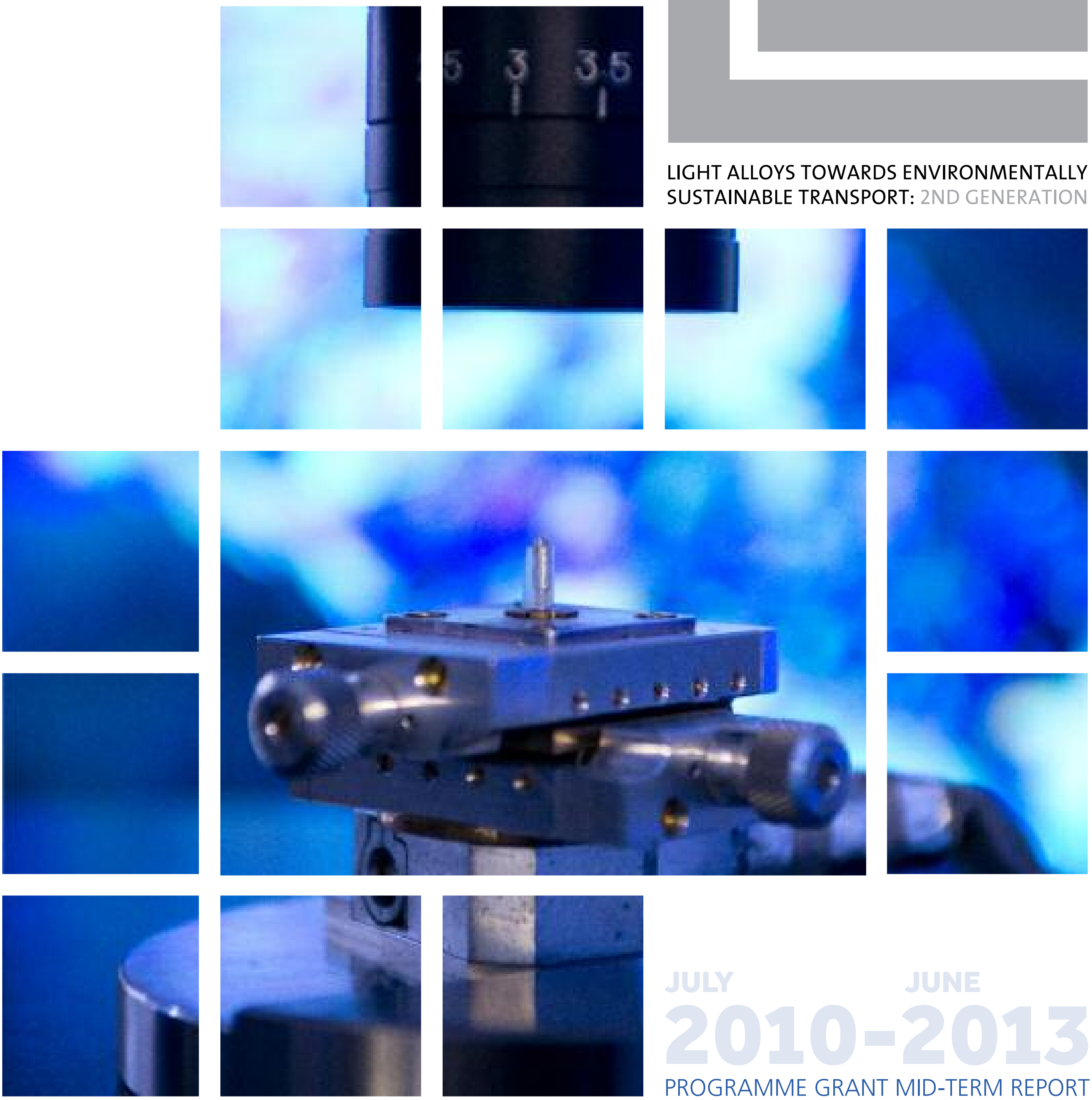
The University of Manchester

LATEST2

LIGHT ALLOYS TOWARDS ENVIRONMENTALLY SUSTAINABLE TRANSPORT: 2ND GENERATION



JULY 2010 – JUNE 2013

PROGRAMME GRANT MID-TERM REPORT

EPSRC
Engineering and Physical Sciences Research Council

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PROFILE

Professor George E. Thompson
LATEST2 Director
Theme Leader
Principle-Investigator
Chair in Materials Engineering
The University of Manchester

George Thompson is the Programme Director for the EPSRC LATEST2 Programme Grant. He graduated in Metallurgy from the University of Nottingham in 1967 and was awarded his PhD from the same institution in 1970 for studies on precipitation in Al-Cu and Al-Li alloys. After postdoctoral studies at Nottingham on the effects of heat and mass transfer on the corrosion behaviour of selected metals, he joined Howson Algraphy Ltd (now Agfa UK), a lithograhic plate manufacturer, in Leeds in 1973. During this period in industry, he was seconded to UMIST (now known as The School of Materials in The University of Manchester); progressive promotions were gained from Section Leader to Principal Scientist. In 1978 he joined the academic staff at the Corrosion and Protection Centre in UMIST, being promoted to Professor of Corrosion Science and Engineering in 1990. He has previously served as Head of the Corrosion and Protection Centre and Deputy Head of the School of Materials at The University of Manchester.

Professor Thompson`s research interests are largely focused on the corrosion and protection of light alloys, with applications in the architecture, automotive, aerospace, lithography and packaging sectors, and electronic materials. He collaborates extensively with scientists in the UK, China, Europe, Japan and America. In his work on material/property/performance relationships, extensive use is made of electrochemical, electronoptical, surface analytical and surface structural probing to understand the influence of the material bulk, near-surface and surface properties on corrosion and its control. Environmentally friendly coatings, with incorporated nanoparticles containing self-healing abilities are of particular current interest.

The research is undertaken in collaboration with academia, research organisations and industry, including, Alcan, Airbus, Akzo Nobel, Avic, BAE Systems, BIAM, Constellium, CSIRO, Elval, Magnesium Elektron, Novelis, Poeton, Rolls Royce, SAPA etc. This successful research has been recognised by appointment as OBE and election to Fellowship of the Royal Academy of Engineering, and many additional awards.

Dear All,

On behalf of the Management Team it gives me great pleasure to present to you the EPSRC LATEST2 (Light Alloys Towards Environmentally Sustainable Transport: 2nd Generation) Programme Grant mid-term report, July 2010 – June 2013. This report is designed to provide an insight into the progress made to date across the breadth of LATEST2 interdisciplinary Research activities and the impact on the community.

The EPSRC LATEST2 Programme builds on the research undertaken during the lifespan of the EPSRC LATEST Portfolio Partnership and is aimed at providing the underpinning research required to help facilitate a step change in high-performance, light alloys and multi-material solutions in the transport sector: this builds on Manchester's recognised capability in this field.

The EPSRC LATEST2 Programme Grant, awarded by the Engineering and Physical Research Council (EPSRC) was officially launched in July 2010 with initial funding of £7.5 million (100% FEC), £6.5 million provided by the EPSRC as the main sponsor and £1 million from The University of Manchester. Since its commencement the EPSRC LATEST2 Team has been striving to grow the Research Programme through added value funding and has already exceeded its target to match the initial funding within the lifespan of the Programme. Indeed, the Team have already achieved a total added value of £8.65 million, reflecting the importance and demand for research in this field.

Since its inception the EPSRC LATEST2 Team have been striving for research excellence to provide high quality training, quality outputs and successful knowledge transfer amongst academic, industrial and national and international communities. The LATEST2 Team act as advocates for the Programme, the engineering and physical sciences in general and the EPSRC on both national and international stages.

The EPSRC LATEST2 Programme has now ramped up to full resource capacity, and we are pleased to announce our 147^{th} project. The Team is working hard to keep up with the outputs and to date we have published over 200 papers, over 55 conference proceedings and given over 40 invited lectures.

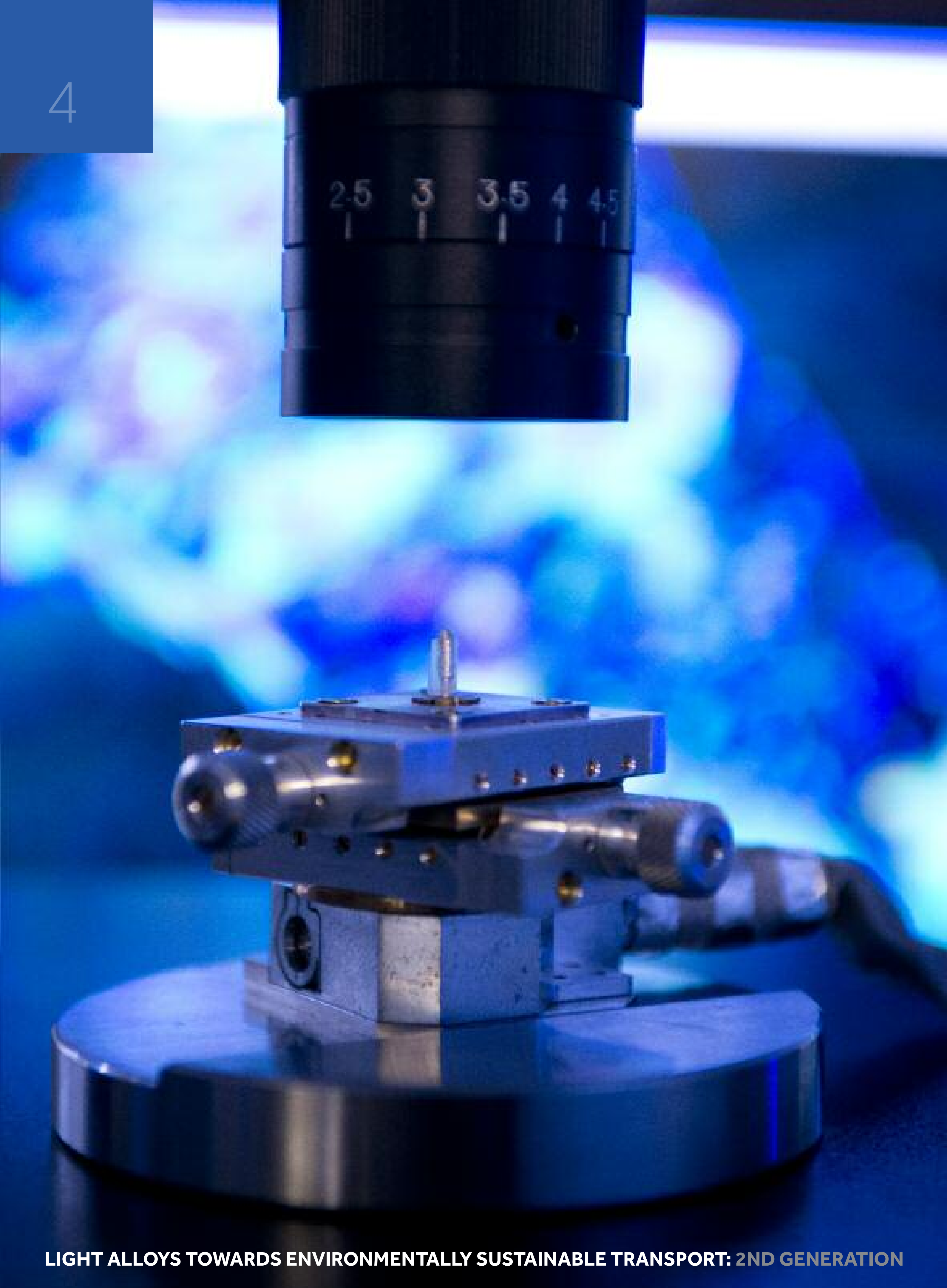
The LATEST2 Team have developed an "IMPACT" science communication strategy where the Programme aims to effectively engage with a wide range of target audiences to increase awareness of the EPSRC, the importance of our research and it's industrial application, as well as the engineering and physical sciences in general.

The Team have achieved strong growth in contact numbers year on year across all target audiences with total contact points standing at over 165,000 across events for schools and colleges, the community and hosted events for industry and academia.

We sincerely hope that you enjoy reading this report, and find something of interest to you. We encourage you to visit our website and apply to be added to our mailing list so we can keep you informed of research developments and news of future EPSRC LATEST2 Programme events. We would be pleased to hear from you and have the opportunity to discuss opportunities to collaborate and ways in which you can engage with the Programme.

Yours sincerely,

Professor George E. Thompson
EPSRC LATEST2 Programme Director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CONTENT

The LATEST2 Vision

The LATEST2 Programme is aimed at providing the underpinning fundamental research required to facilitate a step change in high-performance, light alloy and multi-material solutions in the transport sector leading to a reduction in energy consumption and CO_2 emissions. The programme is carefully tailored to meet the needs of industry and will provide the supporting research needed to maintain global competitiveness in the realignment of manufacturing towards sustainable transport technologies.

Visibility and Reputation

The EPSRC LATEST2 Programme Team are striving to continue to build the visibility and reputation of the research group on both the national and international stage. We have developed clear and consistent branding across all our communication media and the EPSRC LATEST2 Programme is now internationally recognised. The team have hosted a large number of events that have been well-attended with delegates from countries around the world and will continue to develop the UK's reputation for research in this field.

Knowledge Transfer and Research Translation

For the EPSRC LATEST2 Programme to be a successful and sustainable research activity the team are working hard to develop wider engagement with academic institutions, research organisations and industrial companies across the transport sector supply chain. Since launch the Programme has been very successful at leveraging additional funding from UK and European Research Councils and industrial companies and the team are committed both to knowledge transfer and research translation.

Programme Management

The EPSRC LATEST2 Programme is led by the Programme Director (Professor G. E. Thompson), supported by the LATEST2 Management Team consisting of the Programme Co-Investigators, the administrative team led by the LATEST2 Programme Manager which comprises the Programme Administrative Assistant and Science Communication Officer. The Management Team is advised by its International Advisory Panel.

Meet the Management Team Left to Right:
Ms Laura Winters (Science Communication Officer)
Dr Joseph Robson (Co-Investigator)
Dr João Quinta da Fonseca (Co-Investigator)
Professor George Thompson (Programme Director)
Professor Peter Skeldon (Co-Investigator)
Professor Philip Prangnell (Deputy Programme Director)
Dr Michele Curioni (LATEST2 Research Fellow)
Ms Cacia Percival (Programme Administrative Assistant)
Dr Xiaorong Zhou (Co-Investigator)
Ms Susan Davis (Programme Manager)
Professor Michael Preuss (Co-Investigator)

LATEST2 AND THE INDUSTRIAL LANDSCAPE

With a turnover of £30 billion and employing 600,000 people directly and within the supply chain, it is difficult to overstate the importance of aerospace and automotive manufacturing to the UK economy. Our over-dependence on fossil fuels is clearly unsustainable, both in terms of the demand on supply and the effect of the pollution it creates. The world produced approximately 35 billion tonnes of carbon dioxide in 2011, which is double that seen only twenty five years ago. This upward trend can be attributed to the rapid industrialisation of Brazil, Russia, India and China (BRIC) nations and continued world population growth (Figure. 1). Transport is currently responsible for 14% of global emissions of which road traffic accounts for by far the greatest share. Airbus predicts a more than doubling of the world passenger airline fleet by 2030 and, while this presents an unprecedented business opportunity with an estimated value of $4 trillion in aircraft orders, this growth rate is unsustainable without a step change in fuel efficient airfcraft designs. Fortunately this impending crisis is now being taken seriously by governments and industry. In the EC the automotive sector is on track to reach the 130 CO_2 g/km average fleet limit by 2015. However, the next target of 95 g/km by 2020 is far more demanding and there is already talk of a 65 g/km limit by 2050. Other important aspects of sustainability include the impact of the entire product life cycle, and thus the avoidance of the use of energy intensive materials and manufacturing processes, as well as issues such as resource scarcity.

Energy use in transport is closely linked to vehicle mass and, due to the low energy storage density of batteries, electric vehicles also need to be as light as possible to extend their range to the level where they become a credible alternative.

Materials and manufacturing technology is now advancing at a frenetic pace to meet this challenge, with demand out-stripping the supply of new scientists and researchers across the sector. LATEST2 is thus proud to be involved in the Sheffield-Manchester EPSRC Centre of Doctoral Training (CDT) in Metallic Systems, which is aimed at providing high quality, industrially focused, PhD graduates to become the next generation of metallurgical specialists.

In order to reach these ambitious emission reduction targets, applications for light alloys within the transport sector are projected to more than double in the next decade and the trend is accelerating. However, in many cases the properties and cost of the materials and manufacturing processes are inhibiting progress in weight reduction. In the automotive industry the material mix depends on the intended market position. At one end of the market the high volume sector is currently still dependent on steel intensive vehicles. At the top end, carbon fibre reinforced composites are increasingly making their presence felt, but until the cost falls below $10 /kg CFRP will not enter the mass car market. In between these two extremes, in order of volume, companies are introducing hybrid steel-light alloy designs, fully light alloy car bodies and light alloy CFRP composite multi-material products. With reducing costs and increasing pressure it is predicted that the higher cost options solutions will move to higher volume production and fully steel vehicle bodies will soon be replaced with a light alloy intensive multi-material approach. Indeed, the slogan 'right material, right place' has become the mantra of many automotive designs teams. Examples include the ultra-high strength boron steel safety cell with aluminium crash members and closure panels used by Daimler in the 2013 S-class, the new aluminium intensive Jaguar Land Rover (JLR) product range that involves widespread use of magnesium die castings and the CFRP composite- aluminium BMW3i, which incorporates an aluminium intensive chassis, or 'drive module', with a carbon fibre body, 'life module'.

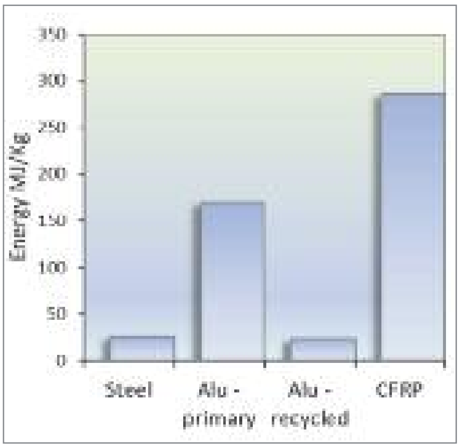


Fig. 2 Comparison of the energy required to produce 1 kg of aluminium, steel and carbon fibre reinforced plastic.

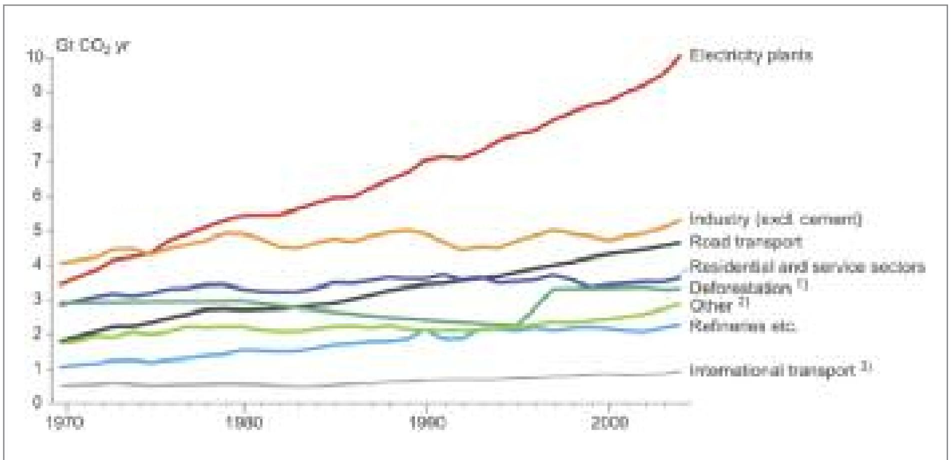


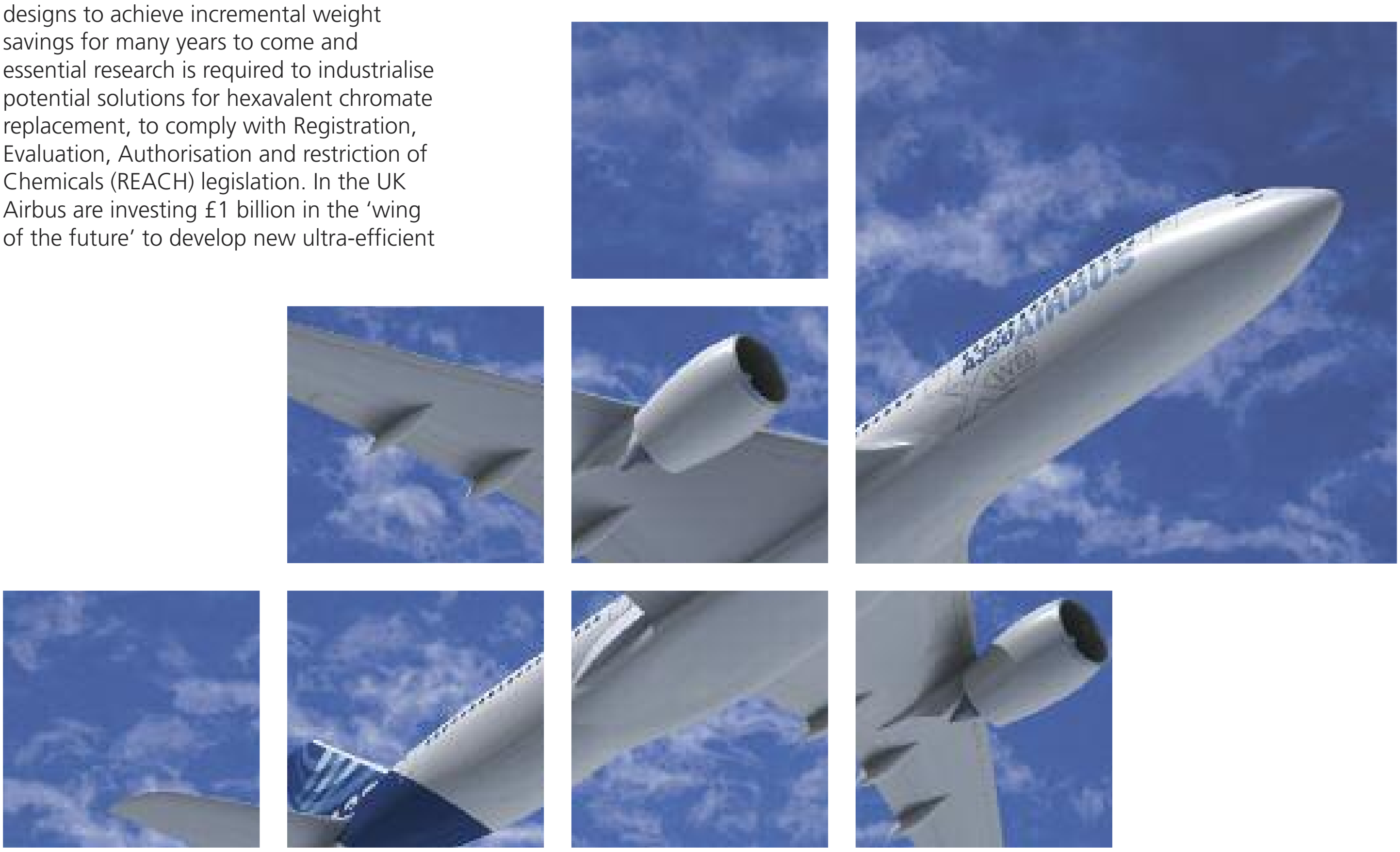
Fig. 1 Annual global CO_2 emissions, by sector (Center for Climate and Energy Solutions)

To be able to introduce more lighter materials in vehicle designs there is an increasing focus on offsetting their higher cost by reducing the part count through the use of larger integral components and near-net-shape technologies. A further issue with the use of carbon fibre composites is that they currently require 286 MJ/kg to produce compared to 23 MJ/Kg for recycled aluminium, and this energy is not recoverable as CFRPs cannot be recycled into the same product form (Figure 2).

