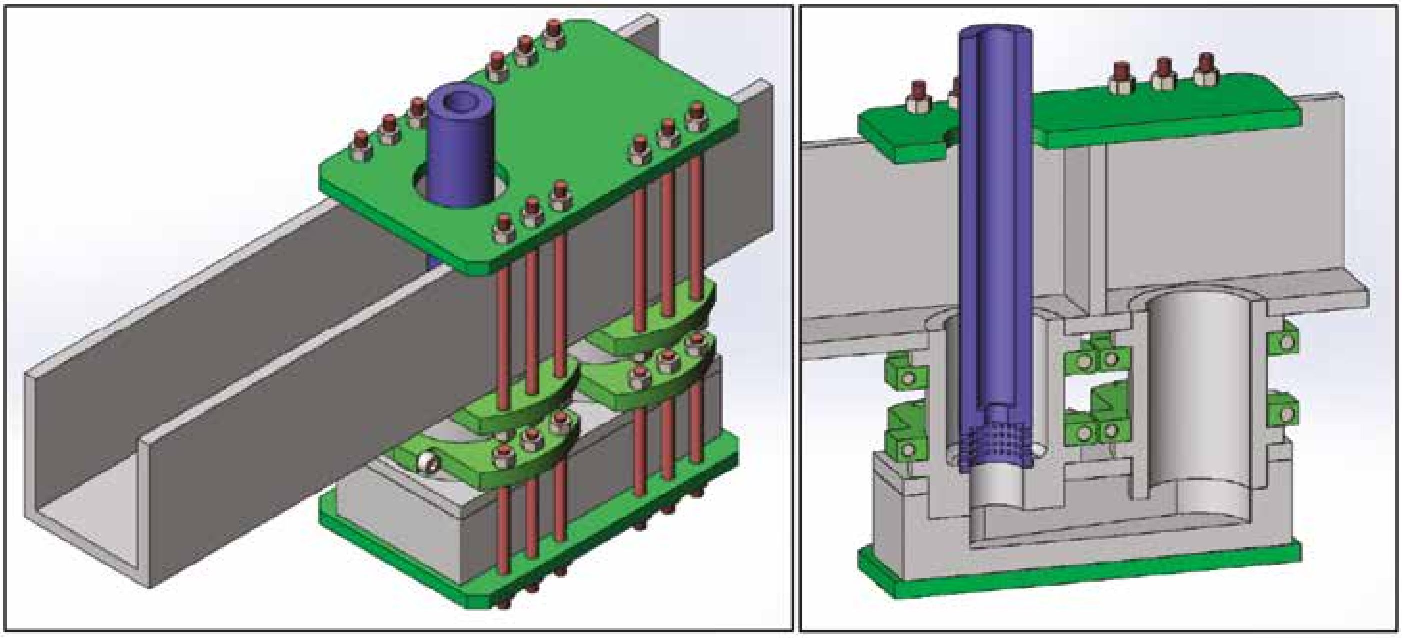
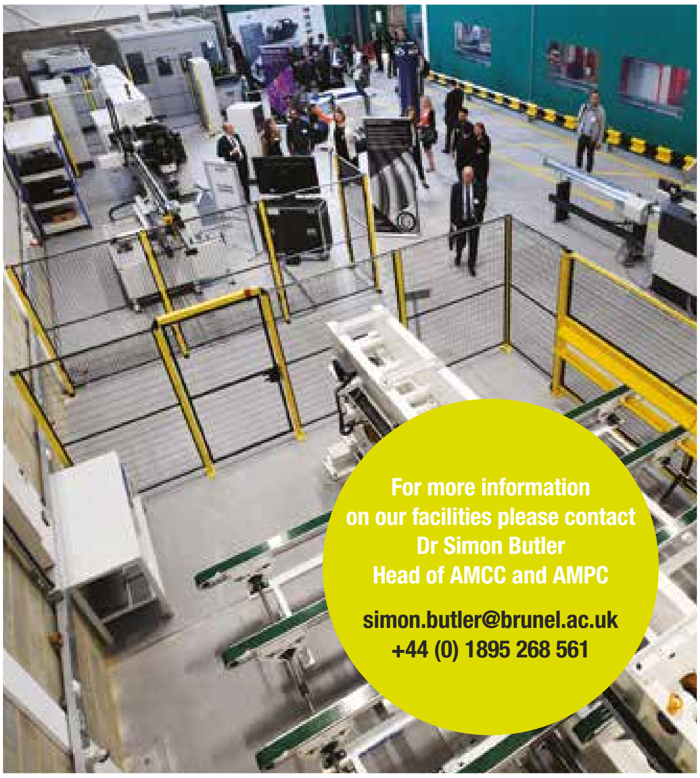


FIGURE 1. Schematic illustrations of the new BCAST in-line high shear melt conditioning system.

These bearings are innovatively and precisely manufactured with mixed layers of polymer and metallic materials, giving them the characteristics of self-lubrication, zero maintenance and a longer service time. Al and Sn do not mix very well due to low solubility of Sn in molten Al, with Sn having a melting point much lower than Al and a density much higher than Al. However, when Sn is added to Al-alloys, it gives the solid Al surface better sliding properties and an increased wear resistance. Hence, a fine and uniform distribution of the Sn-phase in the Al-matrix is highly necessary for better performance. They currently produce the Al-Sn alloy strips by the twin roll casting process, where they need to improve the distribution of the Sn phase in order to gain better performance. The HSMC technology possesses the characteristics of both distributive and dispersive mixing, hence the motivation behind this trial is to improve the size and distribution of the Sn-phase, together with the rest of the advantages of intensive melt shearing. This trial is currently at the design stage, where the HSMC technology will be implemented and integrated into the existing launder system that feeds the twin roll caster, instead of the two holding furnaces, to avoid the challenge of scaling up the HSMC equipment and to apply intensive melt shearing as close as possible to the twin rolls, for better preservation and solidification of the Sn-phase.



For more information on our facilities please contact Dr Simon Butler Head of AMCC and AMPC

simon.butler@brunel.ac.uk
+44 (0) 1895 268 561

AMPC Launch

On 13 June 2018, hosted by Brunel University London, BCAST unveiled the Advanced Metal Processing Centre (AMPC) – the second phase of its unique scale-up facility. Together with the Advanced Metal Casting Centre (AMCC), which opened in April 2016, the AMPC will demonstrate technologies developed in the laboratory at a recognisable industrial scale, and enable industrial partners to develop and trial innovative light alloys and components towards full implementation. The AMPC provides a conduit for delivering the impact of the Future LiME Hub's research.

The AMPC houses industrial scale metal casting and processing facilities, complementary to those of the AMCC; advanced instruments for component testing and performance evaluation; and state-of-the-art capabilities for process modelling and simulation; all in a bespoke 1,500 m^2 building. This has been established with £15 million of funding from the Higher Education Funding Council for England (HEFCE) UKRPIF programme (now managed by Research England), providing the infrastructure to attract significant match support from industrial partners, such as Constellium and Jaguar Land Rover.

The AMPC enables collaborative research programmes that address industrial and environmental challenges, such as carbon emission reductions in the automotive sector through lightweighting of vehicles and upcycling of secondary alloys. Current research partners benefitting from both the AMPC and AMCC facilities include Constellium, Jaguar Land Rover, Grainger & Worrall, Sarginsons Industries, Aeromet International, Innoval Technology and Norton Aluminium, working on innovate UK projects such as LEAAST and CAAHS, as detailed earlier in this report, or through direct funding.

Additionally, the AMPC will help to develop the future generation of engineers, designers, scientists and materials specialists with a key feature that BCAST's researchers and seconded engineers from its partners will work side by side.

At the same event, Constellium announced the expansion of its research and development capability at Brunel by establishing an R&D Centre for Automotive Structures and Industry on the Brunel site dedicated to transitioning technology from the laboratory to its production facilities around the world.

Over 200 people attended the official AMPC launch from business, academia, the professions, funding agencies, the local community and the media. The event was chaired by Dr Mark White, former Jaguar Land Rover Technical Specialist on Light Weight Vehicle Structures. It also featured speakers Lawrence Davies, Chief Adviser to the Automotive Team at the Department for International Trade; Alice Frost, Head of Knowledge Exchange at Research England; Andrew Barlow, Evoque Programme Manager at Jaguar Land Rover; Paul Warton, President of Constellium's Automotive Structures and Industry business unit; Professor Julia Buckingham CBE, Brunel's Vice-Chancellor and President; and Professor Zhongyun Fan, Director of BCAST and the Future LiME Hub.

In a message from Boris Johnson, MP for Uxbridge & South Ruislip, he spoke of his pride in having such research and facilities in his constituency: "This work presents the chance to join with key partners, including Jaguar Land Rover and Constellium, to make a major contribution to rebalancing the UK economy from here in Uxbridge."

As well as the formal agenda, there was plenty of time for networking and tours of AMPC and AMCC where some of the impact already achieved was on show, and a dedicated poster session to highlight the ground-breaking research taking place within BCAST's facilities and the Future LiME Hub.

Following the launch, the day ended with BCAST and the Future LiME Hub hosting the Institute of Materials, Minerals and Mining (IOM3) John Hunt Memorial Award and Lecture, presented by Professor Lindsay Greer, University of Cambridge.

For more information on the AMPC and AMCC please contact
Dr Simon Butler
Head of AMCC and AMPC

simon.butler@brunel.ac.uk
+44 (0) 1895 268 561

Constellium Expands its R&D Capabilities

A longtime partner of Brunel University London and BCAST, Constellium established its first R&D activities within the EPSRC Centre LiME in 2011. Working in partnership and developing a new academic/industrial model of collaborative R&D, in 2016 Constellium took the strategic decision to establish a University Technology Centre (UTC) within Brunel University London. A one of a kind centre of excellence, the UTC was at first dedicated to developing new aluminium alloys for the automotive structural components Constellium produces in Europe, North America and China. Using dedicated industrial scale casting and extrusion equipment in the Advanced Metal Casting Centre (AMCC), Constellium has trialed hundreds of new alloys and novel extrusion shapes and gauges for its automotive customers, reducing the development time for new alloys by more than 50 percent.

Now, with the introduction of the Advanced Metal Processing Centre (AMPC) on the Brunel University London campus, Constellium will be able to form, join and test aluminium automotive components such as Crash Management Systems (CMS), body structures and battery enclosures using techniques like 3D bending, electromagnetic pulse technology, flow drill screwdriving, self-piercing riveting, adhesive bonding and more.

The true challenge, however, is transitioning new technologies from the laboratory to series production. To achieve this, Constellium has dedicated an R&D Centre at Brunel University London to work with its customer teams to apply the techniques on new programmes at its extrusion and Automotive Structure plants.

Speaking about the dedication of the AMPC, Paul Warton, President of Constellium's Automotive Structures and Industry business unit, said, "Automotive suppliers are problem solvers and that is what Constellium is doing at Brunel University London. We are anticipating the future and working with automotive manufacturers to provide solutions for the next generation of lightweight and electric vehicles. Our task is to stay ahead of the market, setting the trends instead of just following them."