In the aerospace sector metals use is also rapidly changing. The first generation of composite dominated multi-material aircraft that are now entering service still contain over 40% metallic structure but have a much higher reliance on titanium alloys owing to incompatibility problems between CFRP and aluminium. The greater use of expensive materials like titanium has increased the focus on near-net-shape manufacturing processes to improve the traditionally high buy-to-fly ratio, and similar issues have been highlighted in automotive manufacturing where reducing costs through greater use of integrated structures and new joining technologies is a high priority. New higher performance titanium and aluminium alloys will also be substituted into existing legacy airframe designs to achieve incremental weight savings for many years to come and essential research is required to industrialise potential solutions for hexavalent chromate replacement, to comply with Registration, Evaluation, Authorisation and restriction of Chemicals (REACH) legislation. In the UK Airbus are investing £1 billion in the 'wing of the future' to develop new ultra-efficient wing concepts, an ambitious project in which LATEST2 has recently been invited to participate.

In this rapidly changing landscape it is essential to develop the knowledge base that supports advanced metals manufacturing. LATEST2 endeavours to continue to serve this role by providing a fundamental view on strategically important materials issues. Examples within the three themed areas of forming, joining and surface engineering include: developing crystal plasticity models of important materials like magnesium and titanium so that we can use sound scientific principles to improve formability of higher specific strength materials than are currently used in industry; developing models of interface reaction between dissimilar metals so that we can design alloy compositions, or coating systems, that prevent intermetallic compound formation during welding dissimilar metals like aluminium to magnesium, or titanium; studying the fundamentals of electrochemical oxide growth on metals so that we can tailor surfaces to have better performance in both corrosive environments and for adhesive bonding and paint finishing, with lower energy input processes.

LATEST2 benefits from the 'joined-up' style of the multidisciplinary team, which allows an integrated approach to tackling challenging problems. For example, 7xxx aluminium alloys have the potential to deliver yields stresses in excess of 600 MPa and could be used in automotive applications with a substantial weight saving if we can better understand how to form them with a cost-effective process. However, at the same time, we also need to tackle the poor stress corrosion behaviour of 7xxx service alloys, particularly when welded, or around self-piercing rivets or fasteners. Other important topics that benefit from this multidisciplinary approach include: the effect of surface deformation in situations such as forming or rectification on corrosion; protection of heterogeneous microstructures associated with welded joints; development of surface treatments to improve adhesion on titanium - composite hyper-joints; the transfer of microstructure models developed for welding processes to predict product variability in additive manufacturing; and the prediction of the influence tramp elements accumulating in closed loop recycling on forming and corrosion behaviour.



THE RESEARCH PROGRAMME

"I enjoy the creative freedom of undertaking academic research with industrial relevance."

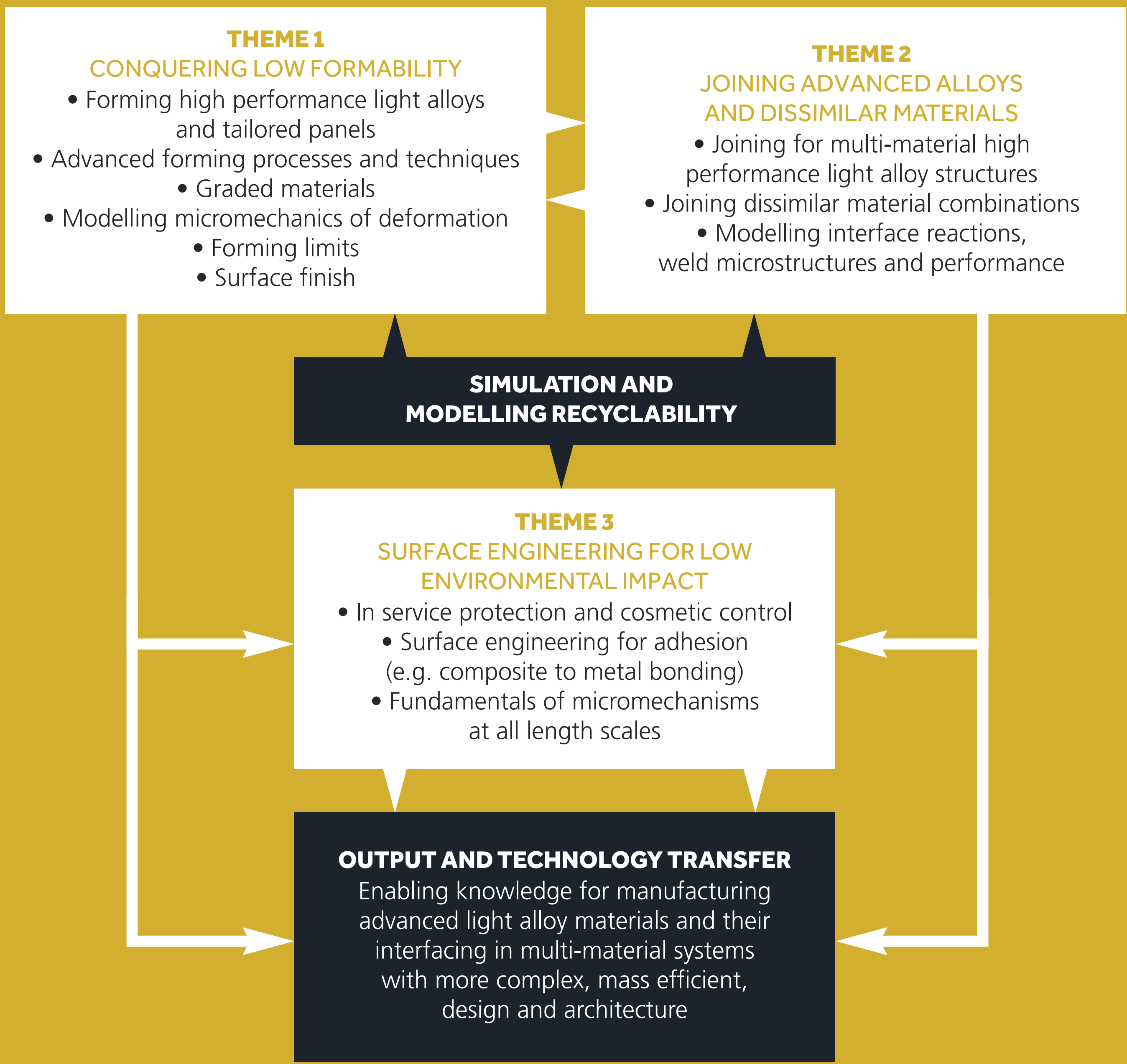
Arnas Fitzner, PhD Student

The EPSRC LATEST2 programme aims to facilitate a step change in weight reduction in transport by developing the science base required to overcome critical issues inhibiting progress towards second generation, light alloy, multi-material designs. We hope to accelerate the exploitation of new transformative, low energy, environmentally-compliant manufacturing processes by providing solutions to the important materials challenges and predictive capabilities required by industry. This requires the development of an enhanced fundamental scientific understanding and modelling capability in key areas.

The future direction of the transport industry requires more geometrically complex designs with a lower part count and the efficient utilisation of more expensive, lighter alloys. At the same time industry will have to cope with the difficulties presented by the introduction of less formable, higher performance and more recycled materials. These conflicting requirements require a better understanding of the fundamental issues controlling forming, joining and surface engineering of light alloy products, as well as the development of more reliable predictive models and the optimisation and introduction of new techniques and technologies.

This research is supported by exciting new approaches to materials analysis, modelling and simulation to facilitate more rapid industrial optimisation, while maintaining cost competitiveness and recyclability. A focus on the use of low energy manufacturing routes and recycled materials will be an important aspect of the research to ensure a competitive cost base as well as a low environmental footprint.

The Programme will be advanced through three principal interacting themes as illustrated opposite.


THEME 1
CONQUERING LOW FORMABILITY
• Forming high performance light alloys and tailored panels
• Advanced forming processes and techniques
• Graded materials
• Modelling micromechanics of deformation
• Forming limits
• Surface finish
THEME 2
JOINING ADVANCED ALLOYS AND DISSIMILAR MATERIALS
• Joining for multi-material high performance light alloy structures
• Joining dissimilar material combinations
• Modelling interface reactions, weld microstructures and performance
SIMULATION AND MODELLING RECYCLABILITY
THEME 3
SURFACE ENGINEERING FOR LOW ENVIRONMENTAL IMPACT
• In service protection and cosmetic control
• Surface engineering for adhesion (e.g. composite to metal bonding)
• Fundamentals of micromechanisms at all length scales
OUTPUT AND TECHNOLOGY TRANSFER
Enabling knowledge for manufacturing advanced light alloy materials and their interfacing in multi-material systems with more complex, mass efficient, design and architecture

"Being part of the LATEST2 Research Team is a great opportunity and a decisive step for my career."

Andronikos Balaskas, PhD Student

CONQUERING LOW FORMABILITY FOR OPTIMISED DESIGN ARCHITECTURES

We aim to develop the scientific base required to optimise energy efficient routes for forming advanced light alloy materials to achieve the more complex shapes required by industry for these difficult materials in a cost effective manner. A key ambition is to develop microstructure sensitive models and optimise innovative techniques for extending formability in higher strength, lower ductility, materials and recycled alloys.

Whereas formability has been extensively investigated in steel and some automotive aluminium alloys, a new approach is required for studying warm deformation in high strength alloys and in hexagonal metals (HCP) e.g. titanium and magnesium. This involves understanding and modelling the development of precipitate distribution and its interaction with deformation during warm forming and then extending the modelling to describe advanced warm forming processes. For titanium and magnesium the aim is to clarify the micromechanics of deformation for implementation in crystal plasticity models that can capture the influences of microstructural and texture heterogeneity that lead to strain localisation and limit formability.

Another important component of the work in Theme 1 is the control of microstructure during thermomechanical processing, which is essential for good formability. There is particular focus on the role of particles in recrystallization of aluminium alloys, which is increasingly important as recycled content increases, and on the texture homogeneity of titanium and the control of texture and grain size in wrought magnesium alloys. There is also a growing activity on microstructural control of additive manufactured titanium material.

The research is aimed at developing the fundamental science required to underpin the following application areas:

- Developing models for microstructural evolution, including texture, during themomechanical processing of light alloys
- Extending shape capabilities in conventional cold forming of medium strength aluminium alloys with increased recycled content
- Selection and optimisation of new warm forming operations for high strength aluminium alloys
- Energy efficient, warm forming of HCP materials (magnesium, titanium)
- Forming more economic roll cast and recycled materials

Dr João Quinta da Fonseca
LATEST2 Theme Leader
Co-Investigator
Academic Outreach Champion
Senior Lecturer
The University of Manchester

João Fonseca completed his PhD on the mechanical behaviour of high volume fraction MMCs at the University of Leeds in 2001. He then moved to the School of Materials at The University of Manchester, where he became a lecturer in 2005 and a senior lecturer in 2011. He is currently active in a number of different research groups, including the Engineering and Process Metallurgy group and the Materials Performance Centre. He is a co-investigator in LATEST2 where he is leader of the formability theme.

His research interests are in understanding/modelling the mechanics of metals at the microscale and their impact on microstructure evolution and their performance in service. This work is based on the innovative use of established characterisation techniques like EBSD and neutron diffraction and the development of new techniques such as high resolution digital image correlation. This experimental work is underpinned by computational crystal plasticity modelling. The goal is to understand the limits of current continuum mechanics approaches and to develop new ways of overcoming these limitations.

Current projects in LATEST2 aim to understand the limits of formability of high strength aluminium alloys and hexagonal metals like titanium and magnesium. He is also working on new models for the deformation of near particles in aluminium to help shed light on the efficiency of particle stimulated nucleation. Other research projects include understanding and modelling the microstructure evolution during thermomechanical processing of zirconium alloys, developing new models for non-proportional loading in steel, and characterising and modelling plasticity at notches in nickel superalloys and at the tips of environmentally assisted cracks.

The importance of this fundamental research is recognised by industry and most of his work is funded by both suppliers and users in the aerospace, energy and automotive sectors. Current industrial collaborators include Novelis, Constelium, TIMET, BaoSteel, Nippon Steel, Otto Fuchs, EdF, Westinghouse, Areva, Rolls-Royce and AMEC.

Investigating the Effect of Particle Shape and Distribution on Recrystallization and Texture in Aluminium Alloys

L. Dwyer, J. D. Robson, J. Quinta da Fonseca, G. E. Thompson, T. Hashimoto
LATEST2, The University of Manchester

Large particles in wrought aluminium alloys are critically used to control the microstructural evolution during processing, in particular to tailor the final grain structure and crystallographic texture. This is especially important in 3xxx aluminium alloy sheet, where particle stimulated nucleation of recrystallization (PSN) is exploited to give a balance of texture components to produce the high level of formability required for can production.

Although the basic principles of PSN are established for idealized spherical particles, little is understood about the influence of the true particle morphologies and distributions encountered in 3xxx aluminium alloys. An improved understanding of these effects is necessary to develop accurate models that can correctly predict the effect coarse particles will have on PSN and texture evolution in real industrial alloys.

In this study, 3-dimensional imaging using X-ray tomography and serial block-face (SBF) sectioning in the scanning electron microscope (Figure 1) has been used to understand the true 3-D particle shapes and distributions encountered at different stages during processing. For the first time it has been possible to image at a sufficiently high resolution to capture both the coarse intermetallics and fine dispersoid particles, which interact in the development of the final grain structure (Figure 2).

It has been demonstrated that the assumption of a spherical morphology is a poor approximation in the case of most of the large particles in real 3xxx alloys, and the particle orientation with respect to the slip bands developed in each grain during deformation therefore becomes important in determining their potency in stimulating recrystallization of a new grain.

More realistic particle morphologies extracted from the SBF data (Figure 3) have been used as inputs to a crystal plasticity finite element model (CPFEM) to help predict the effect of particle shape and orientation on deformation zone formation and hence the likely potency of a particle to initiate PSN. This work is ongoing, with the eventual aim of producing an improved model for PSN that correctly accounts not only for particle size but also for shape and orientation.

This work forms a component of an integrated through process model (TPM) for rolling of 3xxx aluminium alloy sheet being developed in collaboration with Novelis and a consortium of Canadian universities.

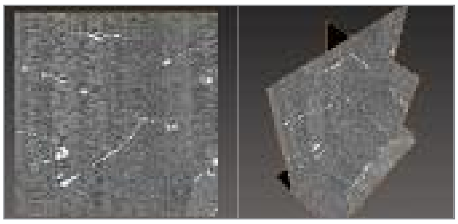


Fig. 1 Image from a single slice (left). More than 500 such slices are used to characerize the microstructure in 3-dimensions (right).

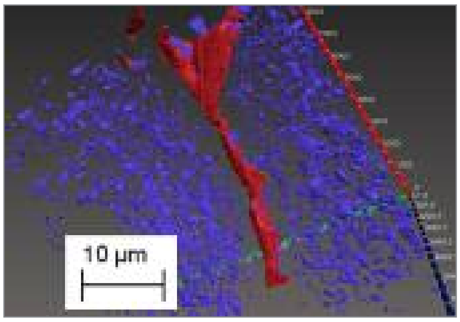


Fig. 2 3-dimensional visualization of large intermetallic constituents (red) on a grain boundary and dispersoids (blue) after homogenization of a 3xxx Al alloy. The dispersoid free zone adjacent to the grain boundary is clearly seen.

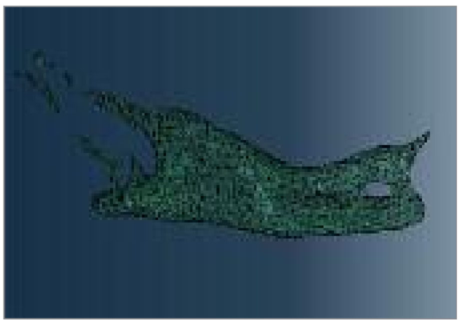


Fig. 3 Particle of complex geometry extracted from 3-dimensional dataset and meshed for use in a finite element model.

Acknowledgements: This LATEST2 project was performed through the EPSRC Centre for Doctoral Training in Advanced Metallic Materials with support from Novelis

Publications: J. D. Robson, J. Q. da Fonseca, L. Dwyer, T. Hashimoto, G. E. Thompson, N. Kamp, Constituent Particles and Dispersoids in an Al-Mn-Fe-Si Alloy Studied in Three-Dimensions by Serial Sectioning, Materials Science Forum 765, 2013, p. 451-455

The Effect of Temperature on the Formability of High Strength Aluminium Alloys

Mr R. Nolan[1], Professor P. B. Prangnell[1], Dr J. Quinta da Fonseca[1] and Dr M-A. Kulas[2]
[1] LATEST2
[2] Constellium

A pressing need to reduce CO_2 emissions and improve motoring efficiency is driving aggressive weight reductions in automotive design. This makes high performance aluminium alloys, with their high strength to weight ratio, the materials of choice for future sheet metal body structures. Alas, their adoption is hindered by poor cold formability and a drastic loss of performance after warm forming. This project, which is a collaboration with Constellium, aims to understand the limits of formability of 7xxx alloys by a combination of mechanical testing, deep drawing and advanced microstructural characterisation.

The high strength of 7xxx aluminium alloys make cold forming effectively impossible, unless it is performed immediately after solution heat treatment. This is both difficult and impractical, making it a costly option. However, since these alloys rely on precipitation strengthening for their performance, warm formability is a complex process. Since the microstructure will change during forming, formability will not simply increase with temperature. A naturally aged material, in the T4 condition, will continue to age and strengthen during forming whereas a peak aged material, in the T6 condition, will lose strength as it overages.

This is readily demonstrated by the results of tensile tests carried out between 150ºC and 250ºC, shown in Figure 1. It is clear that in the T4 condition (naturally aged) increasing temperature leads to a complex change in properties, with a non-linear change in strength work hardening and ductility. In the T6 (peak aged) condition, increasing temperature leads to a decrease in strength. This behaviour is a consequence of complex precipitation and coarsening sequences taking place in this material.

Although tensile tests are informative, deep drawing tests are a more useful measure of formability: the results of these tests are shown in Figure 2 where the effects of warm deformation on microstructure instability are again evident. Although in the T6 condition increasing the temperature always leads to an increase in drawability, drawing was successful at both 190ºC and 250ºC in the T4 condition, but not at other temperatures. This is a counterintuitive finding, but one which offers the promise of a way to warm form these materials in a practical and cost effective manner.

This work is now being followed by detailed microscopic analysis, including TEM work and fracture surface analysis as shown in Figure 3. This analysis, in combination with microstructural modelling, will help establish whether warm formability can be exploited in an industrial setting with existing alloys and how this new understanding of the fundamental deformation mechanisms can be used to develop high strength aluminium alloys with good formability.

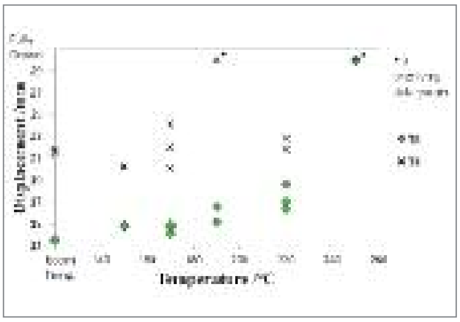


Fig. 2 Deep drawing test results for material in the T4 and T6 conditions at different temperatures.

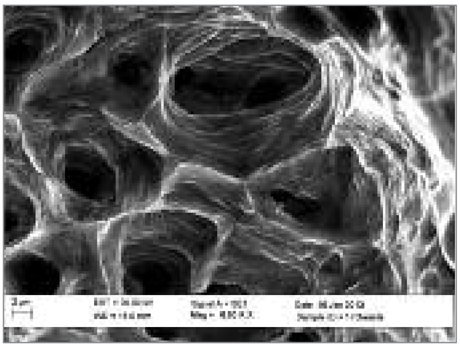


Fig. 3 Fracture surface of the material tested at 170ºC in the T4 condition.

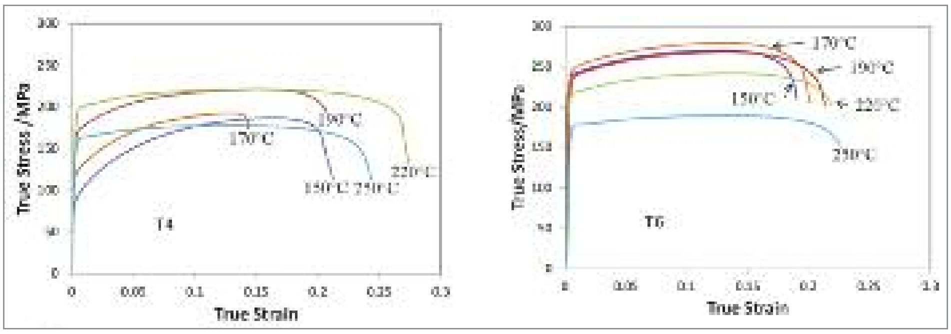


Fig. 1 Tensile test results for material in the T4 (left) and T6 right) conditions at different temperatures.