In all, there are now 25 team members of staff at the Constellium UTC and R&D Centre including engineers, researchers and technicians, as well as post-doctoral fellows, PhD students and apprentices. The goal is to create opportunities for researchers who have worked within the UTC to join the company’s operations in new roles. They will have the chance to be part of the manufacturing process and bring a product to market, or to counsel customers and feed their needs and expectations back to our researchers and technicians. The Constellium team also partners with BCAST and others on a host of projects such as LEAAST and CAAHS.

“Brunel University London is the only place in the world Constellium could have established this R&D activity,” says Martin Jarrett, Director of the Constellium UTC and R&D Centre. “The partnership that we have with BCAST, the expertise of their staff and the calibre of researchers they attract is absolutely unique. Together we are creating an innovation loop that will benefit all the players for many years to come.”

LiME Training Centre

Professor Isaac Chang
Head of LiME Training Centre

In 2017, the Liquid Metal Engineering (LiME) Training Centre delivered four intensive taught modules to cover the basic scientific knowledge on physical metallurgy, metal processing, materials characterisation, materials and process modelling to our PhD students and postdoctoral researchers with varying academic backgrounds. These modules were well received by the students and researchers. There are further plans to develop these modules to an advanced level for our students in the next academic year to cover the most recent scientific knowledge and state-of-the-art material technologies in the development and processing of light alloys.

A total of ten PhD students have been recruited in the 2016-18 academic years. Seven students are supported by Brunel University London and three students are sponsored by industrial companies including Jaguar Land Rover and Constellium. The research projects focus on both fundamental and applied aspects of physical metallurgy. They cover a wide range of topics, including but not limited to, atomistic simulation of solidification, high pressure die casting and thermomechanical processing of aluminium alloys.

There has also been interest to establish joint training programmes and student exchange schemes with the LiME Training Centre from international academic institutions including the Tampere University of Technology and the Belarusian National Technical University.

For more information on the LiME Training Centre please contact
Prof Isaac Chang
Head of LiME Training Centre

isaac.chang@brunel.ac.uk
+44 (0) 1895 268 491

SP17

It was with great honour that BCAST hosted the 6th Decennial Conference on Solidification Processing (SP17) at the Beaumont Estate, Old Windsor, UK, on 25-28 July 2017. The SP series of conferences was established in Brighton in 1967 and then moved to Sheffield for 1977, 1987, 1997 and 2007. Existing for over half a century, it has earned itself a well-deserved name, the World Solidification Olympiad.

SP17 brought together solidification scientists, casting engineers and end users from academia and industry to make a fresh and critical examination of the historical approaches to solidification research and casting technology innovation over the last 50 years. SP17 provided a forum for both the pioneers and emerging leaders to identify and discuss views on future opportunities, challenges and to showcase research successes in the field.

SP17's extensive programme was attended by over 275 delegates and featured 191 oral presentations and 44 poster presentations. The four day conference also featured the 2016 John Hunt Memorial Lecture given by Professor Alain Karma of Northeastern University, Boston, USA, winner of the John Hunt Medal presented by the Institute of Materials, Minerals and Mining. During the evening events a farmers market allowed our international guests to get a feel for the seaside and farm cuisine popular with tourists to the UK and our Gala Dinner offered the opportunity to thank participants for their contributions, and to honour three long standing members of the solidification community, who had attended the very first SP conference in 1967.

The conference ended with a Round-table Discussion to debate the future directions for solidification science and casting technologies, and to make a strategic assessment of where we are heading based on a critical examination of what has happened over the past 50 years.

For a more detailed overview of the conference please visit the SP17 website:

www.sp17.info


BCAST
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Technology
SP17
Solidification
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SP17
SP17

Outreach Activities

The past year has seen us focus even more strongly on our external engagements, influenced by our priority to promote STEM development as the global need for scientific research, development and engineering increases. We are also still actively engaged with our colleagues in academia and industry through numerous channels on both national and international levels.

Some of the key engagements over the past year have included:

Exhibitions, conferences and events. It has been an extremely busy year for the Future LiME Hub. We have exhibited at the Cenex – Low Carbon Vehicle event, Advanced Engineering 2017, Brunel University London's Annual Research Centre Conference 2017 and 2018, Materials Research Exchange 2018, and have been the hosts of the 6th Decennial Conference on Solidification Processing (SP17), the 11th International Conference on Magnesium Alloys and Their Applications (Mg2018) and the Advanced Metal Processing Centre (AMPC) Launch 2018.

Industrial Communications Strategy. Building upon our current communications mechanisms, we established an industrial communications strategy to further assist in ensuring the advancement of our leading edge research is applicable to industrial and manufacturing landscapes. Through providing specifically designed literature in an industrially appropriate voice, we aim to promote information transfer to develop further support and networks, along with helping to further sustain an open exchange of current technical problems experienced by industry to our researchers. The resultant communications strategy of easily digestible literature and articles will be rolled out towards the end of 2018 and will be available online, at events and in trade magazines.

Social Media. Maintaining an active presence on social media, our top tweet came via the @BCAST_Brunel twitter feed promoting our new sand casting facility!

LiME Leaflet. This year also saw the introduction of a new four-page leaflet to allow for easier dissemination of the Future LiME Hub's work at events. The leaflet, as with all of LiME's literature, is available to download from the LiME website.