Publications: The Effect Of Temperature On The Formability Of A High Strength Aluminium Automotive Alloy, Proceedings of MS&T'13, Montreal, Canada, 2013

“I joined LATEST2 because I wanted to work with leading academics.”

Liam Dwyer, PhD Student

Professor Michael Preuss
LATEST2 Co-Investigator
Deputy Director of the Materials Performance Centre and Nuclear Rolls-Royce University Technology Centre
Professor of Metallurgy
The University of Manchester

Michael Preuss is Deputy Director of the Materials Performance Centre and the Nuclear Rolls-Royce University Technology Centre in Manchester. He is a Co-investigator on the EPSRC LATEST2 Programme as well as the New Nuclear Manufacturing (NNUMAN) Programme and the Heterogeneous Mechanics in Hexagonal Alloys across length and time scale (HEXMAT) Programme. In 2010 Michael was awarded an EPSRC Leadership Fellowship which he has started in April 2011.

Michael obtained his PhD from the Technical University Hamburg-Harburg, Germany on creep in two-phase titanium alloys. He joined The University of Manchester in 1999, first working in the field of friction welding nickel-base superalloys and titanium alloys. In 2003 he was appointed to a Lectureship in Materials Performance and became a core member of the Materials Performance Centre. During this time he started to build a new research group on zirconium alloys for nuclear applications while continuing to work in the field of aeroengine materials. In 2010 Michael was appointed Professor of Metallurgy and is currently a member of the Institut Laue-Langevin (ILL) Scientific Council.

Michael's research focuses on microstructure, mechanical properties and residual stresses in high temperature materials for aeroengine and nuclear applications. The materials he is particularly interested in are zirconium alloys used to encapsulate nuclear fuel, as well as titanium alloys and nickel-base superalloys, which are used, for example, in aeroengines. A central aspect of his research is to develop a more physically based understanding of how these complex materials develop their microstructure during processing and the mechanisms that determine their performance. This is achieved by using a range of state-of-the-art analytical tools that enable characterising material in-situ and in 3D. Particularly important research tools are large-scale research facilities such as the European Synchrotron Radiation Facility in Grenoble, France and Diamond and ISIS in Oxfordshire, UK. In addition, lab based facilities like advanced electron microscopy are used to provide a far more complete picture of materials than ever before.

Developing Titainum Alloys with Higher Strength and Improved Ductility

A. Fitzner, J. Quinta da Fonseca, M. Preuss
LATEST2, School of Materials
The University of Manchester

Titanium alloys are high strength, lightweight materials that are becoming increasingly important in the aerospace sector where they are a much better match for the composite fuselage than aluminium alloys. Light weighting can be achieved by increasing the strength of alloys but, in titanium, increased strength often comes with decreased ductility. This LATEST2 project, a collaboration with TIMET, aims to understand the fundamental strengthening mechanisms in titanium alloys and to help develop new compositions that have higher strengths without sacrificing ductility.

Conventionally studies of deformation mechanisms have relied on ex-situ observations of the microstructure and texture via optical or electron microscopy and x-ray diffraction. However, these only show the effects of deformation, leaving much of the active mechanisms to be divined. In-situ studies using digital image correlation (DIC) are more appropriate to track slip activity during deformation. To achieve a spatial sub-grain resolution, gold features in the nanometer scale (Figure 1, top left) are applied on the sample surface. The advantage of having small gold particles on the surface of the material is the fact that they enable, for the first time, strain mapping with sub-micron spatial resolution. The downside of the technique is the tremendous effort to record images using electron microscopes. Patterns obtained using spray paint or etching marks on grain boundaries can be imaged on optical microscopes and are therefore much easier to use, but do not give sub-grain resolution and many of the questions posed by alloy development require sub-grain resolution answers.

Figure 1 shows schematically how the high resolution strain mapping approach works. The top left image is an electron backscattered image of gold droplets on a polished titanium specimen. The strain map shows 0% strain for the macroscopically unloaded state. The microstructure map from electron backscattered diffraction measurements (EBSD) of this alpha titanium alloy shows equiaxed grains. The colours correspond to the crystal orientation, with blue and green tones representing crystals with the prismatic planes orientated towards the loading direction. Images of the gold droplets were acquired step-wise during compression. In accordance with the deformation of the underlying metal grain, the droplets will move on the imaged surface. The DIC software DaVis converts these relative movements into displacement vectors which can be differentiated to give strain. Areas without strain stay dark blue, while areas of high strain appear in bright blue, up to yellow-red for higher strains. As the strain increases slip lines 1-10μm apart become apparent. Finally, at 8.7% strain, a big area of strain localisation is present, which was identified as a deformation twin from the EBSD map after the test. The ex-situ EBSD microstructure maps represent the microstructural evolution from a bigger area: they are not appropriate to represent the slip activity but show therefore the deformation induced twin lamellas. The twins appear red as the basal plane points towards the loading.

It is thought that the interaction between slip localization and deformation twinning is key to obtaining strong alloys with good ductility and with high resolution strain mapping we can study the mechanism as it happens and understand how it is affected by alloy compositions.

Acknowledgements: TIMET (Sponsor) with special thanks to Matthew Thomas.

Publications: A. Fitzner , D. G. L. Prakash, J. Qunita da Fonseca, M. Preuss, M. Thomas, S.Y. Zhang, J. Kelleher, The effect of Aluminium on deformation by twinning in alpha titanium (Conference Proceeding), J.Analytical, Computational, and Experimental Inelasticity in Deformable Solids, NEAT, 2013, pp. 4-6

A. Fitzner, D. G. L. Prakash, J. Qunita da Fonseca, M. Preuss , M. Thomas, S.Y. Zhang, J. Kelleher, The effect of aluminium on deformation and twinning in alpha titanium: The 45° case (Conference Proceeding), J. Materials Science Forum, 765, 2013, pp. 549-553

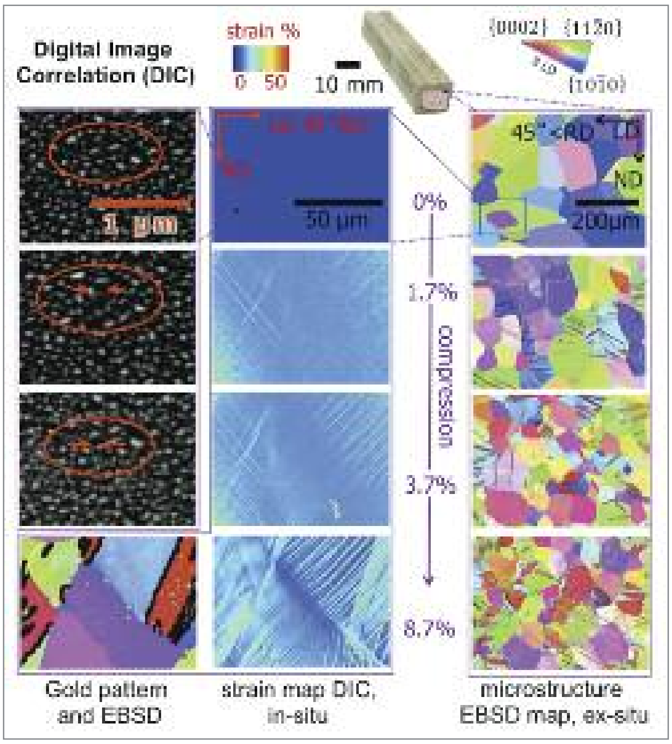


Fig. 1 Starting with a nano-scaled gold pattern (left), used for digital image correlation to evaluate strain localisation (middle) with increasing compressive deformation, which relates to microstructure (right)) development during uniaxial compression.

Improving the Quality of Magnesium Castings using Modelling and 3-Dimensional Imaging

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Magnesium alloys are increasingly being considered for critical structural parts in aerospace and automotive applications due to the weight saving potential associated with their use in place of aluminium or steel. Key to realizing this potential is the development of processing methods that reliably produce components that are free from internal defects that could produce premature failure. The magnesium industry is increasingly making use of non-destructive testing methods such as ultrasonic inspection to ensure that as-cast magnesium billets can meet the stringent requirements demanded by aerospace industry regulation. At present this results in scrapping a large number of defect containing billets, which adds a significant and undesirable penalty to the alloy production cost. A key difficulty is that little is understood about the nature and source of the defects that lead to failure during ultrasonic inspection.

The purpose of this work was to use 3-dimensional imaging methods such as X-ray tomography and serial sectioning to understand in detail the nature of the defects that form in magnesium alloy castings, and then use modelling and targetted experiments to improve the processing to reduce the incidence of such defects.

Material containing defects, as identified by ultrasonic inspection, was isolated and examined using 3-dimensional X-ray tomography across a range of length scales. A tomography image of one of the larger defects inspected is shown in Figure 1. It was found that these defects consisted of two main features; an entrained oxide film surrounded by an agglomeration of large intermetallic particles which were identified by EDX analysis as insoluble Al-Mn phase (Al8Mn5). Serial sectioning using focussed ion beam milling (FIB) revealed further details, showing that the oxide films contained trapped pockets of gas (Figure 2); it is these trapped pockets that lead to a strong signal response in ultrasonic inspection.

A study of the liquid metal filtering used in the casting process and a simulation of the metal flow (Figure 3) and intermetallic evolution was used to understand the origins of the defects during casting. It was demonstrated that the agglomeration of the oxide and coarse intermetallics, which is particularly undesirable, was produced by a trawling effect as the oxide circulates in the melt pool. The model was used to develop a better casting procedure that provided an improved metal flow path. This was tested and demonstrated to greatly reduce the incidence of oxide becoming trapped, and thus significantly reduce failure rates at ultrasonic inspection.

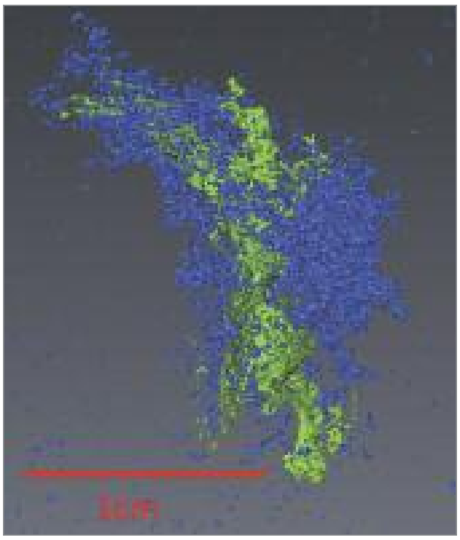

Fig. 1 X-ray tomography image showing a large defect in a magnesium alloy casting. Green regions indicate entrained oxide film, blue indicates large Al8Mn5 intermetallic particles

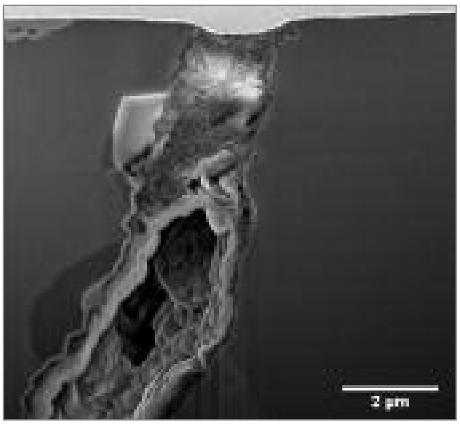

Fig. 2 Slice from serial sectioning experiment revealing a gas pocket trapped between oxide films in a magnesium casting

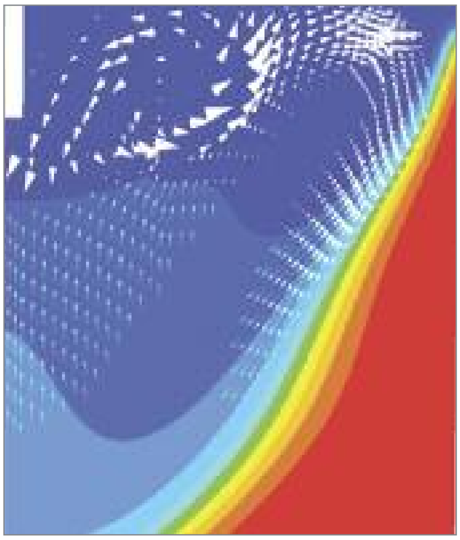

Fig. 3 Simulation of liquid metal circulation in the sump during casting showing velocity vectors

Acknowledgements: This LATEST2 associated project was performed through the EngD centre for advanced manufacturing and processing with support from Magnesium Elektron.

Publications D. Mackie, J. D. Robson, P. J. Withers, and M. Turski, Analysis of Casting Defects in Magnesium-Aluminium-Zinc Direct Chill Castings by X-Ray Tomography, Proc. Magnesium Alloys and their Applications, TMS, 2012

D. Mackie, J. D. Robson, P. J. Withers, M. Turski, T. Wilks, Study of Defects in Direct Chill Magnesium Castings Using X-Ray Tomography, EuroMat 2011, Montpellier, France, 12-15th September 2011

Control of Twinning in Magnesium Alloys Using Precipitates

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Poor low temperature formability and tension/compression asymmetry are often observed in wrought magnesium products and are detrimental to performance. The origin of these effects is now well understood, and is due to the large differences in critical resolved shear stress (CRSS) for the deformation systems operating in the hexagonal crystal. As a result the strength in directions in which easy deformation modes (basal slip and {10-12} c-axis tension twinning) can be activated is low compared to strength in directions where the resolved shear stress for these systems is low.

One potential method to reduce asymmetry and increase formability is to directly suppress twinning by strengthening this deformation mode, whilst promoting alternative slip deformation modes. The current work explores the potential to use precipitates to achieve this objective. On a fundamental level it also aims to better understand the interactions between precipitation and twinning in hexagonal (hcp) metals, a subject that has to date received little attention in the literature but is critical to the performance of most commercial hcp alloys.

In this work, magnesium alloys known to form precipitates of different shape and habit were tested before and after precipitation treatment to study the effect of precipitation on asymmetry and explore in detail how precipitates and twins interact. It was shown (Figure 1) that precipitation in some alloys (e.g. AZ91) leads to a reduction in asymmetry, whereas in other alloys (e.g. Z5) precipitation increases asymmetry. Detailed microscopy was used to explore how precipitates inhibit twin growth Figure 2 shows an example of a basal plate precipitate in AZ91 entering a twin and becoming elastically bent, which introduces an additional back stress inhibiting propagation of the twin.

Based on this understanding a model was developed to predict which precipitates are most effective at reducing asymmetry whilst also increasing alloy strength. The model can be used to produce strengthening maps (e.g. Figure 3) that can be used to predict the precipitate balance needed to meet given property goals.

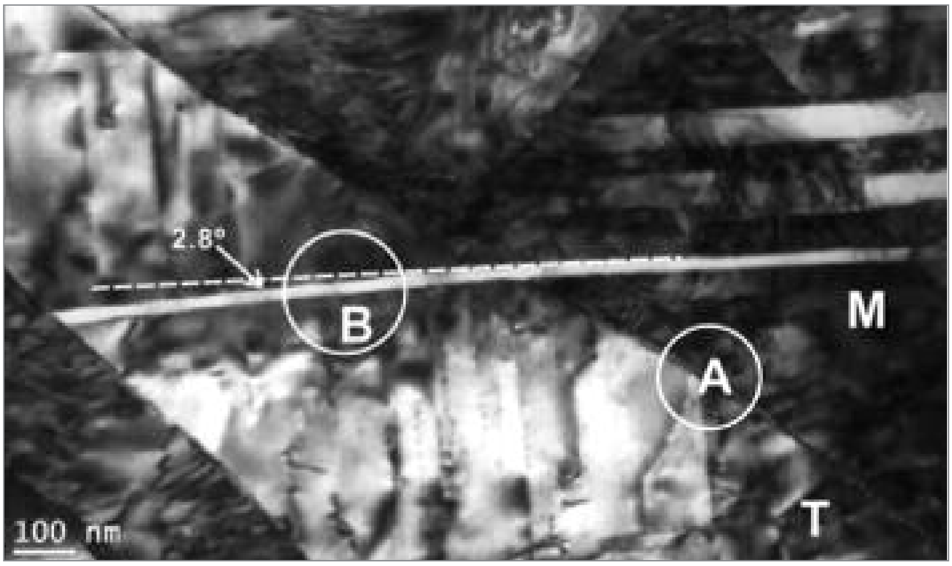

Fig. 1 TEM micrograph showing a plate shaped precipitate in the matrix (M) entering a twin (T) and becoming deflected due to the imposed shear.

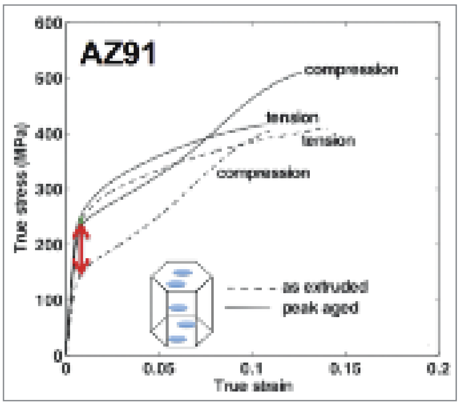

Fig. 2 Stress-strain curves of AZ91 extrusion tested in compression and tension. In the precipitate free case, the compressive strength is low due to twinning leading to a high level of mechanical asymmetry. After precipitation, twinning is suppressed and asymmetry reduced.

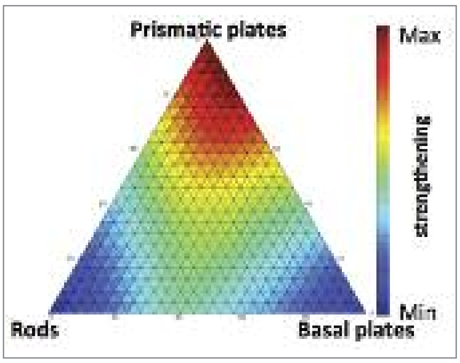

Fig. 3 Model predicted strengthening map showing the effect of different mixtures of the three main precipitate types observed in magnesium

Acknowledgements: This work was carried out with the support of a Global Research Fellowship from the Royal Academy of Engineering (JDR).

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"I enjoy the creative aspects of undertaking academic research."

Heike Krebs, PhD Student

JOINING ADVANCED ALLOYS AND DISSIMILAR MATERIALS

Theme 2's main aim is to develop the underpinning metallurgical science required to support cost effective routes for joining advanced high strength light alloys and multi-material structures. Key areas requiring solutions include; the poor weldability of high strength alloys, interfacial reaction between dissimilar metals, thermal damage, distortion and residual stress, as well as the issues associated with manufacturing metal-composite hyper joints. Theme 3 will also contribute through improving the knowledge of tailoring oxide films on metal surfaces for improved adhesion and investigating the protection of dissimilar material joints, where galvanic coupling is a major issue.

The dissimilar metal combinations required by industry, e.g. Al-steel, Mg-Al, Al-Ti, are very difficult to join by traditional fusion welding methods. We have thus focused on low energy friction joining processes for dissimilar metal combinations and advanced surface engineering to facilitate adhesive bonding and composite to metal joining (Theme 3). Solid state friction welding techniques are highly efficient and have the advantage of far greater weldability and reduce the risk of interfacial reaction when welding dissimilar materials. New advances in welding technology with proven potential for success are being targeted, such as friction stir spot welding (FSSW), and high power ultrasonic spot welding (USW), in conjunction with selected fusion welding techniques such as laser conduction spot and conventional laser seam welding.

A key aspect of the theme is to develop models to predict the microstructure and mechanical behaviour of welds in high-performance multicomponent alloys. We are also trying to better understand the factors that affect the metallurgical interactions between dissimilar metals in welding, so that we can use thermodynamic principles to help inhibit detrimental interactions, such as the formation of brittle intermetallic layers at the weld interface.

The research has been targeted at under pinning the following application areas:

- Energy efficient joining of Mg and Al in automotive bodies,
- Friction welding advanced alloys for aerospace structures with new welding techniques
- Friction welding dissimilar metal combinations requiring control of bond formation and interfacial reaction (e.g. Al to galvanised steel, Ti to Al)
- Low heat input laser welding light alloys and dissimilar metals
- High performance metal-composite joints; facilitated by manufacturing mechanical locking features on the metals surface to increase shear transfer (so called hyper-joints)
- The surface engineering to facilitate adhesive bonding (theme 3)
- Modelling joint performance through linking process models to microstructure and weld zone property predictions.
- Microstructure optimisation of additive layer manufacturing higher performance aerospace components

Professor Philip B. Prangnell
LATEST2 Deputy Director
Theme Leader and Co-Investigator
Chair in Materials Engineering
The University of Manchester and
Co-Director of the Metallic Systems
Doctoral Training Centre in Metallurgy

Phil Prangnell joined the Manchester Materials Science Centre (then part of UMIST) in 1992 after completing his PhD in Metal Matrix Composites at Cambridge University. He was promoted to a chair in Materials Engineering in 2005 and is currently leader of the Engineering and Process Metallurgy group in the School of Materials at Manchester. He has been an active member of the light alloys group for 20 years and is Co-director of the Metallic Systems Doctoral Training Centre in Metallurgy with Sheffield University as well as deputy Director of LATEST2.

His research activities are focused on studying advanced thermomechanical processing and joining techniques for light alloys (mainly aluminium and titanium). In particular, he is interested in understanding and modelling interactions between phase transformations, deformation microstructures, and industrial processes. He has worked extensively with the aerospace industry on developing welding techniques for aerospace alloys.

In recent years his welding research had focused on joining dissimilar metals and friction welding, as well as variations on the friction stir welding process (e.g. FSSW, static shoulder FSW, USW etc.). He is also actively engaged in understanding relationships between microstructure and properties in additive manufacturing. He has worked on other areas of aerospace manufacture, such as creep-age forming, and has a long-standing interest in ultra-high strain deformation.

He has on going collaborations with major aerospace companies, including EADS, Airbus, BAE Systems, as well as companies within the supply chain (e.g. Constellium, Siemens, GKN). He has a range of collaborations with the automotive sector and is also working with DSTL and BAE Land systems on aluminium intensive fighting vehicles.

Surface Engineering Metal - Composite Hyperjoints

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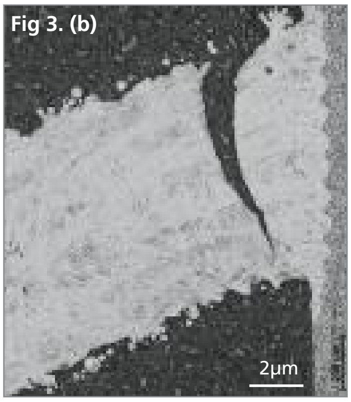
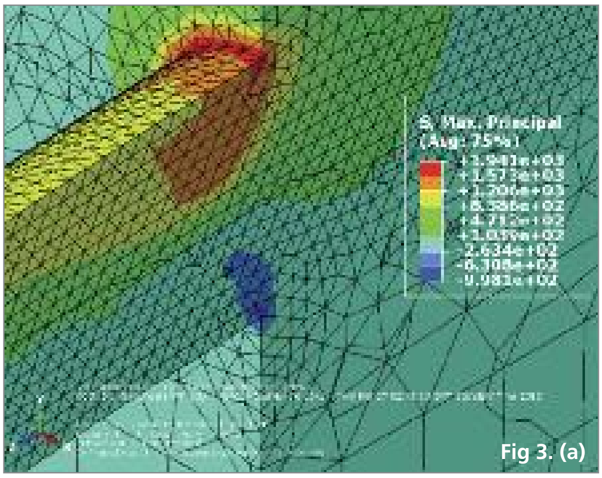
The use of composites is increasing in advanced civil airframe designs to improve fuel efficiency. However, metallic materials, and in particular titanium alloys, still feature strongly where a higher temperature capability or multi-axis loading is required. For example, the new A350XWB ‘composite’ aircraft is actually a multi-material design and contains over 40% metallic structure. Producing reliable joints between high performance titanium alloys and composite components is challenging because of their very different chemical and physical properties and there is a need to improve load transfer efficiency and move away from the reliance on fasteners, which create bearing issues in composite laminates. At the same time, adhesive-only metal-composite joints currently do not have a long enough safe design life, or load transfer capability without a large overlap area, which increases weight.

Recently, a new class of joints has emerged in which both mechanical and adhesive bonding elements are integrated into one design. With this approach, arrays of locking features are engineered on to the metal part that are imbedded into the composite laminate to increase the shear transfer, via both better adhesion and mechanical ‘fit’, through the thickness of the laminate. Such hybrid joints have become known collectively as ‘hyperjoints’ and can greatly improve the joint strength and failure energy.

A typical hyperjoint design requires the ability to reliably manufacture arrays of small pins (typically ~ 1 mm diameter) with an accurate geometry on a titanium substrate (Figure 1). In partnership with the European Aeronautic Defence and Space (EADS) Company, within LATEST2 we have been exploring methods of assessing the quality and predictability of the failure load of hyperpins manufactured by different techniques, so that an industrially viable process can be identified for their full-scale manufacture. Approaches that have been explored, to date, include electron beam surface sculpting (Surfi-Sculpt®) laser additive manufacture (AM), and micro-welding technologies that can be used to attach pre-forged pins sufficiently rapidly for industrialisation. Such methods can have drawbacks including restrictions in the pin shape (Surfi-sculpt) and slow production rates (AM). In LATEST2 we have studied the metallurgical issues associated with each approach, including the critical area between the base of the pins and component substrate (Figure 2) where there is usually a sharp microstructural gradient. Methods have also been developed to test and model the performance of individual pins (Figure 3), as well as to study the damage that develops in a laminate joint assembly under load using the 3-D imaging X-ray Computed Tomography (XCT) facilities in the Manchester X-Ray Imaging Facility (MXIF). Within Theme 3 on surface engineering, work is also ongoing to understand how to use electro-chemical treatments more effectively to tailor titanium surface oxide film pore structures to improve adhesion on metal surfaces.

A potentially viable manufacturing route has now been identified and plans are afoot to expand this activity to investigate the issues associated with scaling up the technology for industrial application.





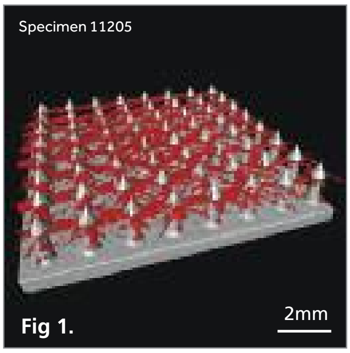


Fig. 1 X-ray microtomography image showing the hyper-pin array in a loaded lap joint with the development of damage in the composite indicated in red.

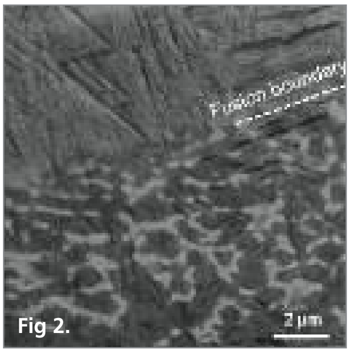


Fig. 2 High resolution SEM image showing the microstructure variation across the melt pool fusion boundary of a ‘welded on’ hyper-pin with a Ti64 rolled plate substrate.

Fig. 3 (a) FE model of an individual hyper-pin under shear load, and cracking in LSM additive manufactured pin during shear testing, **(b)** optical image and **(c)** α phase EBSD map, with prior β grains outlined.

Partners: EADS Innovation works, TWI

Acknowledgements: Mr R. J. Oluleke (EADS- PhD Student), Dr. Fabien Leonard (MXIF)

Publications: R. J. Oluleke, D. Strong, O. Ciuca, J Meyer, A. De Oliveira and P. B. Prangnell, Mechanical and Microstructural Characterization of Percussive Arc Welded Hyper-Pins for Titanium to Composite Metal Joining, in LMT2013, 6th Int. Symp. on Light Metals Technology, Mat Sci Forum, 765 (2013) pp 771-775.

Optimisation of Ultra-Short Cycle Friction Stir Spot welding

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Friction stir spot welding (FSSW) is a low heat input solid state process highly suitable for joining difficult-to-weld high strength aluminium alloys and for forming joints between dissimilar materials. However, the standard process has not been widely adopted in the automotive industry due to a number of perceived problems, which include too long a weld cycle time and the formation of a 'key hole' that causes cosmetic issues and weakens the joint. Recent research in LATEST2 has used a range of techniques, including 3D tomography, to gain a better understanding of the material flow, as well as thermal and microstructure modelling, to try to optimise the process for forming rapid welds in thin aluminium sheet.

This work has shown that the pin on the tool is not necessary in thin sheet welding. By removing the pin from the tool, we have demonstrated that it is possible to weld faster, simplify the process, and solve the keyhole issue. We have also evaluated the Refil™ variant of FSSW developed by HZG, which employs a two part tool that refills the hole as part of the weld cycle. By adopting the same systematic approach, we have shown that high quality welds can be produced within 1 second using the simple pinless tool and within 0.5 seconds with the Refil method. The welds are defect free and show full nugget pull-out-failures. As an added advantage the rapid welding cycle leads to no heat affected zone and after a paint bake cycle the welds become stronger than the parent material, due to the effect of the shorter natural ageing time of the weld zone on the artificial ageing kinetics. The properties of the optimised short cycle friction welds compare very favourably to those of conventional joining techniques such as SPR (Self Piercing Rivets) and RSW (Resistance Spot welding)

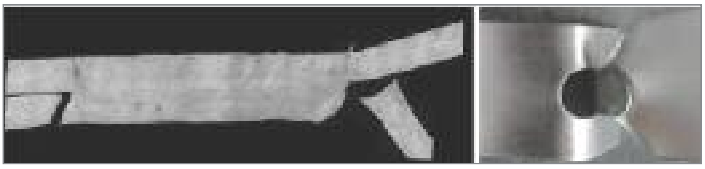

Fig. 3 Failure behaviour of a FSSW-Refil weld produced in 0.55 seconds, from 6111 1 mm thick sheet, during lap shear testing.

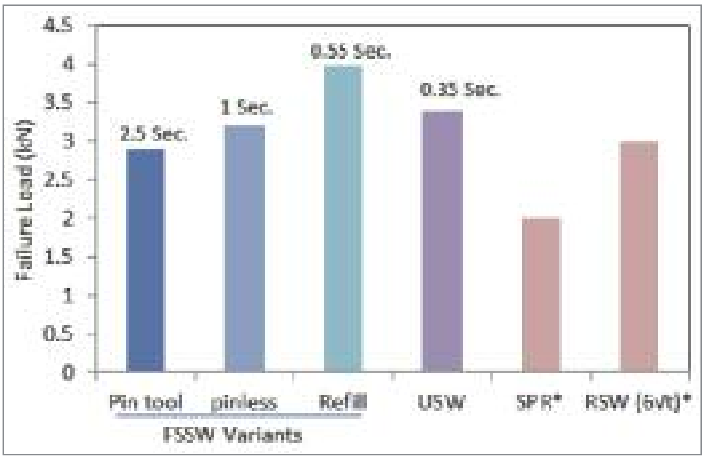

Fig. 4 Comparison of the lap shear test failure loads recorded, for conventional FSW, FSW with a pinless tool (developed in latest) and the FSSW-Refil method to benchmark data for USW and SPR* and RSW*

*Data taken from * L. Han et al. Materials and Design 31 (2010)

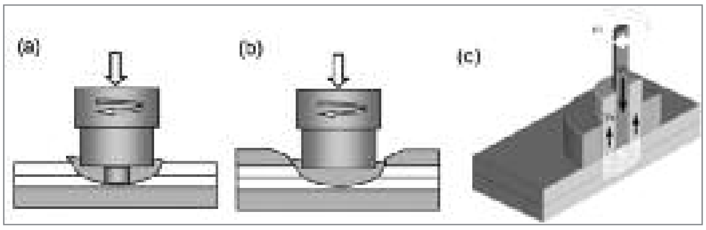

Fig. 1 Schematic diagrams of the (a) conventional FSSW, (b) Pinless FSSW and (c) Refil FSSW processes.

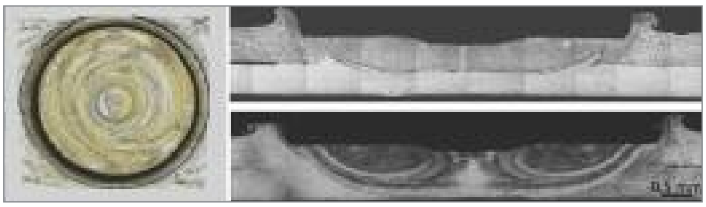

Fig. 2 Examples of flow studies of FSW with a pinless tool.

Partners: Jaguar Land Rover

Acknowledgements: Dr. Y. C. Chen, Mr B. Al-Zubaidy (PhD Student)

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Assessment of the Advantages of Static Shoulder FSW for Joining Aluminium Aerospace Alloys

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Friction Stir Welding (FSW) is now a well-established process that is widely used to join aluminium alloys owing to the excellent weld properties that can be obtained. The technology was originally developed in the UK by the The Welding Institute (TWI) and involves translating a rotating tool along the join line between two butted plates, which forges the two weld members together without melting. Stationary (Static) Shoulder Friction Stir Welding (SS-FSW) is a new variant of FSW that was developed to improve the weldability of titanium alloys because the low thermal conductivity of titanium results in the rotating tool shoulder creating a severe temperature gradient through the plate thickness. However, it could be envisaged that with all materials SS-FSW would be advantageous when welding thicker gauges. This is because in conventional FSW heat is generated predominately under the tool shoulder and with thicker material it is not normally possible to maintain a high enough temperature at the base of the weld to avoid pin failures unless a low travel speed is used. Furthermore, SS-FSW can provide several additional advantages over the conventional method: i) a non-rotating shoulder irons the surface and leads to an improvement in surface quality (Figure 1); ii) the shoulder acts as a heat sink rather than a source so that the heat distribution becomes narrower at the top surface and more symmetric about the plate mid-plane (Figure 2-3) which leads to narrower welds with a reduced heat affected zone width, as well as lower levels of distortion. However, with a conventional tool the power generated by the pin at a fixed rpm is typically only 20-30% of that of the tool shoulder so that the same welding conditions are not appropriate for both processes.

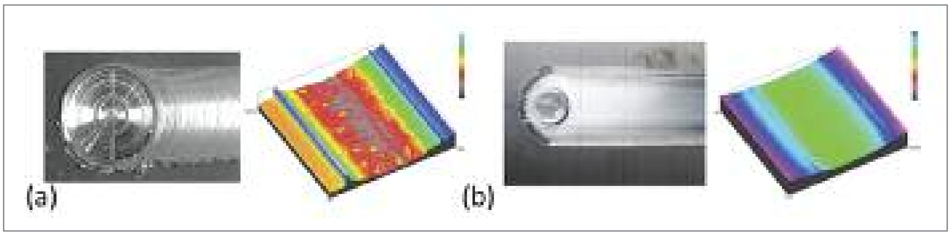

Fig. 1 Comparison of the difference in surface roughness between (a) conventional FSW and (b) static shoulder FSW.

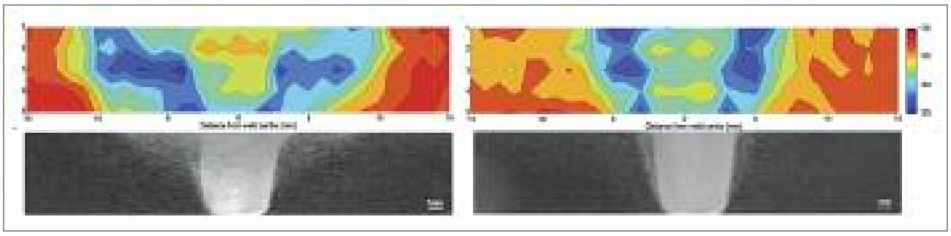

Fig. 2 The difference in HAZ profile for the two processes variants ((a) FSW, (b) SS-FSW) under optimised conditions.

Surprisingly, despite these clear advantages static shoulder FSW has largely been ignored by the aluminium welding community. In LATEST2 we have thus developed a systematic approach for comparing the two processes when applied to joining high strength aluminium aerospace alloys. The approach we adopted was to use an identical shoulder and pin geometry for each method and to first understand and model the relationship between the heat input and the welding parameters, so that both processes can be compared using a rational selection of welding conditions. Modelling has also been used to fit the thermal field for each process and predict the systematic effect of varying the contribution of the shoulder on the HAZ shape. We have also studied the surface finish that can be achieved and the formation of weld defects that can be specific to the SS-FSW process.

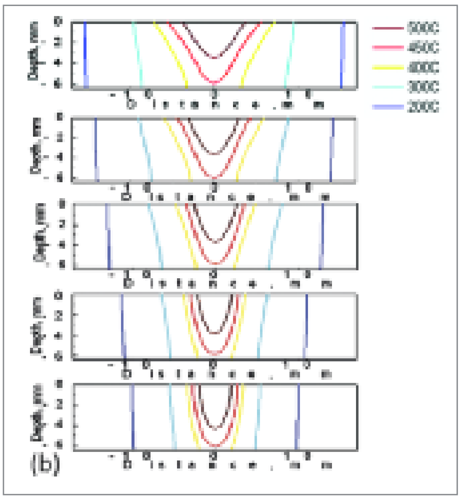

Fig. 3 Thermal model showing the effect of reducing the shoulder power input while increasing the probe power to maintain the same weld temperature near the weld root.

Acknowledgements: Mr H. Wu (PhD Student), Dr Y. C. Chen

Publications: H. Wu, Y. C. Chen, D. Strong, and P. B. Prangnell, Assessment of the Advantages of Static Shoulder FSW for Joining Aluminium Aerospace Alloys, Thermec, Las Vegas, USA, December 2013 – in press

Critical Assessment of Welding Techniques for Dissimilar Joining of Aluminium to Steel

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The University of Manchester

New design concepts for light weight vehicles will increasingly involve multi-material structures, as they provide the best compromise solution between mass reduction, performance, and cost. Such designs allow materials to be used more efficiently and will involve combining light alloys with high strength steels and composites. Dissimilar joining is thus a key technology area for enabling increased fuel efficiency in transport.

Within LATEST2 we have taken an objective fundamental look at a range of welding technologies that could potentially be used for joining steel to aluminium. This work has focused on solid state processes, or processes with rapid thermal cycles to try to reduce the tendency for intermetallic (IMC) reaction at the joint interface, which is the main limiting factor in producing joints with acceptable failure energies. Examples of the processes studied to date include; ultrasonic spot welding (USW), variants of friction stir spot welding (FSSW), and laser conduction spot welding. Ongoing work in the team is also directed at gaining a better understanding of IMC reactions in rapid dissimilar metal welding so that modelling tools and solutions can be evaluated for reducing the reaction rate in parallel with process developments.

A full range of techniques has been used to better understand the reaction behaviour, defects formed and, in the case of solid state welding, the material flow and bonding process; including 3D tomography, modelling and high resolution microscopy of the weld interfaces. With laser spot welding it has been shown that is very difficult to control the IMC layer to a thin enough level. There are also distinct problems when welding coated steels due to evaporation of the zinc. Friction based solid state processes appear more promising, but forming a reliable bond between a hard steel surface and a soft flowing aluminium alloy has been found to greatly increase the weld cycle time, which also allows significant IMC reaction to take place. This occurs because flow studies have shown that the aluminium sheet tends to develop a sticking condition on the steel surface at an early stage in welding and as result there is little relative motion of the two materials across the interface. There is thus little benefit in terms of cleaning oxide off the steel surface and the joining mechanism is principally one of diffusion bonding, facilitated by frictional heating. There is also an issue with galvanised steels due to the low melting point eutectic reaction between aluminium and zinc, which creates a liquid film at the join line, leading to weld defects. As a result of the fundamental studies performed within LATEST2, one possible solution has immerged that has been termed 'abrasive circle welding'. This technique involves adapting the friction stir spot welding technique to use a slight orbital path, so that the tool probe lightly abrades the steel surface over a circular area to produce an oxide free surface during the welding cycle. This process has allowed successful welds to be produced between steel and aluminium with a very rapid weld cycle of less than one second, which greatly reduces IMC growth and, as a result, weld failure energies equivalent to that of aluminium-aluminium joints have been achieved. With the same approach, successful dissimilar welds have also been demonstrated on galvannealed zinc coated steel sheets.

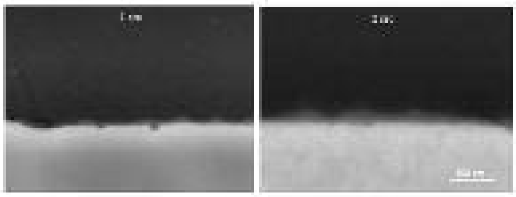

Fig. 1

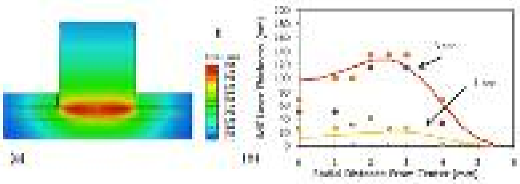

Fig. 2

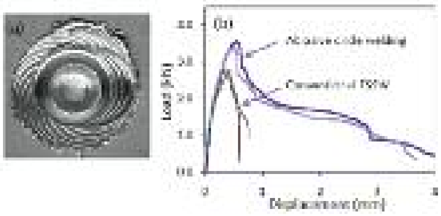

Fig. 3

Fig. 1 Development of a thin IMC reaction layer in a conventional FSSW between steel and aluminium with increasing welding time.

Fig. 2 (a) Predicted weld temperature distribution (courtesy of H. Shercliff Cambridge Engineering) and (b) corresponding IMC reaction layer thickness across the weld interface in an Al-steel FSSW.

Fig. 3 (a) Surface appearance of an abrasive circle friction spot weld between Al and steel and a comparison of the lap shear test load displacement curves with that from a conventional FSSW.

Partners: Jaguar Land Rover

Acknowledgements: Dr. H. Shercliff (Uni. Cambridge Engineering) Dr. S. Ganguly (Uni. Cranfield) Dr F. Haddadi (PhD Completed Student), Dr Y. C. Chen (Latest RA), Mr Lei Xu (PhD student)

Publications: Y. C. Chen, A. Gholinia, P. B. Prangnell, Interface structure and bonding in abrasion circle friction stir spot welding: A novel approach for rapid welding aluminium alloy to steel automotive sheet, Materials Chemistry and Physics, 134 (2012), pp. 459-463

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Predicting Heterogeneity and Defects in Additive Manufacturing

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Additive manufacturing (AM) is an exciting up-and-coming near-net-shape technology that is in the process of being rapidly industrialised for aerospace manufacturing. AM is extremely attractive to the aerospace industry as it allows great design flexibility, reduces lead times, and most importantly greatly reduces the amount of machining required to produce components made out of expensive and difficult to machine materials like titanium alloys. For example, the buy-to-fly ratio for a typical titanium component machined from forged billet is 10 - 20:1 compared to 2 - 7:1 when manufactured by AM. A range of AM platforms are available from laser and electron beam powder bed, to blown powder and wire based systems, such as plasma or laser wire deposition. These systems vary in resolution (layer height) and the deposition rate and size of components that can be built. There is thus a trade-off between precision and component scale; i.e. laser powder bed is most suitable for complex high precision, but small (typically less than 0.5 m), components, whereas plasma wire deposition can be used to produce large less complex parts (over 10 m in length). Although a lot of work has been done to develop these technologies surprisingly little work has been devoted to understanding the materials issues they present, particularly in terms of their microstructure and property variability, which is a key issue for qualification.

In AM the material solidifies in a small moving melt pool, and material is built up with many overlapping raster tracks, leading to very high solidification and cooling rates and a complex cyclic thermal history. The microstructures produced are thus novel and their deformation behaviour and response to fatigue loading is still poorly understood at a fundamental level. Furthermore, the microstructures tend to show heterogeneities, such as banding, due to the variable temperature experienced during layer deposition and can be sensitive to the raster pattern, or the build strategy used and the part geometry. The small melt pool solidification conditions in AM also tend to promote very coarse directional primary grain structures, particularly in titanium alloys. In addition, defects such as porosity are often observed, particularly in powder-based systems.