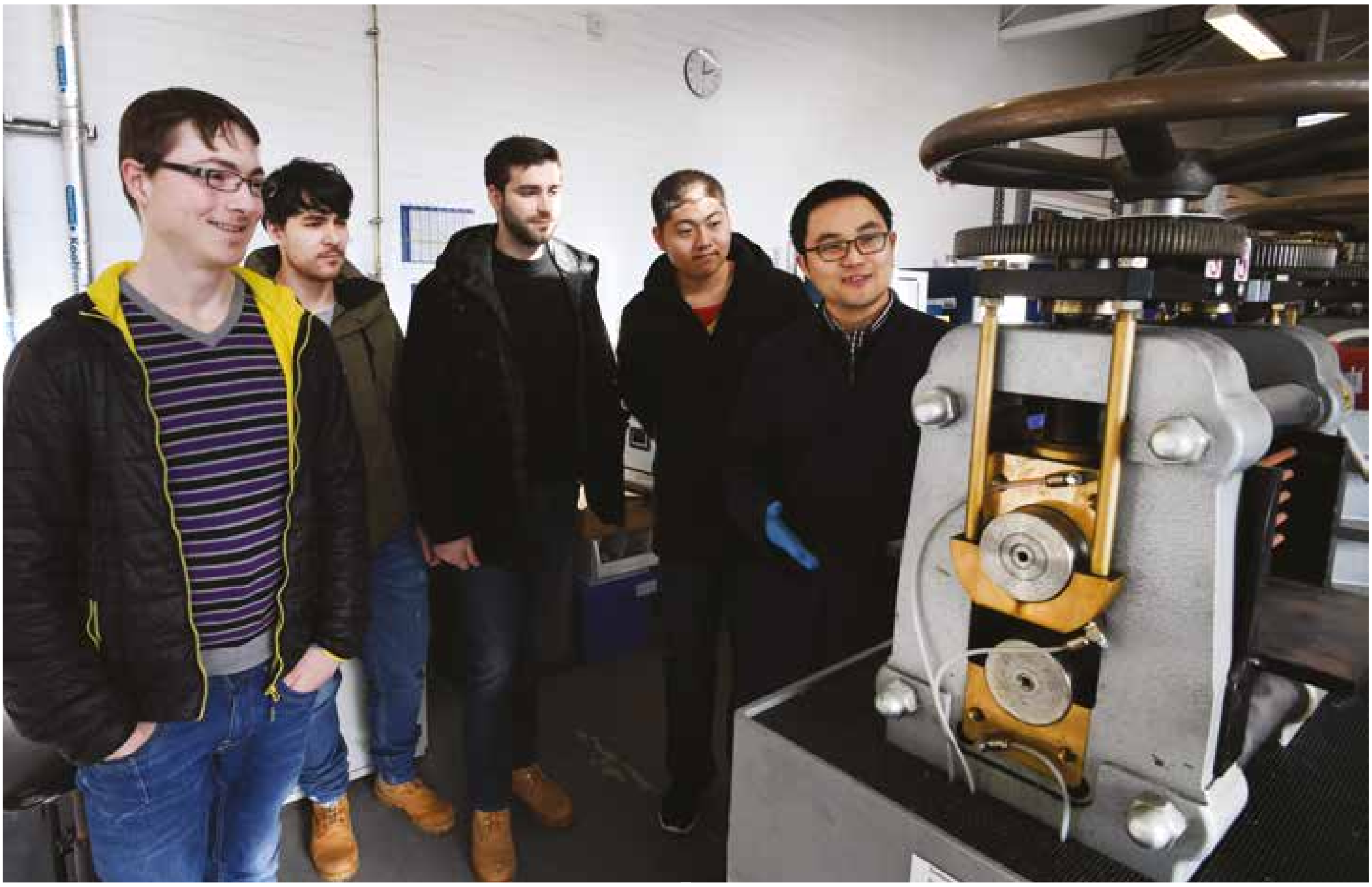
Experience days. The activities undertaken via our custom-made experience days allow students and visitors to gain a deeper understanding of the research, vision, and objectives of the Future LiME Hub. The has further helped us to ensure that we work with other institutions to encourage, facilitate, inform and build connections with the next generation of scientists and engineers. The visits consist of an introduction and overview of the facilities, information on the equipment and research that goes on within the Future LiME Hub and incorporates tours, demonstrations, presentations and practical work where appropriate. Having hosted the centre for doctoral training experience day for its third year, we have also hosted a work experience week for school age students and day visits for retired members from the Institute of Physics, providing the opportunity for visitors of all ages and backgrounds to engage with the Future LiME Hub's activities.

What's next? As we continue to develop and expand the focal points of outreach over the next year include leading the first of our Creativity@home workshops, which will focus on further strengthening our communications and teamwork, our UK Solidification workshop and the Light Metals Technology workshop.

For more information please contact Lauren Wigmore LiME Administrator

lauren.wigmore@brunel.ac.uk

+44 (0) 1895 267 703



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Mg2018

On 24-27 July 2018 BCAST will host the 11th International Conference on Magnesium Alloys and Their Applications (Mg2018) at Beaumont Estate, Old Windsor, UK.

Mg2018 continues on the success of the triennial Mg Conference series, which started in 1986 as the Magnesium Technology Conference in London, and aims to show the correlation of processing, microstructure and properties to understand how to fully exploit the full potential of Mg. The conference will feature 170 oral presentations, including selected Plenary presentations and 70 poster presentations, along with the inaugural Karl Kainer Lecture and networking opportunities for all those in attendance. Topics of research to be presented comprise casting and solidification (nucleation, grain refinement, processing); deformation behaviour and deformation processing; alloy development (cast and wrought applications); corrosion behaviour; microstructures; biomaterials and composites.

As the least mature of the structural metallic materials, magnesium has enormous potential for facilitating lightweighting in transport and consumer electronic applications through the development of alloys and optimising production processes.