LATEST2 is heavily involved in developing an improved understanding of AM materials and their mechanical performance. As a first step, we are developing automated tools to quantify and map the defect content, microstructure, texture and its heterogeneity within a component, to facilitate a better understanding of the relationship to the process variables e.g. what happens when there is a local change in section thickness? We are also developing the capability to understand how this affects the materials' mechanical behaviour at a fundamental level; for example, how defects, local texture and microstructural variation affect crack propagation under fatigue loading, and in the long term we hope to develop models to predict the microstructure in AM processes.

Fig. 1 A geometrically optimised design for a hinge bracket produce by AM (Coutesy of EADS).

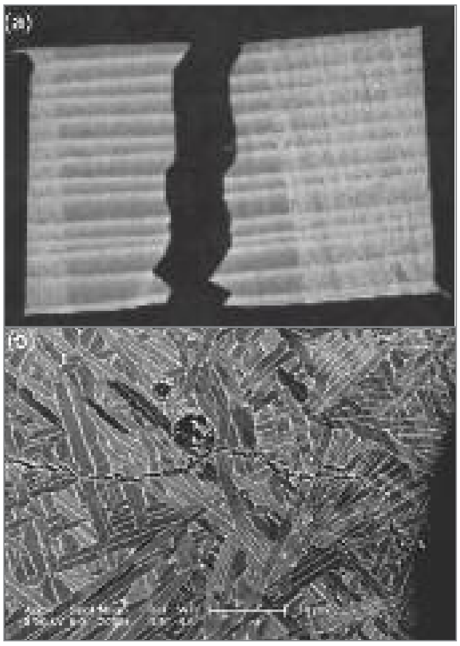

Fig. 2 (a) Effect of microstructural banding on macroscopic fatigue crack growth and (b) an example of a crack connecting a pore through the complex Widemanstätten – colony alpha transformation microstructure found in a titanium 64 Wire-Arc titanium deposit.

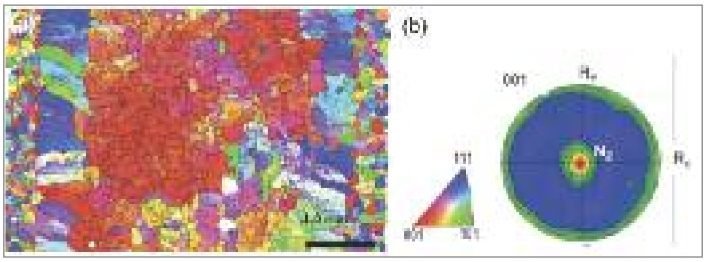

Fig. 3 IPF contrast EBSD map (a) of the reconstructed β grain structure seen in a cross section a Ti64 AM component, produced by through an electron beam powder bed procures, showing the different grain structure in the section outline contour pass compared to that generated by infill hatching. Note the strong <001>β fibre texture (red) in the bulk of the part – accompanying pole figure (b).

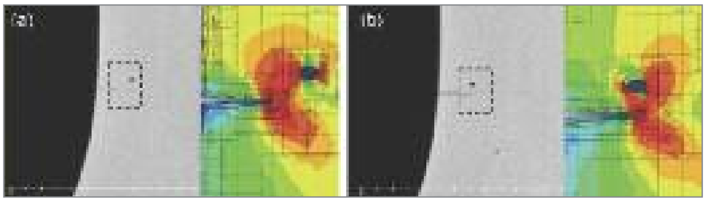

Fig. 4 3D X-ray tomography of a crack growing in a fatigue sample and an FE model constructed of the actual crack – directly from the tomography data – to see how crack growth is affected by pores present in an electron beam powder bed produced test sample.

Partners: Airbus, UK, EADS, Innovation Works, Filton, UK, GKN Aerospace, UK

Acknowledgements: Dr A. Antonysamy (ex EADS-PhD Student now at GKN), H. Zhao (PhD student) S. Tamas-Williams (RRs- PhD student)

Publications: A. A. Antonysamy, J. Meyerb, P. B. Prangnell, Effect of build geometry on the β-grain structure and texture in additive manufacture of Ti6Al4V by selective electron beam melting, Materials Characterization, 84 (2013) 1pp. 53–168.

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Dr Joseph. D. Robson
LATEST2 Co-Investigator
Reader
The University of Manchester

Joe Robson graduated in Natural Sciences from the University of Cambridge in 1993, and obtained his PhD from the same institution in 1996. Since then he has worked at Cambridge, Swansea, and Manchester universities, and in 2003 was appointed to a Lectureship, becoming a Senior Lecturer in 2007 and Reader in 2012. Joe is a Co-investigator on the EPSRC LATEST2 Programme Grant and a member of the Light Alloy Processing group with research interests that are focussed on microstructural evolution and control in industrial alloys, with an emphasis on modelling.

Current work involves the coupling of thermodynamic models, based on Calphad methods, to novel kinetic models, enabling the time and temperature dependence of microstructure to be determined for complex industrial alloys and processes. Such an approach is being used to predict microstructure evolution and subsequent effect on properties for a range of aluminium, magnesium, and zirconium alloys during processes such as hot rolling and welding. Applications for these materials include the automotive, aerospace, and nuclear industries. Joe also has a major activity in understanding and controlling microstructure, texture, and twinning in magnesium alloys to improve the performance of these alloys; for example to improve formability or increase strength.

Joe also has an active interest in developing a better understanding of the effects of processing and service on the microstructure of metals through the use of electron microscopy and other advanced analytical techniques. Ongoing work includes investigating microstructural evolution during solid state dissimilar metal welding, laser welding of aerospace aluminium alloys, and processing of magnesium and aluminium alloys. Joe's work involves close collaboration with a range of industrial partners including Magnesium Elektron, Novelis, Constellium, Alcoa, and BP plus international research centres including Helmholtz Zentrum Geesthacht and Deakin University, Australia.

Modelling and Controlling Interfacial Reaction in Dissimilar Metal Welding

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Multi-material structures are required to best exploit light metals, allowing different alloys with optimized properties to be used for different components. Such structures require joining, and solid-state welding methods such as friction stir welding and ultrasonic welding are attractive candidate processes. Experimental studies carried out within LATEST2 Theme 1 have investigated the feasibility of using these methods to perform dissimilar metal joining between a range of aluminium, magnesium and titanium alloys as well as joining of these metals to steels.

The experimental work has revealed that the key to improving the mechanical properties (and in particular the toughness) of dissimilar metal joints is controlling the formation of brittle intermetallic phases that are produced by the reaction between the dissimilar metals at the interface. It has been revealed that the thickness of the reaction layer on process conditions, but also depends on the base alloy composition. This suggests there is potential not only to optimize process conditions to control reaction, but also to design alloys specifically tailored for dissimilar metal joining.

To understand the effect of processing and alloy chemistry on intermetallic formation during dissimilar metal welding and to enable rapid assessment of potential solutions to control interface reaction, an integrated modelling approach is being developed. This work is a collaboration between Cambridge University Engineering Department, who are providing expertise on modelling of solid state welding processes, and LATEST2 who are developing the interface reaction and property models.

The process model takes the weld geometry and process conditions as inputs and outputs information such as the thermal and strain rate history for any region of the weld. These outputs are used as inputs to the interface reaction model, which itself consists of several components to model all of the physical processes that occur during welding. Figure 1 shows the steps considered in the model for ultrasonic welding; together these control the final thickness of the intermetallic layer. The necessary material data for such models are derived from multicomponent calculations (using Pandat and JMatPro software) to account for the complex chemistries encountered in real industrial alloys.

Figure 2 shows example outputs from the model for ultrasonic welding applied to the dissimilar joining of an aluminium and magnesium alloy. The model predict each step in the process, and gives a final prediction of intermetallic layer thickness that agrees well with that determined experimentally.

Ongoing work is developing similar models for friction stir welding, and applying such models to design alloy compositions or interlayers to retard interfacial reaction and hence produce a step change improvement in dissimilar weld properties.

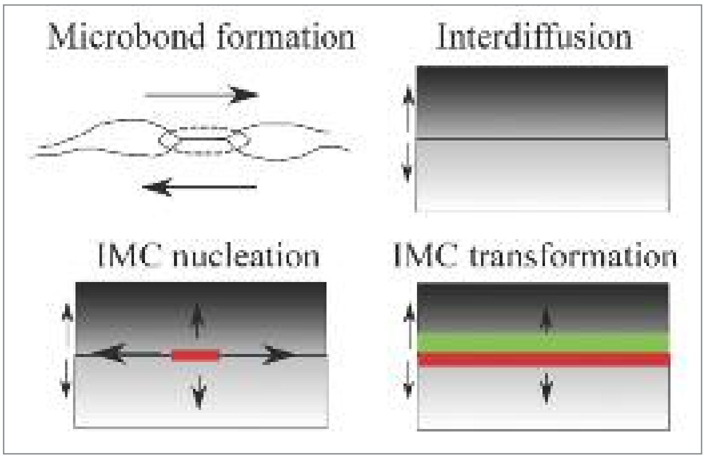

Fig. 1 Sequence of events that occur during intermetallic compound (IMC) formation during dissimilar metal ultrasonic

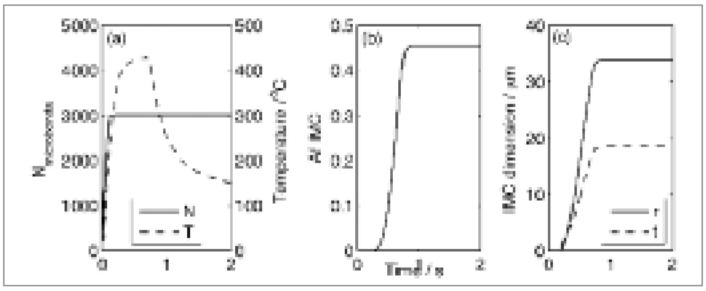

Fig. 2 Example model outputs for a 1s weld. (a) Temperature evolution and number of microbonds. (b) Area fraction of interface covered by intermetallic. (c) Size and thickness of intermetallic regions.

Publications: J. D. Robson, A. Pantelli, P. B. Prangnell, Modelling intermetallic phase formation in dissimilar metal ultrasonic welding of aluminium and magnesium alloys, Science and Technology of Welding and Joining, 17, 2012, p. 447-453

Predicting Stir Zone Grain Size in Friction Stir Welding and Processing

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One advantage of friction stir welding over fusion welding methods is that the weld nugget (correctly referred to as the stir zone) usually shows much improved strength and ductility. Indeed, the properties of a FSW stir zone often exceed that of the parent material, and this is taken advantage of in friction stir process (FSP), where the same technology is used to refine the microstructure rather than produce a joint.

A key reason for the excellent properties of FSW stir zone is the grain refinement that occurs as a result of the local severe plastic deformation. However, the grain size obtained (and hence critical properties) is strongly dependent on both alloy and processing conditions. A model to predict grain size would therefore be of great utility in helping to optimize both alloy and processing conditions to acheive the required level of grain refinement to produce target properties.

In this work, the first physical model for grain size evolution in FSW/FSP has been developed. In this model, a prediction of the local strain rate and temperature history from a process model (e.g. Figure 1) is coupled to a microstructure model that calculates both the formation of new grains (recrystallization step) and the growth of those grains in the hot material trailing the tool. The model for grain refinement is coupled to a precipitate evolution model developed previously (LATEST1). This allows the interaction between precipitation and grain refinement to be predicted. Such coupling is critical to correctly simulate the microstructural evolution in aerospace aluminium alloys during FSP or FSW.

The model has been tested against experimental welds produced at HZG using their innovative FlexiStir system, a FSW machine that sits on a synchrotron X-ray beam line (DESY) allowing in-situ monitoring of the microstructure during welding. The model has been shown to give good predictions to experiement, providing a valuable tool for optimization of FSW and FSP.

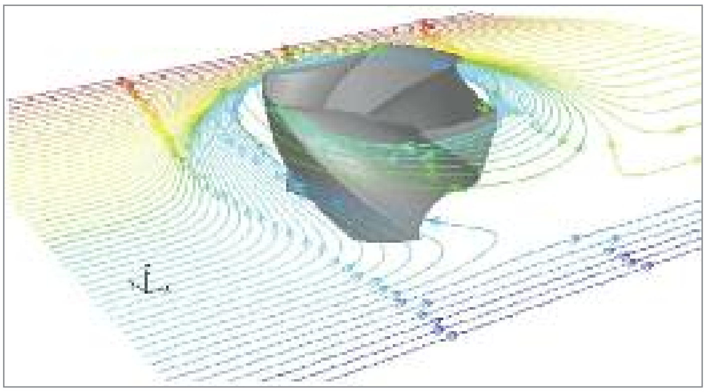

Fig. 1 Predicted flow of material around a friction stir welding tool from a process model. Temperature and strain rate data extracted from this model are used as inputs to microstructure prediction.

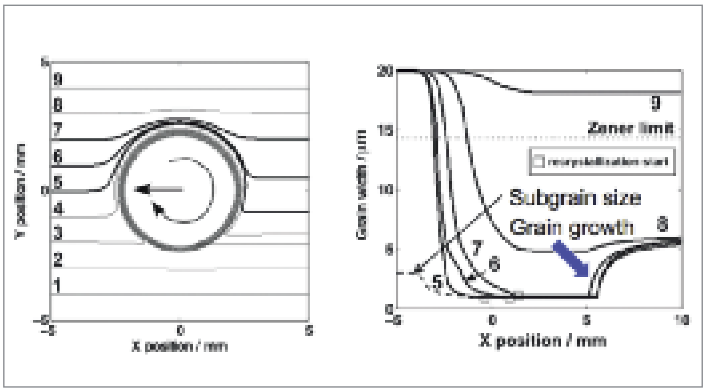

Fig. 2 Predicted material flow lines at increasing distance from the FSW tool (left) and the associated prediction of grain size evolution (right).

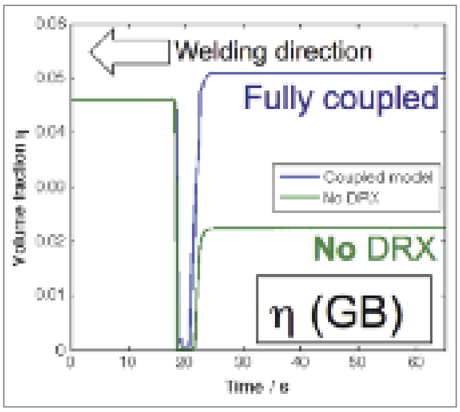

Fig. 3 Prediction of the effect of grain refinement in the stir zone on grain boundary precipitation (7xxx aluminium alloy). Only the fully coupled model that considers dynamic recrystallization (DRX) correctly predicts the large fraction of grain boundary precipitation observed in practice.

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Modelling of Blast Performance of Welded Aluminium Structures in Military Vehicles

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The use of Improvised Explosive Devices (IEDs) on the modern battlefield is widely considered to be a major threat to military land vehicles. Consequently, there is interest in understanding the performance of aluminium armour materials and welded structures subjected to blast and ballistic loading. The performance of joints is of particular interest as they generally represent the weakest points of any structure. Welding processes are energy intensive and generally cause significant microstructural changes owing to the weld thermal cycle. These changes generally result in significant local variation in the material properties across a weld and typically induce localised weakening of the material.

It is the long term objective of research within LATEST2, in collaboration with Defence Science and Technology Laboratory (DSTL), to develop a modelling capability to predict the structural response of welds in advanced aluminium alloys, like 2139, under blast loading. The aim of the project is thus to link process and microstructural models to predict the weld zone static and dynamic properties, which can then be incorporated into an FE model to give the deflection and deformation behaviour of a welded joint under blast conditions. The resultant increased understanding of the relationships between the welding parameters, material properties in the weld zones, and the structural performance of an overall welded panel in blast, sought in the project, will enable design principles to be developed for building safer military vehicles.

Fig. 1 Warrior armoured vehicle

Fig. 2 Failed blast test panel

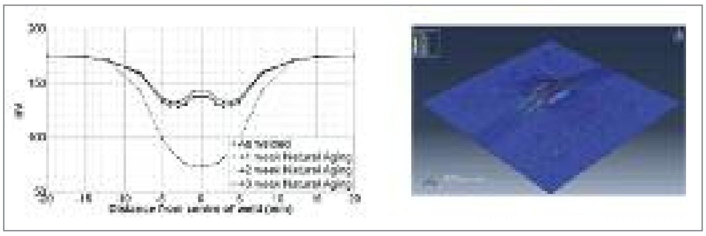

Fig. 3 Model prediction for the hardness distribution across a welded joint as a function of natural ageing time and an FE simulation showing the resultant plastic strain distribution expected across a weld in a blast test.

Partners: DSTL, Constellium, BAE Systems

Acknowledgements: Mr J. Draup (PhD Student), Dr Y. C. Chen

Publications: A. J. Awang Draup, J. D. Robson, P. B. Prangnell, M. J. Lunt, Modelling of blast performance of welded aluminium structures in military vehicles manufactured by friction stir welding, LightMat 2013, Bremen Germany, 3-5 September 2013.

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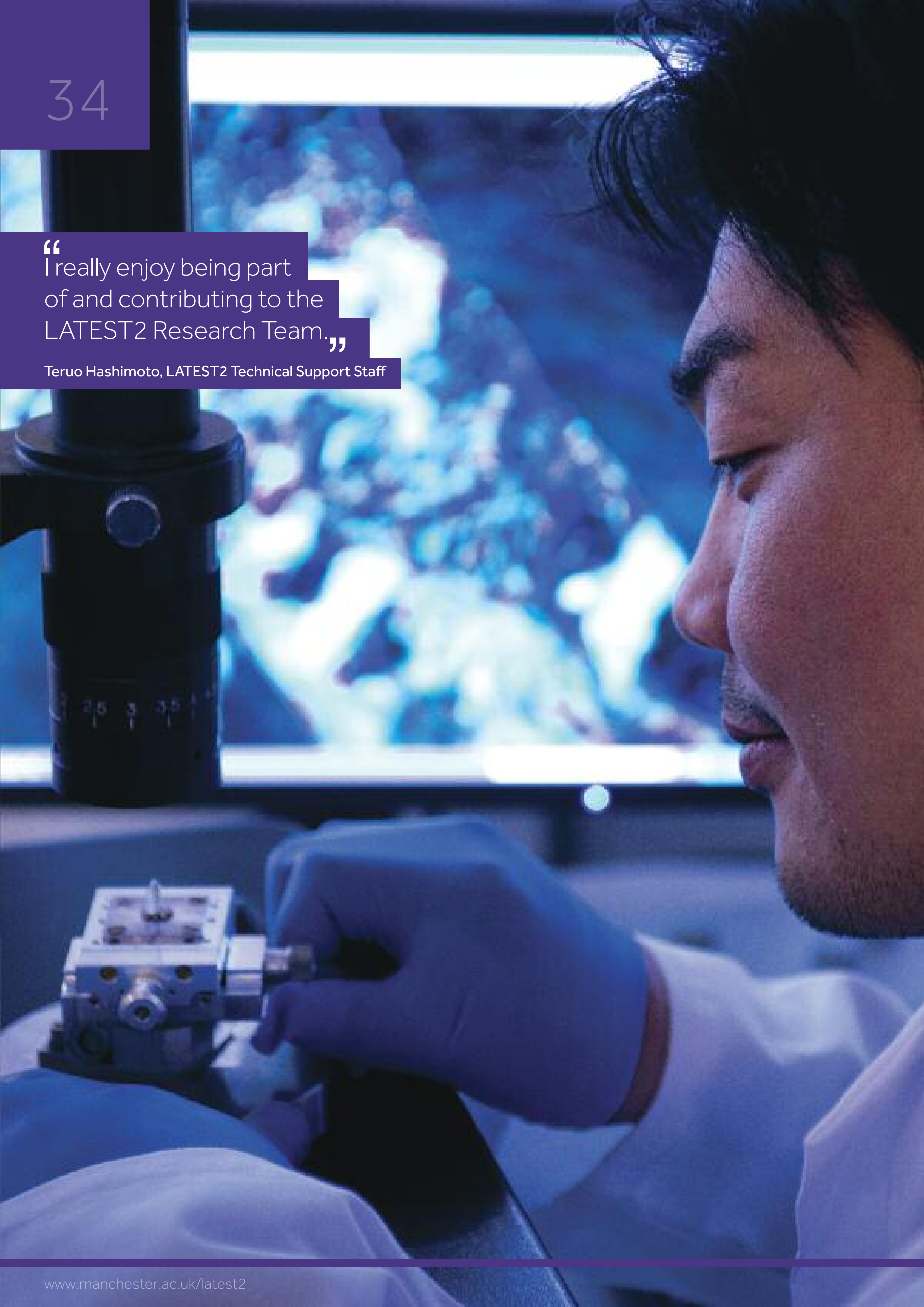

“I really enjoy being part of and contributing to the LATEST2 Research Team.”

Teruo Hashimoto, LATEST2 Technical Support Staff

SURFACE ENGINEERING FOR LOW ENVIRONMENTAL IMPACT AND INTERFACE DESIGN

The aim of Theme 3 is to develop the scientific understanding required to underpin and explore creative, new, environmentally-compliant and economically viable solutions to i) enhance surface properties and performance, including reduced corrosion susceptibility, ii) facilitate joining of dissimilar materials (e.g. metals to composites) and the manufacture of hybrid materials (i.e. low density core metal skin laminates) and iii) protect multi-material structures, thus facilitating the introduction of more efficient designs.

For light alloys, corrosion control is a vital aspect of many surface treatments where, for example, local variations in microstructure impact significantly on both corrosion susceptibility and the uniformity of protective coating development. Importantly, microgalvanic effects are also decisive in determining the performance in service. Consequently, major inputs to this theme include understanding of the roles of microstructure at all length scales, including advancement of 3D electron imaging of corrosion fronts and protected systems, and local subsurface microstructures, textures and surface roughening, developed through forming and joining, on surface properties.

Such understanding will also provide improved surface appearance and performance of formed materials from knowledge of the impact of near-surface deformed layers on optical appearance and surface integrity. For surface treatments, a more detailed knowledge of conventional anodizing and plasma electrolytic oxidation of light alloys will also enhance practical applications. In addition, other treatments including sol gel processes and conversion coating are also of importance for future, effective use of light alloys.