This is due to Mg having 33 % lower density, greater castability, higher damping capacity for noise and vibration, higher electromagnetic shielding capacity and better machinability when compared with Al. It is the perceived weaknesses in Mg, that of lower resistance to both corrosion and creep and a lower deformability at room temperature, that has resulted in its application being limited to high pressure die castings for only a select number of items within the transport industry and consumer electronic applications.

Mg2018 will therefore provide a forum for discussion on all aspects of magnesium alloys, providing the most up to date developments in both its fundamental science and application.

Further information is available at www.mg2018.org

For a more detailed overview of the conference please visit the Mg2018 website:

www.mg2018.org

Grant Awards

Project	Investigator	Sponsor	Value (£)	Duration
High Reliability Interconnects: New Methodologies for Pb-free Solders	Christopher Gourlay	EPSRC	1,299,714	July 2018-June 2021
The Development of Next Generation Antibacterial Ti Implants with Integrated Chemical and Topographical Modifications	Yan Huang	The Royal Society International Exchanges 2017 Cost Share (China)	12,000	March 2018-March 2020
Advanced Magnesium Piston Development	Shouxun Ji	Husqvana Group (Sweden)	400,000	Jan 2018-Jan 2020
Recycled Aluminium through Innovative Technology (REALITY)	Zhongyun Fan	Innovate UK	374,285	Apr 2017-Mar 2020
Advanced Propulsion Centre 6 – CHAMELEON	Zhongyun Fan	Innovate UK	648,132	Jun 2017-May 2019
Alliance Casting European Development Centre (ACE-DC)	Zhongyun Fan	Innovate UK	781,245	Jun 2017-Nov 2020
Frog Bikes Innovate UK Manufacturing and Materials Application	Shouxun Ji	Innovate UK	299,995	Jul 2017-Mar 2019
Wear Resistant Austempersed Ductile Iron for Camshaft in Automotive Engine - (IAA)	Shouxun Ji	EPSRC	19,900	Jul 2017-Jul 2019
Rapid Aluminium Cost-Effective Forming (RACEForm)	Zhongyun Fan	Innovate UK	860,027	Nov 2017-Apr 2020
Novel Processing of 6xxx Alloys for Automotive Applications - iCASE Studentship Chrysoula Tzileroglou	Isaac Chang	EPSRC	83,296	Oct 2017-Sept 2022
Synthetic Biology System for Lightweight Boron Carbide Composite Armour (SynBA)	Isaac Chang	Defence Science & Technology Laboratory (Dstl)	285,545	Oct 2017-Sept 2019
Upscaling Environment-Friendly Cavitation Melt Treatment (UltraMelt2)	Dmitry Eskin	EPSRC	497,022	Mar 2018-Mar 2020
Aluminium for Ultra Low Emission Vehicles (Al-ULEV)	Geoff Scamans and Zhongyun Fan	Innovate UK	752,450	Jul 2018-Jun 2020
LightFORM Programme Grant	Xiaorong Zhou	EPSRC	4,800,000	Oct 2017-Sept 2022
Understanding Intermetallic Compound Nucleation and Growth using Simultaneous Radiography and Pixel based Spectroscopy	Enzo Liotti and Patrick Grant	Soleil Synchrotron	15 shifts, approximately 45,000	Apr 2018
Understanding Intermetallic Compound Nucleation and Growth using Simultaneous Radiography and Pixel based Fluorescence Spectroscopy	Enzo Liotti and Patrick Grant	European Synchrotron Radiation Facility	15 shifts, approximately 45,000	Jul 2018
Sir Henry Royce Institute - Oxford	Patrick Grant	EPSRC	1,500,000	Apr 2017-Mar 2021

Prestige

Prof Z. Fan
Chairman of the 11th International Conference on Magnesium Alloys and Their Applications, 2018, UK

Co-Chairman of the 6th International Conference on Solidification and Gravity, 2018, Hungary

Member of Editorial Board, Journal of Magnesium and Alloys

Honorary Professorship, General Research Institute of Non-Ferrous Metals (GRINM), China

Honorary Professorship, Harbin Institute of Technology (HIT), China

Honorary Professorship, Huazhong University of Science and Technology (HUST), China

Member of Editorial Board, Rare Metals

Member of International Scientific Committee, International Conference on Magnesium Alloys and Their Applications, since 2012

Member of International Scientific Committee, International Conference on Advanced Solidification Processes (ICASP), since 2011

Member of International Scientific Committee, International Light Metals Technology Conference (LMT), since 2011

Member of International Scientific Committee, International Conference on Solidification and Gravity (SolGrav), since 2008

Member of International Scientific Committee, International Conference on Solidification and Solidification Processing (ICSSP), since 2006

Member of International Scientific Committee, International Conference on Semisolid Processing of Alloys and Composites (S2P), since 2004

Prof G.M. Scamans
Aluminium Industry Award, Aluminium Federation, 2017

Prof P.S. Grant
Member of Constellium Scientific Council

Member of Rolls-Royce Materials, Manufacture and Structures Advisory Board

Dr C.M. Gourlay
Member of the Board of Associate Editors, Journal of Crystal Growth, since 2015

Member of the Editorial Board, Journal of Materials Science: Materials in Electronics, since 2018

Organising Committee Member, Emerging Interconnect and Pb-free Materials for Advanced Packaging Technology Symposium, TMS Annual Meeting & Exhibition, 2018

Prof X. Zhou
Member of Editorial Board, Journal of Aeronautical Materials

Dr C.L. Mendis
Member of Technical Committee, TMS Mg, since 2007

Member of Awards Sub-Committee, TMS Mg, since 2018

Member of Publications Sub-Committee, TMS Mg, since 2017

Dr Y. Huang
Member of Editorial Board, Insights in Biomedical Engineering – OPR Science

Member of Editorial Board, MS Journal of Biomedical Engineering

Member of Editorial Board, Journal of Aerospace Engineering and Mechanics

Member of Editorial Board, Journal of Materials Science and Research

Member of International Scientific Committee, Organising Committee for 12th International Conference on Technology of Plasticity (ICTP), 17-22 September 2017, Cambridge, UK

Member of International Scientific Committee, International Conference on Materials Science and Materials Chemistry 2018, 20-22 August 2018, Paris, France

Dr S. Ji
Member of Editorial Board, Innovations in Corrosion and Materials Science

Member of Editorial Board, SciFed Journal of Metallurgical Science

Member of Editorial Board, Journal of Mineral, Metal and Material Engineering

Member of Technical Committee, NFE035 Light Metals and Their Alloys, BSI International, UK, since 2017

Member of Technical Committee, ISO/TC 079/SC07 Aluminium and Cast Aluminium Alloys, ISO, since 2017

Member of Technical Committee, ISO/TC 079/SC06 Wrought Aluminium and Aluminium Alloys, ISO, since 2017

Member of Technical Committee, ISO/TC 079/SC05 Magnesium and Alloys of Cast or Wrought Magnesium, ISO, since 2017

Member of Organising Committee, Materials Chemistry – 6th International Science and Chemistry Conference, since 2018

Dr S. Ji and Dr X. Dong
UK Cast Metal Industry Awards - CMF Innovation Award 2017 for LEAAST project BD1 alloy, Cast Metals Federation, 2017

Mr E. Nyberg
Chairman of TMS Light Metals Division

Dr G. Zeng
Excellent Oral Presentation Award for Quantification of Al_8Mn_5 Growth during the Solidification of AZ91, 6th International Conference on Magnesium (ICM6), 2017

Dr G. Zeng and Dr C.M. Gourlay
TMS Light Metals Magnesium Best Paper Award – Applications, for Growth Al_8Mn_5 Intermetallic in AZ91, 2017

Dr S. Butler
Chairman of The Casting & Solidification Society, The Institute of Materials, Minerals and Mining (IOM3), since 2017

Invited Lectures

Y. Huang, Invited Lecture, Microstructure, Mechanical and Electrochemical Performance of a Biodegradable Mg-2Zn-0.2Mn-0.5Ca/2HA Nanocomposite, 9th International Symposium on Biodegradable Metals (BIOMETAL 2017), Bertinoro, Italy, August-September 2017

S. Ji, Plenary Lecture, The Formation Mechanism of Metastable Al6(Fe, Mn) Phase in Die-cast Al-Mg alloys, 6th International Conference and Exhibition on Materials Science and Chemistry, Rome, Italy, May 2018

Z. Fan, Plenary Lecture, A New Framework for Understanding Heterogeneous Nucleation and Grain Refinement, 6th Decennial International Conference on Solidification Processing (SP17), Old Windsor, UK, July 2017

J. Patel, Invited Lecture, Development of the Multi-purpose High Shear Mixing Technology for Continuous Processing of Al and Mg Alloys, 6th Decennial International Conference on Solidification Processing (SP17), Old Windsor, UK, July 2017

Y. Wang, Invited Lecture, Effect of Interfacial Segregation on Heterogeneous Nucleation, 6th Decennial International Conference on Solidification Processing (SP17), Old Windsor, UK, July 2017

G.M. Scamans, Invited Lecture, Developments in Scrap Sorting, Processing and Melt Conditioning, CRU 22nd World Aluminium Conference, London, UK, May 2017

G.M. Scamans, Invited Lecture, Removing Iron from Aluminium using High Shear Melt Processing, Workshop of the Aluminium Innovation Hub, Aachen, Germany, June 2017

G.M. Scamans, Invited Lecture, Sensor Based Aluminium End-of-Life Scrap Sorting and Recycling, TOMRA Leads Global Conference, Future Perspectives in Recycling, Koblenz, Germany, October 2017

G.M. Scamans, Invited Lecture, Upcycling End-of-Life Auto Scrap into "New" Sheet and Other Products, Metal Bulletin's 25th International Recycled Aluminium Conference, Warsaw, Poland, November 2017

G.M. Scamans, Keynote Speaker, Aluminium Automotive Alloys of the Future, AlFed Advanced Aluminium Engineering for the Automotive Industry Conference, Birmingham, UK, November 2017

G.M. Scamans, Invited Lecture, Aluminium from Cans to Sustainable Cars, APC Tailpipe Dreams, Future of Technology Series, London, UK, April 2018

G.M. Scamans, Invited Lecture, Aluminium from End-of-Life Scrap to Cars, CRU 23rd World Aluminium Conference, London, UK, April 2018

I.T.H. Chang, Invited Lecture, Microbial Assisted Synthesis of Boron Carbide Composite, Dstl Synthetic Biology Showcase 2018, Edinburgh, UK, May 2018

A. Mullis, Invited Lecture, Phase Field Modelling of Multiphase Alloy Solidification: A Review, 6th Decennial International Conference on Solidification Processing (SP17), Old Windsor, UK, July 2017

C.M. Gourlay, Invited Lecture, Heterogeneous Nucleation of Sn in Solder Joints, 18th International Conference of the Union of Materials Research Societies in Asia (IUMRS-ICA 2017), Taipei, Taiwan, November 2017

C.M. Gourlay, Keynote Speaker, Solidification of BGA Solder Joints: Controlling Nucleation and Growth, Electronic Packaging Interconnect Technology Symposium 2017 (EPITS 2017), Fukuoka, Japan, November 2017