The research is aimed at supporting the following application areas:
Development of environmentally-friendly, economic coating routes for advanced light alloys across the transport sector.
Prevention of cosmetic corrosion in automotive closure panels by control of surface activated corrosion.
Development of self-healing and 'smart' coating technologies and new system assessment procedures, for example, image assisted electrochemical noise analysis to replace accelerated testing.
Designing versatile surface treatment and finishing procedures to support the use of advanced forming and joining approaches for advanced light alloys.
Development of targeted surface treatments for protecting welded joints between dissimilar materials.
Surface engineering for enhanced bonding of metals in hybrid materials/ laminates and to polymer matrix composites.
Use of more recycled material, by understanding the impact on surface engineering for in-service performance.

Professor Peter Skeldon
LATEST2 Co-Investigator
Chair in Corrosion Science Engineering
The University of Manchester

Peter Skeldon graduated in Physics from The University of Manchester in 1974, and obtained a PhD from the same institution in 1977. He subsequently worked in industry in the area of electronic and composite materials, before joining the United Kingdom Atomic Energy Authority, where he was employed for ten years researching corrosion of reactor materials in high-temperature water and sodium environments. He was appointed to a Lectureship at The University of Manchester Institute of Science Technology in 1992, becoming Professor in Corrosion Science and Engineering at The University of Manchester in 2005. Peter is a Co-investigator on the EPSRC LATEST2 Programme Grant, with research interests that are focused on surface treatments of light alloys.

Professor Skeldon has main interests in anodic oxidation of light metals, including both fundamental and practical aspects. A large part of his work has addressed the mechanisms of formation of anodic oxide, in particular from the combined use of ion beam analysis and high-resolution transmission electron microscopy. His research also encompasses conversion coating processes, plasma electrolytic oxidation, electroless treatments, laser surface treatment, and physical vapour deposition. Current research is providing new insights into the mechanism of pore formation in anodic oxides on aluminium through the development of novel tracer techniques, with knowledge transfer to anodizing of aluminium alloys for corrosion protection.

Peter's work involves collaboration with a range of industrial partners, plus international research centres including Institut des NanoSciences, Université de Pierre et Marie Curie, University of Hokkaido, University of Palermo, University of Antioquia, CEMES-Madrid and Universidad Complutense de Madrid.

Formation of Electroless Nickel-Boron on Magnesium and AZ91D Alloy

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[2]LATEST2, School of Materials, The University of Manchester

Due to a low density and high strength-to-weight ratio, magnesium alloys have become a commonly preferred choice for weight reduction in applications such as automobile and computer parts, aerospace components, mobile phones, sporting goods, handheld tools and household equipment. However, poor corrosion and wear resistance are challenges to the successful use of magnesium alloys. Various coatings, which provide a means to avoid direct contact of the alloy with the environment, are being investigated to provide corrosion protection. Recently, electroless nickel–boron has attracted research interest due to its ability to provide a hard, wear and corrosion resistant surface. The most difficult aspect of the electroless process is often the selection of an appropriate pre-treatment, which should promote a rapid initiation of the electroless coating and minimize corrosion of the substrate. Some plating technologies use hydrofluoric acid (HF) or chromic compounds in order to protect the magnesium surface or to generate a suitably rough surface to enhance coating adhesion. However, such chemicals are hazardous to health. Notably, little work has been reported on the formation of electroless Ni–B on magnesium alloys without the use of these compounds.

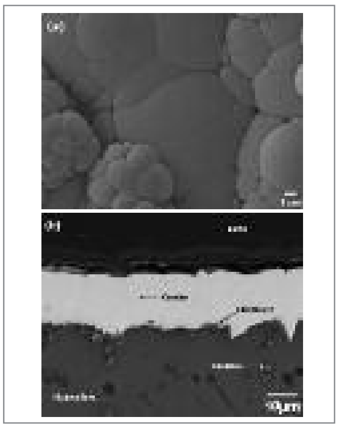

Fig. 1 Scanning electron micrographs (backscattered electrons) of magnesium in (a) plan and (b) cross-section after 120 min immersion in an alkaline Ni–B electroless bath containing 5 g/l NH_4HF_2.

Within the LATEST2 programme, in collaboration with the University of Antioquia, procedures have been developed to coat commercial purity magnesium and the general purpose casting alloy AZ91 by means of an electroless Ni–B process that provides a uniform, adherent and continuous layer without employing HF or chromic compounds. The substrates were mechanically polished with wet 100 grit SiC paper, then grit-blasted with alumina (150 µm), rinsed with deionized water, immersed sequentially in ultrasonic baths containing acetone and ethanol, and dried in a hot air stream. A final cleaning was carried out in 37 g/l NaOH and 10 g/l Na_3PO_4 for 10 min at 65 °C, followed by activation in 200 g/l NH_4HF_2 at room temperature for 10 min, and finally immersion in an electroless bath containing various additives, listed in Table 1, including NH_4HF_2, which is easier to handle, less volatile and cheaper than HF.

Table 1. Chemical composition of the electroless nickel plating bath and coating conditions.

Chemical composition	
$NiCl_2 \cdot 6H_2O$	20 g/l
$NaBH_4$	8 g/l
CH_4N_2S	1 mg/l
$C_2H_8N_2$	35 ml/l
NaOH	110 g/l
NH_4HF_2	Variable
Operating conditions	
pH	> 12
Temperature	80 °C
Plating time	120 min

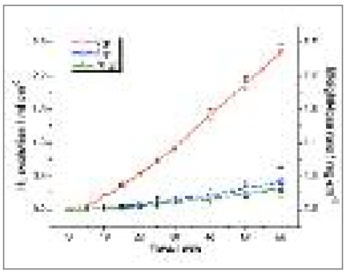

Fig. 2 Dependence of the amount of hydrogen evolved and average weight loss rate on time of immersion in 3.5 wt.% sodium chloride solution for magnesium with electroless Ni–B coatings formed in baths containing different concentrations of NH_4HF_2.

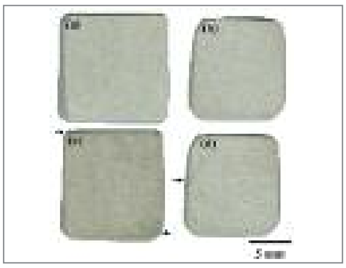

Fig. 3 The appearances of specimens treated in an electroless bath containing 5 g/l before (a, b) and after (c, d) immersion in 3.5 wt.% sodium chloride solution for 60 minutes. Arrows point to locations of corrosion.

Figure 1 shows the typical nodular morphology of the coatings, which can be grown to various thicknesses by selection of the time of immersion in the electroless bath. The rate of coating growth is approximately constant, of the order 10 µm/h, and only weakly dependent on the composition of the substrate. Control of the fluoride concentration in the electroless bath is important to minimize the corrosion rate of the coated alloy, as demonstrated in Figure 2, which displays the amount of hydrogen gas generated due to corrosion of the coated magnesium in sodium chloride solution. The coatings were formed in baths with a range of fluoride contents, with the results showing that corrosion is accelerated by an excess of fluoride, which is related to generation of porosity in the coating. With an optimized bath composition, corrosion of coated coupons following immersion in sodium chloride solution is limited to the edges and corners, as shown in figure 3. Further testing has revealed an excellent wear resistance of the coatings, with a greatly reduced wear rate compared with that of the uncoated alloy. Parallel investigations have also developed baths for generation of Ni-P coatings, which generally show a better corrosion protection than Ni-B coatings. Work is continuing on the development of the coatings.

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New Insights into Pore Initiation in Anodic Alumina

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Porous anodic films are of great importance to the protection of aluminium alloys against corrosion and wear. The films are composed of amorphous alumina permeated by fine, cylindrical pores that extend from the film surface almost to the metal substrate. A much thinner, non-porous barrier layer separates the pores from the metal, as shown in the example of a transmission electron micrograph of a porous film that was formed in a phosphoric acid electrolyte, presented in Figure 1. Over the last fifty years, the growth of the films and the formation of the pores have usually been explained by a field-assisted dissolution model. In this model, the anodic alumina is formed at the metal/film interface due to migration of O^{2-} ions across the barrier layer. The migration takes place under a high electric field at the barrier layer, which is established by the external power supply in the electrolytic cell. At the same time that the oxide is formed, dissolution occurs at the pore base, such that the barrier layer remains of constant thickness. The dissolution is vastly accelerated in comparison with the usual chemical dissolution of the film in the electrolyte, which is attributed to the effect of the electric field at the pore base.

There has been a resurgence of interest in porous anodic films, partly due to the interest in potential applications in nanotechnology, but also for the development of new processes that can eliminate the need for anodizing in chromic acid, which is an often favoured process for aerospace applications, but which is now under legislative pressure due to environmental and health reasons. Within the LATEST Portfolio Partnership and LATEST2 programmes, alternative anodizing processes have been investigated in detail, coupled with fundamental research into the growth mechanism of the films. The latter has led to a re-evaluation of the mechanism of pore formation. Firstly, using tungsten tracers, it was shown that the pore growth involves flow of oxide within the barrier layer, with field-assisted dissolution having a minor or negligible role under many conditions of film growth. Thus, as new oxide is added at the base of the barrier layer, oxide within the barrier layer is pushed toward the pore walls due to the stresses associated with the film growth. The oxide is made plastic due to the ionic transport processes within the barrier layer that involve migration of both Al^{3+} and O^{2-} ions.

In more recent work, attention has been directed toward the initiation of pores and for this purpose a new tracer approach was developed using arsenic species, which do not migrate during the film growth. The arsenic is introduced into the film by a first stage of anodizing in sodium arsenate electrolyte. The aluminium is then further anodized in a phosphoric acid electrolyte. Figure 2(a) shows transmission electron micrographs and elemental maps of the film at an early stage of re-anodizing, before the pores have initiated. The arsenic is revealed to be buried slightly below the film surface, and phosphorus species are also present in the outer region of the film. Figure 2(b) shows the film at later stage, when the main pores of the film have begun to form. The arsenic map discloses a thin band of arsenic within the barrier layer at the base of the pore. The distribution of the arsenic can be explained by the flow of oxide inward from the original surface of the film. Figure 3 shows schematically the progress of pore development in the anodic alumina film, and the displacement of the arsenic by the flow of oxide. This is the first time that such a process has been demonstrated experimentally. The new tracer approach is currently being further applied to examine pore formation under a range of conditions of film growth, including anodizing in chromic acid which results in a different pore morphology. It also has a potential for application to studies of pore formation in oxides other than porous alumina.

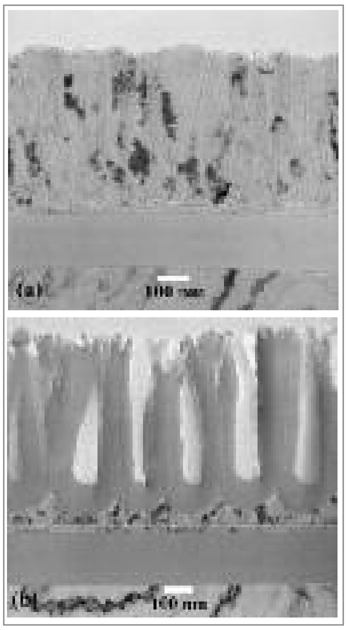

Fig. 1 Transmission electron micrographs of a porous film formed in phosphoric acid on a thin layer of sputtering-deposited aluminium. (a) The original aluminium layer on top of an amorphous layer of anodic alumina. (b) The porous film.

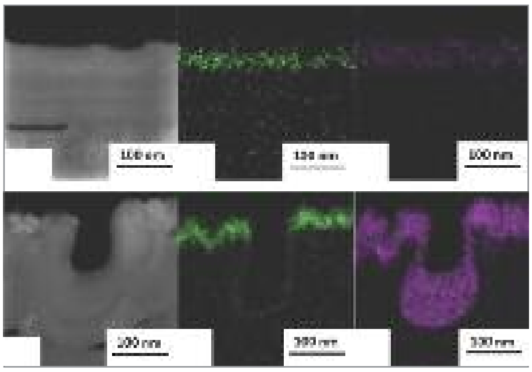

Fig. 2 High angle annular dark field scanning transmission electron micrographs and energy-dispersive X-ray SDD spectrum images of arsenic and phosphorus obtained from a cross-sectioned specimen of aluminium following anodizing to 60 V at 5 mA cm^{-2} in 0.1 mol. dm^{-3} sodium arsenate electrolyte at 296 K and re-anodizing at 110 V in 0.4 mol dm^{-3} phosphoric acid electrolyte at 296 K for (a) 15 s and (b) 180 s.

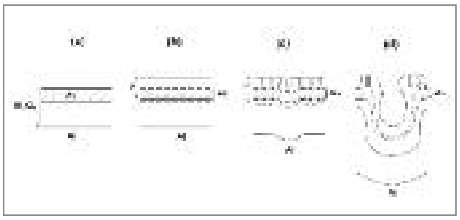

Fig. 3 Schematic diagrams of the formation of anodic films on aluminium. (a) Barrier film formed to 60 V at 5 mA cm^{-2} in 0.1 mol dm^{-3} sodium arsenate at 296 K, showing incorporation of arsenic species. (b) Barrier film formed after re-anodizing the specimen depicted in (a) for ~15 s at 110 V in 0.4 mol dm^{-3} phosphoric acid at 296 K, showing the burial of the arsenic. (c) Nucleation and growth of incipient pores and nucleation of a major pore in the film of (b) following further anodizing in the phosphoric acid. (d) Growth of the major pore. Arsenic species are retained in the film and transported inward by plasticized film.

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Plasma Electrolytic Oxidation of Coupled Light Metals

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The use of multi-material components is rapidly increasing in modern designs in order to optimize performance and reduce weight. If these are subject to corrosive environments, protection schemes may be required to ensure durability of the product. In the case of light metals, protection usually requires application of conversion coatings, anodic coatings and paints as part of a coating system. However, conversion and anodic treatments are usually metal-specific, i.e. designed for application to aluminium, magnesium or titanium parts, and hence are not suited individually to treatment of a mixed-metal component in a single treatment process. However, plasma electrolytic oxidation offers a potential to overcome this difficulty. Plasma electrolytic oxidation involves polarization of a metal at a high potential in an aqueous electrolyte, usually under AC or pulsed DC conditions. The high potential results in numerous, short-lived discharges on the treated surface, where coating material is formed through a combination of anodic oxidation, thermal oxidation, thermolysis and plasma-chemical processes. The mechanism of coating growth is not well-understood, since the discharges are small and have lifetimes often of the order of microseconds, making it difficult to probe the formation mechanism by conventional approaches. Nevertheless, coatings of up to several hundred microns thickness are readily formed in suitable electrolytes that are regarded as environmentally-friendly and safe to handle. Further, the coatings can provide excellent wear resistance due to the formation of high-temperature, crystalline oxide phases, and can also provide corrosion protection; for the last case, this may require a sealing treatment or paint top-coat since the coatings contain porosity. Many studies are available in the literature on the formation of coatings on aluminium, magnesium and titanium and their respective alloys, usually using different compositions of the electrolyte and different electrical regimes. However, only one study has addressed the applicability of the process to treatment of mixed-metal systems. Thus, within the LATEST2 programme, investigations have been carried out on the treatment of mixed-metal systems consisting of a combination of either aluminium and AA 7075-T6 aluminium alloy or of ZE41 magnesium alloy and AA 7075-T6 aluminium. These have shown the possibility of successfully forming thick coating on both combinations of metals. The work utilized an alkaline electrolyte and an AC electrical regime, with various RMS current densities applied. A key observation was the requirement to select an appropriate current density to achieve similar thicknesses of coating on the metal combination. Clearly, due to the dissimilar compositions of the metals, the details of the discharge conditions and the coating compositions differ between the two metals. Consequently, the current flow to the two parts is not stable during the coating formation as each of the coupled metals presents a different and varying resistance as the coating builds in thickness, as shown in Figure 1. If an inappropriate current density is employed the currents may diverge, such that large differences in the coating thickness result on the treated metals. However, with proper selection of the current, the current flow to each metal can be maintained at a similar level, such that coatings can be formed of similar morphology and thickness to those on the individually treated metals, as shown in Figure 2. Thus, the work has demonstrated the potential suitability of plasma electrolytic oxidation for the treatment of mixed light alloys. However, further investigation is required to ascertain the general applicability of the approach, for instance to combinations with titanium, to treatments under voltage rather than current control and to combined metals with different area ratios.

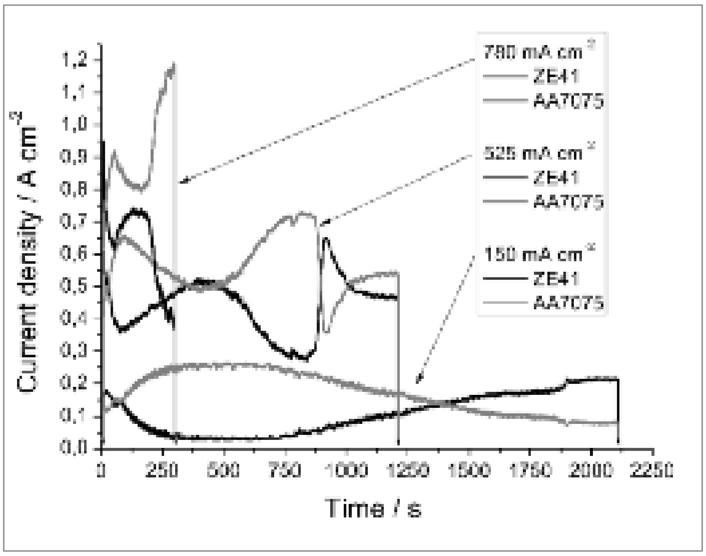

Fig. 1 Current density responses of AA7075 alloy/ZE41 alloy couples oxidized in sodium phosphate/sodium silicate electrolyte at 150, 525 and 780 mA cm^{-2}.

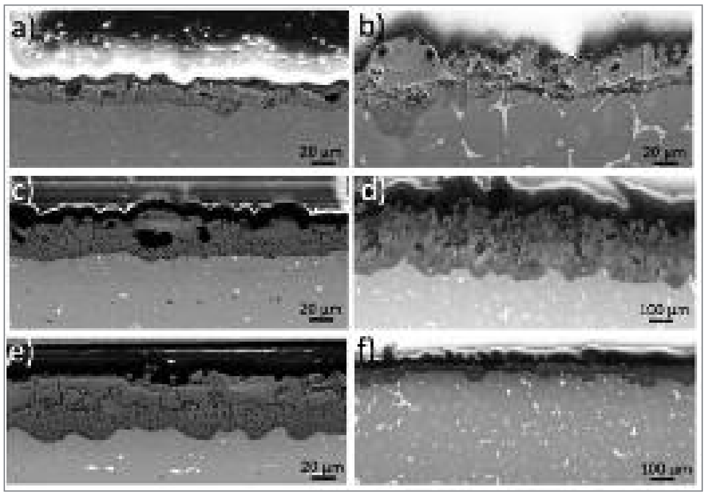

Fig. 2 Cross-sections of coatings formed on the coupled AA7075/ZE41 substrates at (a,b) 150 mA cm^{-2} and (c,d) 525 mA cm^{-2}. (e,f) Coatings formed on the respective individually-oxidized alloys.

Acknowledgements: The authors are grateful to the European Community for financial assistance within the Integrating Activity "Support of Public and Industrial Research Using Ion Beam Technology (SPIRIT)", under EC contract no. 227012. In addition, they wish to acknowledge the support of the European Community's Seventh Framework Programme FP7/2007-2013 through the award of a Marie Curie Fellowship to ABW under grant agreement No PIEF-GA-2008-219913.

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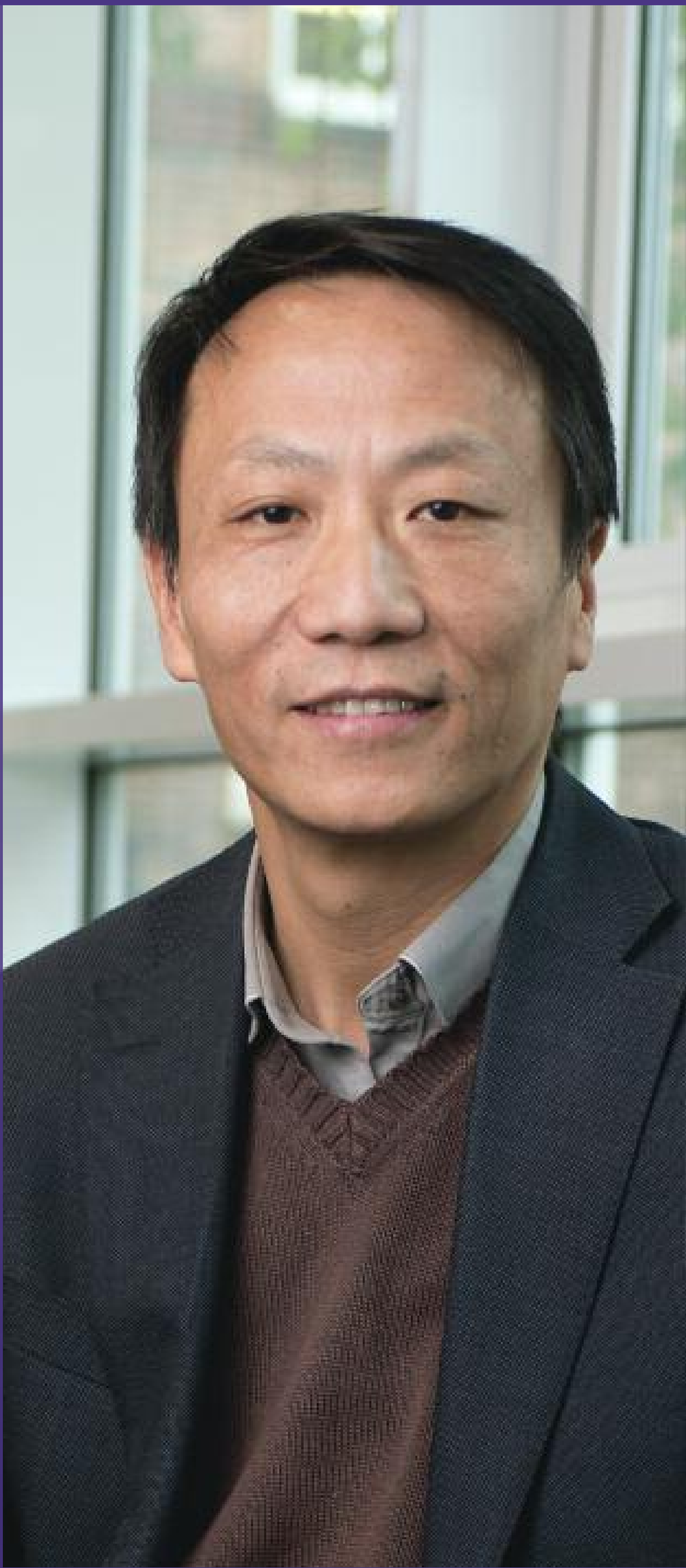

Xiaorong Zhou graduated from the Department of Chemistry and Chemical Engineering of Hunan University, China in 1983. He obtained an MSc in materials science and engineering at Beijing University of Aeronautics and Astronautics, China in 1986. He was then appointed research engineer in Beijing Institute of Aeronautical Materials. He received his PhD in corrosion science and engineering from UMIST in 1994. Subsequently, he joined the Corrosion and Protection Centre of The University of Manchester (then UMIST) in 1994 initially as Research Fellow, then Lecturer, Senior Lecturer and Reader. Xiaorong is a Co-investigator on the EPSRC LATEST2 Programme Grant and a member of the Corrosion and Protection Group. Xiaorong is visiting professor to The University of Santiago of Chile, Chile and The Beijing Aeronautical Manufacturing Technology Research Institute, China.