C.M. Gourlay, Keynote Speaker, Nucleation and Growth of Al-Mn-(Fe) Intermetallics in AZ91, 6th International Conference on Magnesium (ICM6), Shenyang, China, September 2017

C.M. Gourlay, Invited Lecture, Heterogeneous Nucleation Mechanisms in Solder Joints, 6th Decennial International Conference on Solidification Processing (SP17), Old Windsor, UK, July 2017

P.S. Grant, Invited Lecture, Measurement of Grain Formation Rate using In-situ X-ray Synchrotron Radiography and Machine Learning, 6th Decennial International Conference on Solidification Processing (SP17), Old Windsor, UK, July 2017

P.S. Grant, Invited Lecture, The Faraday Institution, UK China Energy Symposium, China, January 2018

P.S. Grant, Invited Lecture, Synchrotron X-ray Radiography Measurement of Intermetallic Compound (IMC) Selection and Growth During Al Alloy Solidification, TMS 2017, 146th Annual Meeting and Exhibition, California, USA, Feb-March 2017

P.S. Grant, Invited Lecture, Processing of Advanced Materials – Additive Manufacture, Sheffield Metallurgical Association, Sheffield, UK, July 2017

X. Zhou, Invited Lecture, The Influence of Quench Sensitivity on Intergranular Corrosion in Al-Mg-Si Alloy, 8th International Conference on Aluminium Surface Science and Technology, Helsingør, Denmark, May 2018

Publications

Peer Reviewed Journal Articles

C.B. Basak, H.B. Nadendla
Influence of Cu on Modifying the Beta Phase and Enhancing the Mechanical Properties of Recycled Al-Si-Fe Cast Alloys
Scientific Reports, 7 (2017), 5779
DOI: 10.1038/s41598-017-05937-2

H.-T. Li, P. Zhao, R. Yang, J.B. Patel, X. Chen, Z. Fan
Grain Refinement and Improvement of Solidification Defects in Direct-Chill Cast Billets of A4032 Alloy by Melt Conditioning
Metallurgical and Materials Transactions B, 48 (2017), 2481-2492
DOI: 10.1007/s11663-017-1016-7

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A Homogeneous Billet Layer Casting Fabrication Method
Metallurgical and Materials Transactions A, 48 (2017), 4453-4457
DOI: 10.1007/s11661-017-4239-y

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High Performance Gravity Cast Al9Si0.45Mg0.4Cu Alloy Inoculated with AlB_2 and TiB_2
Journal of Materials Processing Technology, 252 (2018), 604-611
DOI: 10.1016/j.jmatprotec.2017.10.028

Y. Zhang, S. Ji, Z. Fan
Improvement of Mechanical Properties of Al-Si Alloy with Effective Grain Refinement by In-situ Integrated Al2.2Ti1B-Mg Refiner
Journal of Alloys and Compounds, 710 (2017), 166-171
DOI: 10.1016/j.jallcom.2017.03.244

G. Liu, S. Ji, L. Grechcini, A. Bentley, Z. Fan
Microstructure and Mechanical Properties of Sn–Cu alloys for Detonating and Explosive Cords
Materials Science and Technology, 33 (2017), 1907-1918
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S. Ji, H. Yang, X. Cui, Z. Fan
Macro-heterogeneities in Microstructures, Concentrations, Defects and Tensile Properties of Die Cast Al–Mg–Si Alloys
Materials Science and Technology, 33 (2017), 2223-2233
DOI: 10.1080/02670836.2017.1334309

Y. Zhang, S. Ji, G. Scamans, Z. Fan
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Journal of Materials Processing Technology, 243 (2017), 197-204
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Halo Formation of Zn-Al alloys under Conventional Solidification and Intensive Convection Solidification
Journal of Alloys and Compounds, 696 (2017), 460-469
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Insight into the Partial Solutionisation of a High Pressure Die-cast Al-Mg-Zn-Si Alloy for Mechanical Property Enhancement
Materials Science and Engineering: A, 682 (2017), 85-89
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X. Dong, Y. Zhang, S. Ji
Enhancement of Mechanical Properties in High Silicon Gravity Cast AlSi9Mg Alloy Refined by Al3Ti3B Master Alloy
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DOI: 10.1016/j.msea.2017.06.005

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Journal of Materials Engineering and Performance, 26 (2017), 4166-4176
DOI: 10.1007/s11665-017-2853-x

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G.S. Peng, Y. Wang, K.H. Chen, S.Y. Chen
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Societies, Trade Organisations and Funding Bodies

IMA International Magnesium Association

TMS The Minerals, Metals & Materials Society

IOM3

CMF

icme

ALFED ALUMINIUM FEDERATION

CATAPULT High Value Manufacturing

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ADVANCED PROPULSION CENTRE UK

Automotive Investment Organisation | UK Trade & Investment

EPSRC Engineering and Physical Sciences Research Council

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DLR Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center