Xiaorong's research interests lie in corrosion control of light alloys and developing novel surface engineering approaches, with emphasis on surface and interface characterisation from the nanoscale upward, allowing detailed understanding of relationships between forming, joining and prediction of corrosion susceptibility, and protection mechanisms. Xiaorong's work is validated by innovative electron microscopy approaches enabling the progress of corrosion to be followed, and susceptible regions in the microstructure, i.e. near-surface altered layers, to be defined three-dimensionally. The research has led to the award of the Jim Kape Memorial Medal of the Institute of Metal Finishing in 2001.

Xiaorong's research has found applications in many market sectors including automotive, aerospace power generation, architecture, packaging etc, involving close collaboration with industrial partners including Novelis, Constellium, Alcan, Sapa Group, as material producers and end users such as AVIC, Airbus, US Navy, EDF.

Nanotomography Coupled with RF-GDOES for Evaluation of the Corrosion Performance of Processed Aluminium Alloys

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It is known that the thermomechanical processing of aluminium alloys by rolling and extrusion significantly alters their microstructures. These microstructures can be beneficial to the mechanical behaviour of the material, but they can also be detrimental to the corrosion properties in real-life situations. In particular, an altered microstructure is developed in the near-surface regions during thermomechanical processing.

The understanding of the corrosion behaviour of a commercially produced aluminium alloy is important for material durability. Employing a technique recently developed at The University of Manchester, nanoscale in-SEM tomography allows the observation of the nanoscale structures developed within the near-surface region of commercially produced alloys. Examples of results are presented in Figures 1 and 2 The information that can be acquired from this technique can quantify changes in the size, shape and distribution of the relevant microstructural features.

During rolling, the altered near-surface microstructure is distributed across the surface by the rolls in a manner that can result in inconsistent distributions of such microstructures. The varying microstructure across the surface can have significantly different corrosion behaviour when compared to the bulk alloy.

Further, it is often difficult to assess the corrosion properties of the commercially produced alloys due to the complex nature of altered near-surface microstructures, which also have altered phase distributions. In particular, contact with the rolls can lead to the incorporation of various hot-formed oxides into the near-surface region. Microalloying of various types of oxides, including those of magnesium, zinc and aluminium, have been witnessed beneath the surface.

Elemental depth profiles of the same commercially produced alloy are provided by radio frequency glow discharge optical emission spectroscopy. Analysis of the first few microns of the rolled surface can provide accurate readings relating to elemental concentrations present within the near-surface region, as shown in Figure 3. Such analysis helps to correlate the corrosion behaviour of the alloy to the distribution of the chemical species in the near-surface region of the alloy.

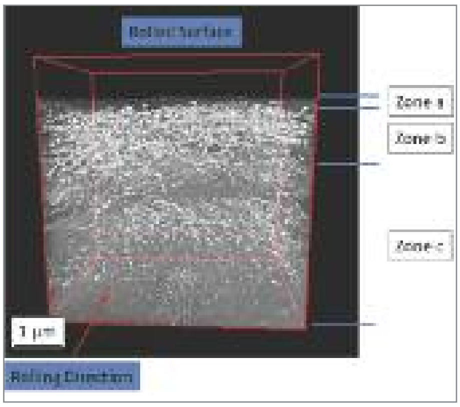

Fig. 1 3D rendering of the volume of the microstructure associated with the near-surface region of a commercially produced AA7xxx alloy, revealing three zones: namely a, b and c, with significantly different microstructures compared with the bulk.

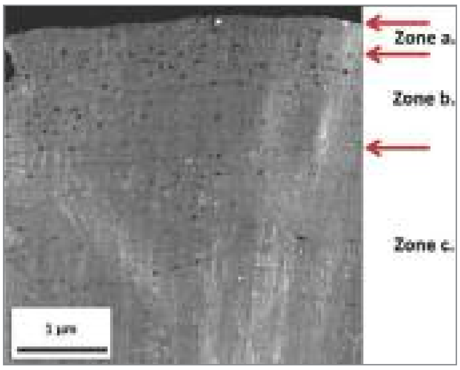

Fig. 2 HAADF micrograph of the cross section of the same near-surface region rendered in 3D in Fig. 1. Features within the zones are readily compared.

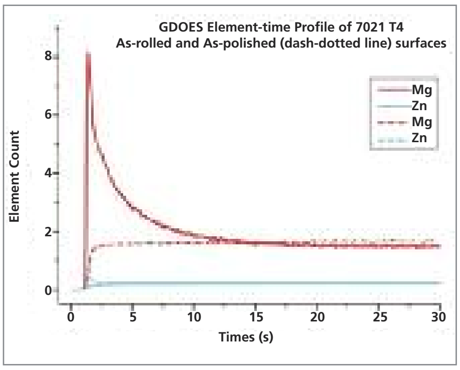

Fig. 3 The elemental depth profiles for magnesium and zinc which contribute significantly to the corrosion behaviour of the alloy. A sputtering rate of 66 nm/s was achieved. Magnesium oxides are present at the surface after rolling.

Acknowledgements: This LATEST2 project was performed with support from Constellium.

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Environmentally Friendly Surface Treatment for New Generation Aluminium-Lithium Aerospace Alloys

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Increasing payload and fuel efficiency are drivers for the aerospace industry to strive to improve lightweight materials for application in aircraft structures. Lithium-containing aluminum alloys are attractive due to their low density and high stiffness compared with conventional aluminum alloys. For service performance, an adequate, economic, and environmentally-friendly corrosion protection scheme is necessary. Traditionally, the anticorrosion performance of aerospace aluminum alloys has been achieved through chromic acid anodizing (CAA), followed by painting. However, the increasing environmental concerns and strict legislation on the use of chromic acid require the development of low-cost and environmentally-friendly anodizing electrolytes.

In this work, the anodizing behavior of a commercial Al-Li-Cu alloy in an environmentally-friendly electrolyte, namely tartaric-sulfuric acid (TSA), has been investigated. Attention is focused on optimizing the process parameters to tailor the morphology, composition and structure of the resultant porous anodic films to achieve desirable performance.

A relatively fine porous anodic film, with well-defined cells, was observed at relatively low voltages, with copper-rich nanoparticles occluded in the film material (Figure 1). Pores of increased dimensions, with lateral porosity, were observed at increased voltages (Figure 2). The oxidation of copper is responsible for the additional lateral porosity in the anodic film. It is also revealed that copper in the alloy matrix can be occluded in the anodic film material as copper-rich nanoparticles (Figure 3) or it can be oxidized and incorporated into the film material as copper ions, depending on the anodizing voltage. Further, lattice images of copper-rich nanoparticles indicate that they have structures consistent with either the Θ, Θ' or Θ"phases, regardless of their locations in the anodic films.

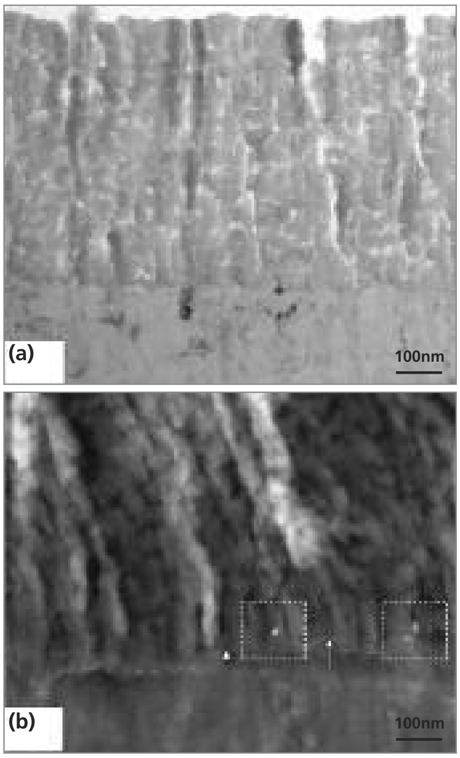

Fig. 2 Transmission electron micrographs of an ultramicrotomed section of AA 2099-T8 aluminum alloy after anodizing at a constant voltage of 14 V: (a) bright field image; (b) HAADF image.

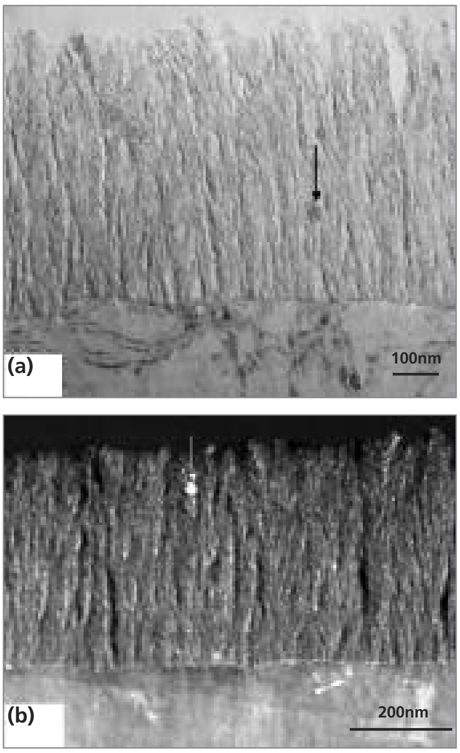

Fig. 1 Transmission electron micrographs of an ultramicrotomed cross section of AA 2099-T8 aluminum alloy after anodizing from the OCP to 3 V (SCE) at a sweep rate of 0.03 V/min: (a) bright field image; (b) HAADF image.

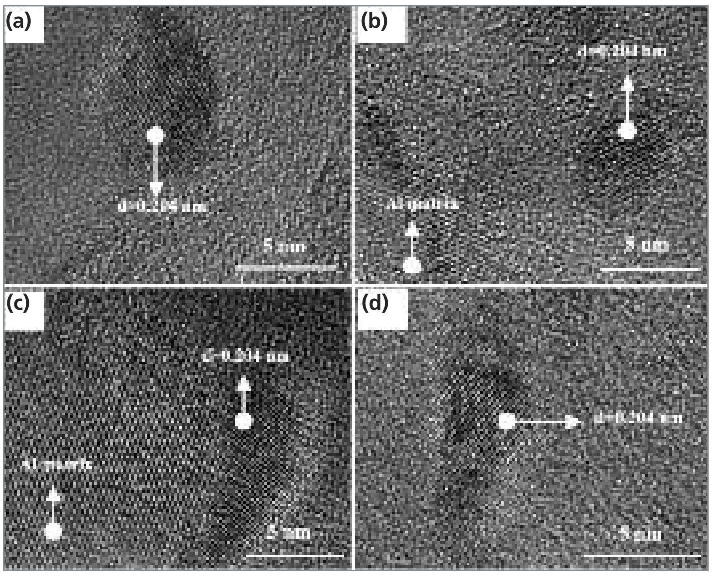

Fig.3 Lattice images of copper-rich nanoparticles: (a-d) in different regions of the anodic film.

Acknowledgements: This LATEST2 project was performed with support from Airbus Publication

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Impact of Shot Peening Forming on Surface Integrity of Aluminum Alloys

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Shot peen forming is a dieless process performed at room temperature which has been widely used to form various aircraft components. Shot peening usually produces spherically-shaped dents (Figure 1) on the peened component after small, round steel shots impact the surface of the work piece, resulting in stretching of the material in the near-surface region and local plastic deformation that result in residual compressive stress. The compressive stress induces a convex curvature on the peened side. In order to achieve weight reduction and improved service life, integrated construction panels are employed as mainly load-bearing components in wings or the fuselage of large aircraft. Due to the overall size and the complex curves of the large panels, large size shots are used to improve the efficiency of shot peen forming.

In the present study, the microstructure evolution in the near-surface layer induced by a shot peen forming process is investigated. Due to the use of large shots, deep dents are generated on the surface of the alloy and defects, such as microcracks, may develop around the dents. The fatigue life of the formed panels may be influenced by such defects. Thus, it is essential to determine the defect distribution around the dents. The objective of the investigation is to understand the effect of processing parameters on the microstructure in the near-surface layer and, therefore, to optimize shot peen forming for improvement of the mechanical properties of the components.

It was revealed that severe plastic deformation and, consequently, a modified microstructure, including ultrafine grains, microcracks and redistribution of intermetallic particles, were introduced to the near-surface layer (Figure 2). The coarse intermetallic particles in the near-surface layer beneath the dents were broken up into finer ones and redistributed during shot peen forming, which retards the propagation of cracks and, hence, improves the fatigue properties of the alloy. Further, an ultrafine grained structure was produced in the near-surface layer of the dent region on the aluminium alloy subjected to shot peen forming (Figure 3). The co-action of dislocation activities and dynamic recrystallization was considered to be the main mechanism responsible for grain refinement. The thicknesses of the refined grain layers increased with the increasing air pressure.

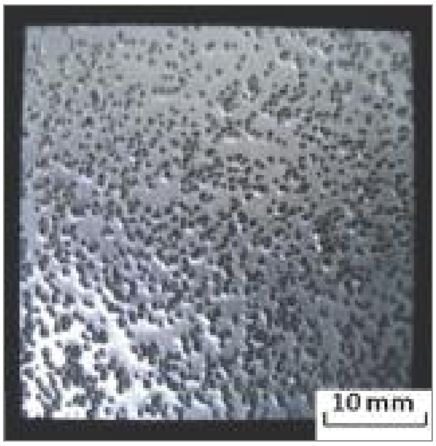

Fig. 1 Optical image of the alloy surface after shot peen forming.

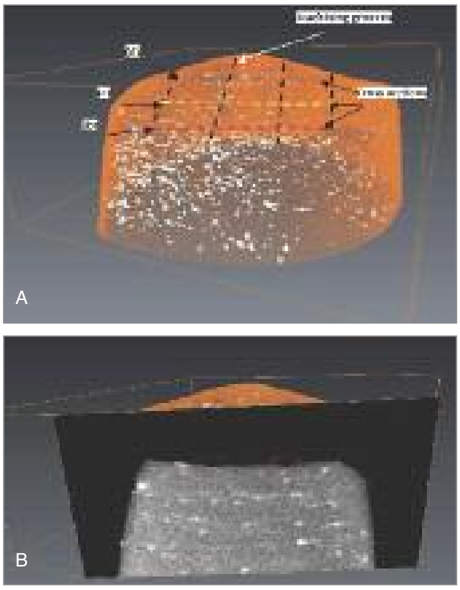

Fig. 2 3D X-ray volume reconstruction of a dent on the surface of the alloy peened at 0.5 MPa.

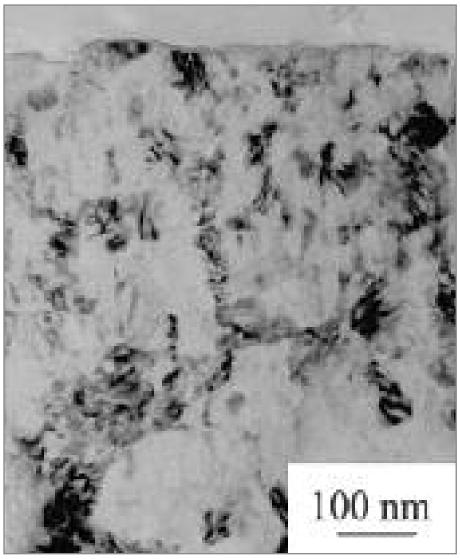

Fig. 3 Transmission electron micrograph of a cross section of the near-surface region at the centre of a dent, revealing an altered microstructure characterized by ultrafine grains.

Acknowledgements: This LATEST2 project was performed with support from BAMTRI

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PROFILE

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Michele Curioni graduated in Materials Science and Engineering from Politecnico di Milano (Italy) in 2003 and obtained an MSc in Materials Science and Engineering from the same institution in 2005. Subsequently, he moved to The University of Manchester where he was awarded a PhD in 2009. Since then, he has worked at The University of Manchester initially as a Research Associate and, from 2011, as LATEST2 Research Fellow. Michele is a member of the Corrosion and Protection Group with research interests focusing on corrosion protection of light alloys and electrochemical methods for assessment of anticorrosion performance.

Current work is investigating protective surface treatments for light alloys with particular attention given to anodic oxidation and use of environmentally friendly inhibitors to provide long-term active protection. The approach involves the investigation of fundamental and applied aspects of the anodic oxidation process such as the effects of the electrical parameters and electrolyte composition on the long term protective behaviour. Particular attention is paid to understanding the interactions between the microstructural features present on practical alloys and the corrosion environment, in the presence or absence of protective treatments and corrosion inhibitors.

Additionally, Michele works on the exploitation and development of advanced electrochemical methods for the assessment and the prediction of the corrosion behaviour. In particular, he focuses on electrochemical techniques that enable corrosion-related information to be obtained by applying minimal or no electrical perturbation to the corroding surface and are therefore intrinsically representative of the real-life behaviour. Michele is actively developing software and hardware for measurement and analysis of electrochemical noise generated during corrosion. His works involves collaboration with a range of aerospace industries and foreign universities.

Electrochemical Testing Coupled with Real Time Imaging, a New Tool for Assessment of Anticorrosion Performance

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There is general agreement that industrial accelerated corrosion tests such as the Salt Spray Test (SST) and others are not always adequate to evaluate real-life performance. The source of concern is that accelerated tests rely on a particularly aggressive environment to reduce the time to failure during the test. Thus, corrosion mechanisms that would never be present under real-life conditions could be initiated and cause failure. Further, the output of such tests is generally expressed as pass (no corrosion) or reject (unacceptable corrosion) and little or no information on the time-evolution of the corrosion process is obtained.

On the other hand, electrochemical tests, more common in Academia, rely on measuring the response due to an externally applied voltage or current of an immersed corroding surface. They are fast and provide fundamental information on the corrosion processes but it is debated if they are representative of the real-life behaviour due to the electrical perturbation of the corroding surface. Further, they are generally not standardized and difficult to standardize, since the optimum test parameters depend on the material-environment combination; optimization and interpretation requires a well-trained operator.

Electrochemical Noise Analysis is unique among the electrochemical techniques because it does not require the application of a probing signal to the corroding surfaces. In practice, two nominally identical specimens are immersed in a test solution and electrically connected through an external circuit. As a result of corrosion on the surfaces, current and potential fluctuations are detected and recorded. The theory behind the interpretation of the electrochemical noise signal is well established, but relatively complex. For this reason, a specific software package has been recently developed and distributed online (Figure 1). The package requires minimal user knowledge and estimates the electrode impedance (inversely proportional to corrosion rate), the average charge (proportional to volume of material corroded) and the frequency of corrosion events, as a function of exposure time.

Data obtained from electrochemical noise measurements are intrinsically representative of a freely corroding system because no probing signal is applied. Further, the use of ready-made software to extract relevant, time-dependent, corrosion-related quantities, does not require detailed understanding of the underlying theory (Figure 2).

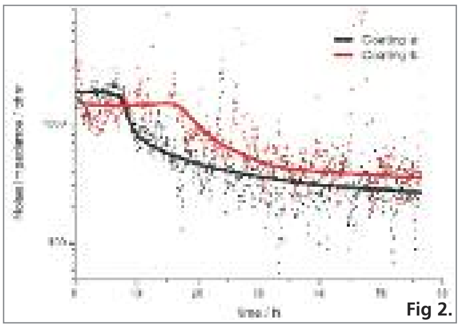
Fig 2.

For these reasons, the method is an ideal candidate to be standardised (by standardising the test environment) and to provide simultaneously quantitative fundamental and practical performance data.

Being an immersion test, as an added benefit, the surface of the specimens can be imaged in real time and image-analysis techniques and accelerated footages can be used to highlight the details of corrosion initiation and propagation (Figure 3). The two combined approaches, automated electrochemical noise analysis and associated surface imaging, provide a new intuitive, low cost and robust tool for the comparative evaluation of the corrosion performance of protective treatments, inhibitors and paints. A stand alone cabinet, capable of simultaneously recording and analysing the electrochemical noise signal and the surface appearance of the corroding specimens has been recently developed. Direct comparison of images and time-lapse video allows a rapid identification of the best candidate treatment between competing solutions. Consideration of the values of low-frequency noise impedance provides quantitative estimation of the anticorrosion performance. Once finalized and commercially available, it will be a powerful tool for both fundamental and applied corrosion studies, enabling reliable information to be obtained without requiring a highly trained operator.

Fig. 2 Time evolution of the low-frequency noise impedance for two ZE41 magnesium alloy specimens supporting oxide coatings obtained by plasma electrolytic oxidation; a) 10 mA and b) 20 mA for 10 min, corrosive electrolyte: 3.5% NaCl. High values of impedance indicate low corrosion rates, low values of impedance indicate that corrosion is propagating, rapid decrease indicates corrosion initiation. Lines are intended as a guide to the eye.


Fig 1.