Helmholtz-Zentrum Geesthacht Zentrum für Material- und Küstenforschung

БНТУ

Team Members

Investigators

Professor Zhongyun Fan, Director, Principal Investigator, Brunel University London
Professor Patrick Grant, Co-Investigator, University of Oxford
Professor Andrew Mullis, Co-Investigator, University of Leeds
Professor Geoff Scamans, Co-Investigator, Brunel University London
Professor Xiaorong Zhou, Co-Investigator, University of Manchester
Professor Luiz Wrobel, Co-Investigator, Brunel University London
Professor Dmitry Eskin, Co-Investigator, Brunel University London
Dr Shouxun Ji, Co-Investigator, Brunel University London
Dr Christopher Gourlay, Co-Investigator, Imperial College London
Professor Hari-Babu Nadendla, Co-Investigator, Brunel University London
Dr Yan Huang, Co-Investigator, Brunel University London
Dr Brian McKay, Co-Investigator, Brunel University London
Professor Peter Jimack, Co-Investigator, University of Leeds
Dr Jayesh Patel, Senior Research Fellow, Brunel University London
Dr Yun Wang, Senior Research Fellow, Brunel University London
Professor Hamid Assadi, Head of the Virtual Engineering Centre, Brunel University London
Professor Isaac Chang, Head of LiME Training Centre, Brunel University London
Dr Chamini Mendis, Reader, Brunel University London
Professor Alan Dinsdale, Senior Research Fellow, Brunel University London
Professor Alain Jacot, Professor of Solidification Research, Brunel University London

Researchers

Dr Onuh Adole, Research Assistant, Brunel University London
Dr Kawther Al-Helal, Research Fellow, Brunel University London
Dr Inigo Anza, Research Fellow, Brunel University London
Dr Sajjad Amirkanlou, Research Fellow, Brunel University London
Dr Nilam Barekar, Research Fellow, Brunel University London
Dr Chandra Basak, Research Fellow, Brunel University London
Dr Ashutosh Bhagurkar, Research Fellow, Brunel University London
Dr Peter Bollada, Research Fellow, University of Leeds
Dr Paula Camean Queijo, Research Fellow, Brunel University London
Dr Xixi Dong, Research Fellow, Brunel University London
Dr Kun Dou, Research Fellow, Brunel University London
Dr Changming Fang, Senior Research Fellow, Brunel University London
Dr Arnas Fitzner, Research Fellow, Brunel University London
Dr Junwei Fu, Visiting Research Fellow, Brunel University London
Dr Feng Gao, Research Fellow, Brunel University London
Dr Binyan He, Research Fellow, Brunel University London
Dr Elizabeth Hinton, Research Fellow, Brunel University London
Dr Erdem Karakulak, Research Fellow, Brunel University London
Dr Yueqian Ke, Visiting Research Fellow, Brunel University London
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Dr Jaime Lazaro Nebreda, Research Fellow, Brunel University London
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Dr Hu-Tian Li, Research Fellow, Brunel University London
Dr Zaidao Li, Research Fellow, Brunel University London
Dr Enzo Liotti, Post-Doctoral Research Assistant, University of Oxford
Dr Dan Luo, Research Fellow, Brunel University London
Dr Hongkui Mao, Visiting Research Fellow, Brunel University London
Dr Hua Men, Research Fellow, Brunel University London
Dr Alberto Miranda, Research Fellow, Brunel University London
Dr Zhongping Que, Research Fellow, Brunel University London
Dr Mehdi Rahimian, Research Fellow, Brunel University London
Dr Georges Salloum-Abou-Jaoude, Research Fellow, Brunel University London
Dr Tungky Subroto, Research Fellow, Brunel University London
Dr Holly Tetlow, Research Fellow, Brunel University London
Dr Douglas Watson, Research Fellow, Brunel University London
Dr Feng Wang, Research Fellow, Brunel University London
Dr Junhai Xia, Research Fellow, Brunel University London
Dr Xinliang Yang, Research Fellow, Brunel University London
Dr Jiamin Yu, Research Associate, University of Manchester
Dr Guang Zeng, Post-Doctoral Research Assistant, Imperial College London
Dr Yijie Zhang, Research Fellow, Brunel University London
Dr Xiangzhen Zhu, Research Fellow, Brunel University London
Mr Umar Amin, PhD Student, Brunel University London
Mr Qing Cai, PhD Student, Brunel University London
Ms Suwaree Chankitmunkang, Visiting PhD Student, Brunel University London
Mr Jon Church, PhD Student, University of Leeds
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Y. Wang, T. Hashimoto, X. Zh
Introduction
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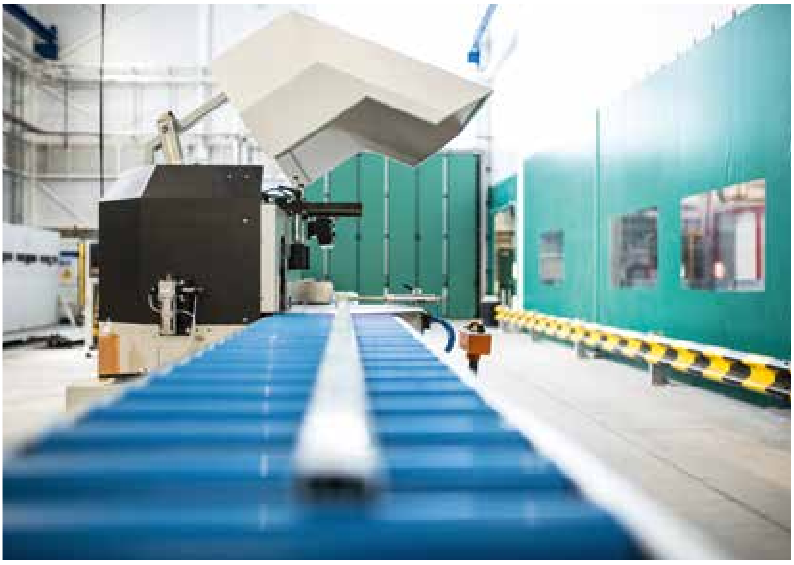


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Uxbridge, Middlesex, UB8 3PH

lime@brunel.ac.uk
+44 (0) 1895 267 703

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