Fig. 1 Homepage of the website where the electrochemical noise analysis software can be downloaded (www.electrochemicalnoise.com)

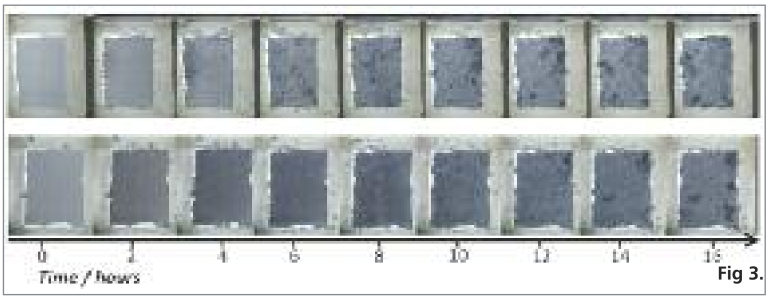
Fig 3.

Fig. 3 Images acquired during corrosion of ZE41 magnesium alloy supporting oxide coatings obtained by plasma electrolytic oxidation; a) 10 mA and b) 20 mA for 10 min. Red arrows indicate the first sign of coating failure (4 hr and 12 hr respectively), corrosive electrolyte: 3.5% NaCl.

Publications: Interpretation of Electrochemical Noise Generated by Multiple Electrodes, M. Curioni, R. A. Cottis and G. E. Thompson, Corrosion, 69, 158 (2013).

An Alternative to the Use of a Zero Resistance Ammeter for Electrochemical Noise Measurement: Theoretical Analysis, Experimental Validation and Evaluation of Electrodes Asymmetry, M.Curioni, A.C. Balaskas and G. E. Thompson, Corrosion Science, 77, 281 (2013).

Application of Electrochemical Noise Analysis to Corroding Aluminium Alloys, M. Curioni, R.A. Cottis and G. E. Thompson, Surface and Interface Analysis, 45, 1564 (2013).

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A New Approach for Contrast Segmentation of Microstructural Features for 3D-Imaging and Material Characterisation

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With the widespread application of microscopy in natural sciences, it is evident that two-dimensional information has limitations concerning connectivity of features etc. Conversely, three dimensional (3D) observations of objects often provide direct links to their functionality. As a result, the development of microscopic techniques has generally progressed into "3D microscopy". 3D microscopy information has also become more informative for materials science, and many analytical microscopy techniques have introduced 3D methods over the past twenty years.

A relatively new, in-situ ultramicrotome – containing scanning electron microscope (GATAN 3View placed in an FEI Quanta 250 FEG SEM) is ideal for 3D microscopy, giving tools for analytical probing at the microscale and nanoscale in a single instrument. The stage design does not require major image alignment, and tilting is not necessary as for conventional SEM imaging, but unlike focused ion beam approaches. Concerning the specimen, a sharp-edged diamond knife is utilized for generation of slice thicknesses in the range 10 to 100 nm. As a consequence of the previous sequential slicing, fresh, relatively smooth and non-contaminated surfaces of the specimen are available routinely for low voltage, high resolution imaging without charging in the pressure-controlled SEM chamber.

The sequential slicing and imaging steps yield a stack of images that are sampled equidistantly through the volume of interest and, finally, that are available for 3D reconstruction. Within the LATEST2 project, this novel and innovative approach has successfully generated 3D images to give better understanding of the materials of interest. In studies of metallic alloys and their performance, i.e. corrosion behaviour, it is important to quantify the distribution of intermetallic particles and their dimensions, grain size and grain orientation, and the locations of particles within the alloy microstructure, as well as the composition of the material of interest and connectivity of features and relation to the corrosion front.

Series of images are usually obtained using a backscattered electron (BSE) detector. The detector collects deflected primary electrons due to the strong electrical field of the specimen's atomic nuclei. Therefore, BSE imaging is highly dependent on the atomic numbers of the materials of interest. Figure 1 shows the relationship between the BSE coefficient and the average gray scale of intermetallics and the aluminium matrix in AA2024 T3 at 2.5 kV. In order to confirm the relationship with the gray scale level, composition quantification was obtained by energy dispersive X-ray analysis (EDX) in the green circled regions displayed in Figure 1. The BSE coefficient is in good agreement with the gray scale; the blue and red arrows indicate the Al_2MgCu (S) and Cu_2Al (Θ) phases respectively. It is also evident that such information is able to contribute to a database for various materials. In summary, the established database then provides information for elemental 3D imaging without further EDX analysis.

A further advantage of SEM imaging is the presence of electron channeling effects, which result from change of electron penetration depth with different crystal orientations in the same material. This penetration depth difference reflects the BSE signal intensity as a function of angle relative to the Bragg angle. These signals are generated from a few nanometres below the surface. This intensity difference is able to locate grain boundaries and, thus, enable measurement of the grain size distribution. However, the relatively low electron penetration depth renders the signal sensitive to the roughness and deformation of the block face (the block being the specimen that is sliced sequentially with the diamond knife). In fact, forces applied on the block face as a result of mechanical slicing with the diamond knife introduce some roughness and deformation on and immediately below the block face respectively. This roughness and deformation may change the surface crystal orientation locally, with the result that the image shows differences of regular gray level, with such differences being distinct in individual grains. Figure 2 shows the difference of regularity of gray level on individual grains of an aluminum alloy specimen, and reveals the 3D reconstruction, with segmentation imaging based on this difference.

The understanding of the relationship of the regular gray scale difference with roughness and deformation, and the reduction of associated damage on the block face are crucial for future advancement of this analytical approach. Current work is aimed at minimizing or avoiding damage to the block face, which will allow the next important advance of understanding through strain or deformation measurements and 2D and 3D EBSD.

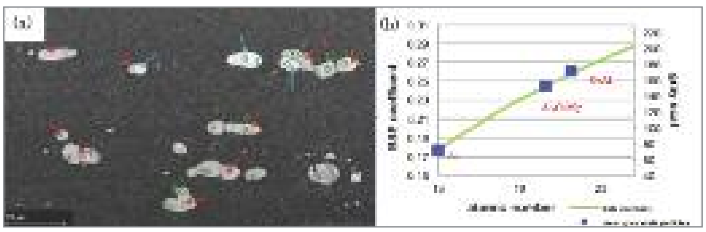

Fig. 1 (a) BSE image of AA2024 T3 at 2.5 kV. (b) Variation of the BSE coefficient with average gray scale of the intermetallics revealed in the image.

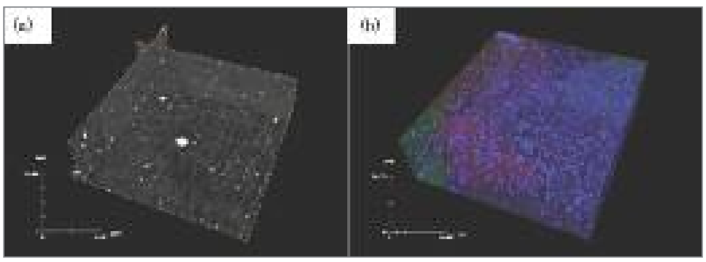

Fig. 2 3D reconstructed image of AA 2024 T3 aluminium alloy. The true intermetallic particle shapes and distributions provide accurate volume fractions and locations for informing thermomechanical processing for material performance: (a) orthoslice imaging of 3D volume; (b) segmented imaging of intermetallics and grains (the intermetallics are coloured blue and the aluminium rich matrix grains are coloured green, red, yellow and light blue).

The Origin of Streaks on Aluminium Alloy Extrusions

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Surface integrity is an important characteristic of high quality aluminium extrusions, especially for applications in the automotive industry. Defects such as streaking (Figure 1) are often present on anodized extrusions of aluminium alloys, increasing the fabrication cost of extrusion profiles. Streaking on the surfaces of anodized extrusions is typically characterised by narrow bands of different contrast to the neighbouring material. The streak bands may appear darker or lighter, duller or brighter, in colour and tone compared to the surrounding material. However, streaking often only becomes visible after etching and anodizing treatments, rather than in the as-extruded condition, making it difficult to identify the original causes of the defect.

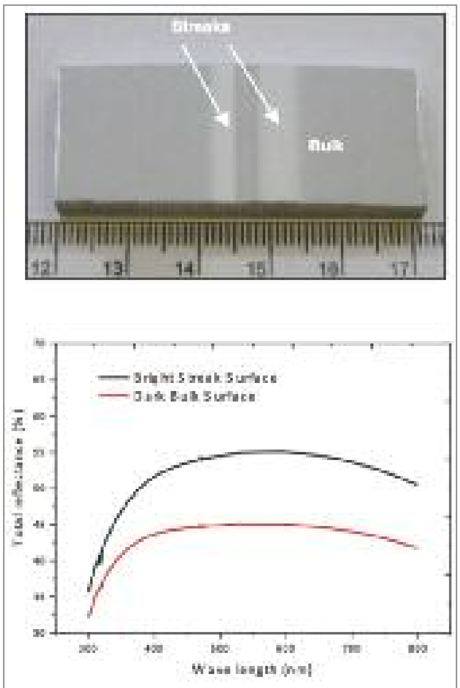


Fig. 1 (a) Optical image of the extrusion with streak defects and (b) total reflectance of the streak and bulk regions.

The objectives of this work are to determine the root causes of streak defects on an anodized aluminium extrusion weld and its associated microstructural features in the alloy and to eliminate the defects. The extrusion was initially etched in sodium hydroxide solution and, subsequently, anodized in sulphuric acid solution. Optical and electron microscopy have been conducted on the as-anodized extrusion and the alloy after film stripping, re-etching and re-anodizing.

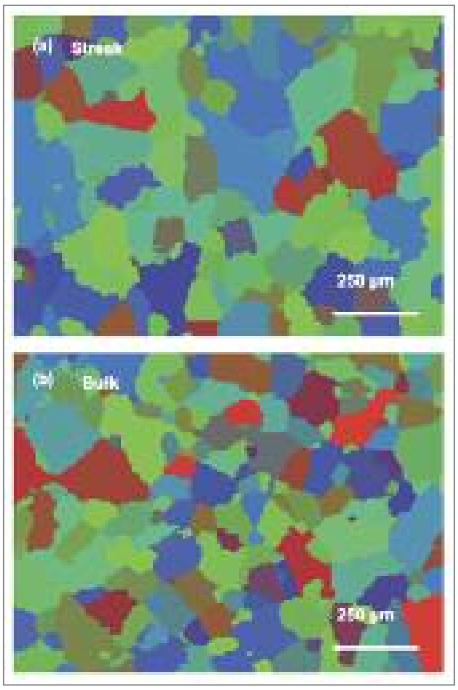


Fig. 2 EBSD map of the alloy substrate after film stripping: (a) streak and (b) bulk regions.

It was found that the appearance of etched and anodized aluminium alloy is associated with grain boundary grooves, etching steps and surface scallops, which are determined by the distributions of grain size and crystallographic orientation. It was also revealed that the bright streaking regions are associated with an extrusion weld zone which had relatively large grains with a relatively strong texture (Figure 2). The microstructure resulted in reduced light scattering by grain boundary grooves, surface scallops and etching steps and, consequently, contributed to a brighter appearance (Figure 3). The different microstructure in the streaking regions might have originated from the extrusion process due to non-uniform alloy deformation and non-uniform distribution of friction force, and consequent heat build-up in local regions.

Acknowledgements: This LATEST2 project was performed with support from Sapa Group

Publications: Y. Ma, X. Zhou, G. E. Thompson, J-O. Nilsson, M. Gustavsson and A. Crispin. The Origin of Streaks on Anodized Aluminium Alloy Extrusions, Trans. Inst. Met. Fin., 91, 11-16, 2013.

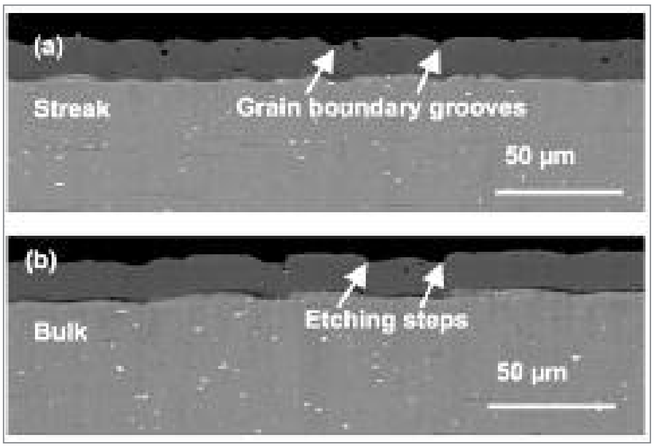


Fig. 3 Backscattered electron micrographs of the cross section of the anodic film attached to the alloy substrate: (a) streak and (b) bulk regions.

RESEARCH PROJECT LIST

Key: Completed | On Track | On Hold | Stopped

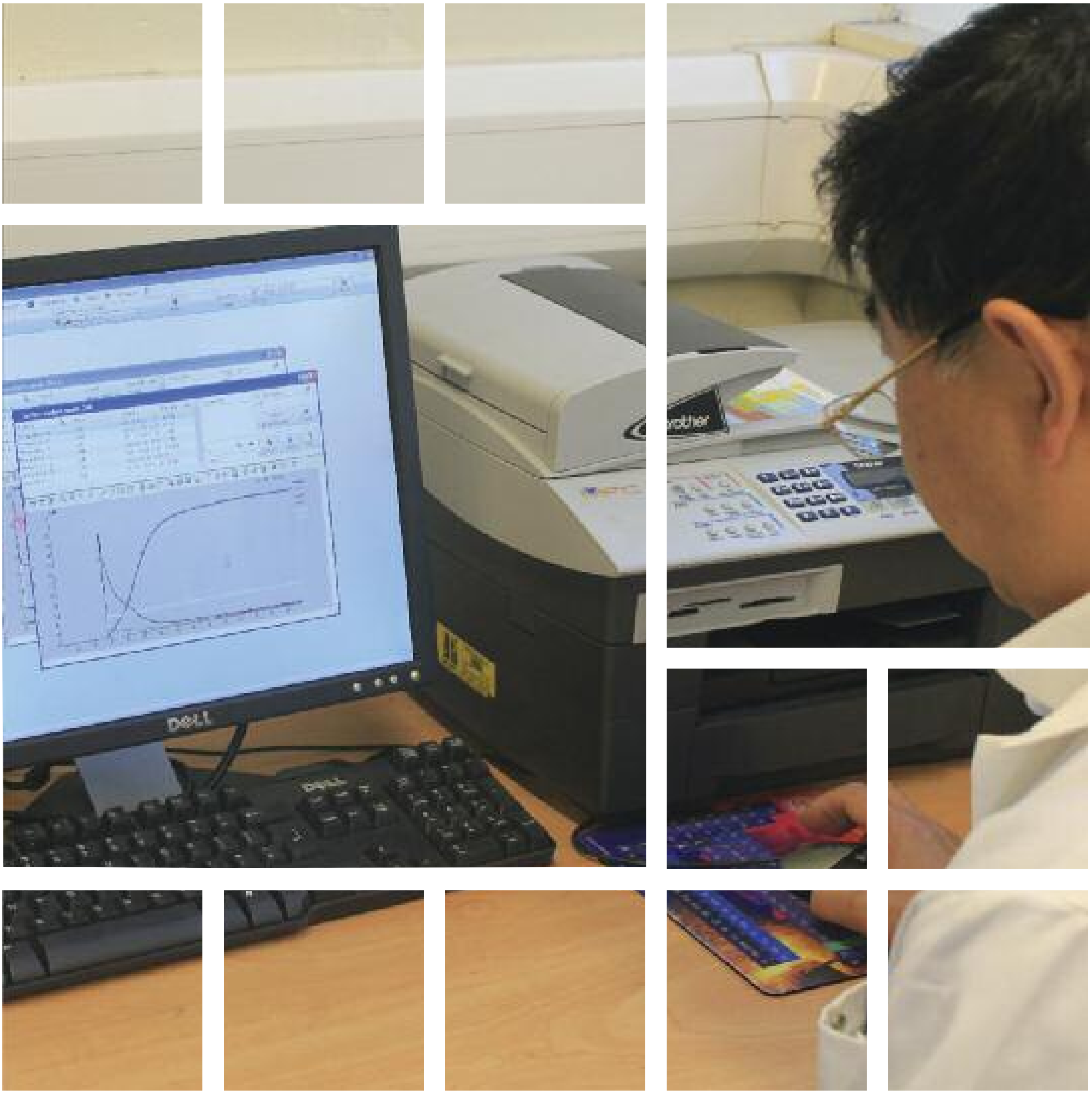
	Status	Target/actual End Date
Postdoctoral Research Projects		
Alloy Composition/Forming and Performance	Completed	12/12
Anodic Treatments of Light Alloys (Plasma Electrolytic Oxidation/Anodizing)	On Track	01/16
Development of a Distributable Software Package for Electrochemical Noise Analysis	Completed	03/12
Development of DIC Formability Assessment Methodology and Formability of Mg Alloy Sheets	On Track	01/16
Environmentally-Friendly Anodizing/Corrosion Testing	On Track	01/16
Grain Boundary Structure of New Generation Aerospace Alloys	Completed	12/12
Improving the Performance of Extruded Aluminium	On Track	12/14
Interfacial Reaction – Modelling and Control In Friction Joining and Fusion Welds	On Track	01/16
Modelling Twin Clustering and Its Effect on Formability	On Track	01/16
New chrome-free coatings and inhibitors for protection of aluminium alloys	On Track	11/15
Novel Friction Joining Processes for Dissimilar Metals	Completed	03/12
Novel Friction Joining Processes for Light Alloys	On Track	01/16
Replacement of copper conductors with aluminium	Completed	11/12
Use of selected ionic fluids for finishing of light alloys	On Track	11/14
Electron Optics Specialist Projects		
Use of Advanced Electron optical approaches for understanding the performance of light alloys	Completed	09/13
Research Assistant Projects		
Laser welding of aluminium-lithium alloys and performing validation of such models	Completed	02/12
Repair of Armoured Vehicles - Weld Re-Processing	Completed	09/13
PhD Research Projects		
A Novel Refill Friction Stir Spot Welding Approach to Joining Automotive Sheets	On Track	09/16
Anodic Films on Titanium	On Track	05/14
Anodizing of Aluminium Alloys with Rare Earth Additions	On Track	03/15
Characterisation and Simulation on Interface in Metallic Matrix Composites	On Track	09/15
Controlling Interfacial Reaction in Aluminium to Steel Dissimilar Metal Welding	On Track	03/15
Controlling Interfacial Reaction in Titanium to Aluminium for Aerospace Applications	On Track	09/14
Conversion Coatings of Aluminium	On Track	09/15
Optimisation of Stationary Shoulder FSW	On Track	09/15
Corrosion Control of Dissimilar Metals	On Track	09/15
Corrosion Control of Heat Exchange Alloys	Completed	12/11
Corrosion Protection by Encapsulated Inhibitors	On Track	12/15
Deformation Mechanisms in Polycrystalline Materials Studied By Diffraction Contrast Tomography	On Track	12/13
Development of Near-Surface Microstructure and Its Influence on Performance of AA3104 Aluminium Alloy	On Track	12/13
Effect of Microstructure on Corrosion Resistance and Anodizing Behaviour of AA2099T8 Alloys	Completed	12/10
Environmentally-Friendly Novel Coatings for Aerospace Alloys	On Track	09/14
Excessive Grain Coarsening In IN718 Engine Disc Forgings	On Track	09/15
Friction Joining of Aluminium to Magnesium for Light Weight Automotive Applications	Completed	09/12
Friction Stir Welding of Aluminium AA5xxx Alloys	Completed	09/12
Galvanic Corrosion of Magnesium Alloys	On Track	06/14
High Resolution, Low Voltage Electron Imaging	Completed	07/12
Hybrid Additive Manufacture with Deformation for Large Scale Near Net Shape Manufacture of Titanium Aerospace Components	On Track	09/15
Impact of Fabrication Process on the Performance of Aerospace Aluminium Alloys	On Track	09/15
Impact of Near Surface Microstructure on the Performance of Metallic Materials	On Track	09/14
Improving Aluminium-To-Magnesium Dissimilar Welding For Lightweight Automobile Applications	On Track	12/15
Influence of Forming On Corrosion of Lean 7000 Alloys	On Track	12/13
Interaction of Solute and Second Phase Particle Evolution with Deformation Mechanisms in Commercial Aluminium Alloys	On Track	12/13
Joint Performance and Interface Reactions in Dissimilar Aluminium to Steel Ultrasonic Spot Welding	Completed	09/12
Laser Spot Welding Dissimilar Materials	On Track	12/13
Laser Surface Processing	Completed	09/13
Laser Surface Treatment of Magnesium Alloys	On Track	12/13
Local Electrochemistry/Microstructural Revelation	Completed	09/12
Localised Corrosion of High Strength Aluminium Alloys	Completed	12/11
Mechanism of Pore Formation in Anodic Alumina	On Track	10/15

Key: Completed | On Track | On Hold | Stopped

	Status	Target/actual End Date
Metallurgical Performance of Hyper-Joint Pins in Composite to Metal Joining	On Track	03/14
Microstructural Descriptors and Deformation Heterogeneity in Titanium Alloys	Completed	09/11
Microstructure Characterisation and Corrosion Properties of the Heat Affected Zones of the Automotive AA6111 Alloy	Completed	06/12
Microstructure Formability Relationships in New Generation High Strength Aluminium Automotive Alloys	On Track	09/14
Microstructure Modelling For FSW	On Hold	09/11
Microstructure, Texture and Mechanical Property Evolution during Additive Manufacturing of Ti6Al4V Alloy for Aerospace Applications	Completed	12/11
Modelling of Friction Welding Processes	Completed	09/13
Modelling of the Friction Spot Welding Process	Completed	09/13
Nanotube Formation on Zirconium	Completed	09/11
Near-Surface Microstructures and their Influence on Performances of 8xxx and AA5182 Aluminium Alloys	Completed	02/13
Optimising Precipitate Shape and Habit for Strengthening in Magnesium Alloys	On Track	09/14
Particle Effects on Local Deformation, Recovery and Stored Energy in Aluminium Alloys By Measurement and Simulation	On Track	09/15
Particle Stimulated Nucleation: Deformation around Particles	On Track	12/13
Performance of Recycled Aluminium Alloys	On Track	12/15
Performance of Recycled Magnesium Alloys	On Track	12/15
Plasma Electrolytic Oxidation of Titanium	On Track	10/14
Predicting Performance of Al Armour Alloy Welds under Blast Conditions	On Track	09/15
Prediction of the Role of Defects in Fatigue Failure in Additive Manufactured SEBM Titanium Components	On Track	09/14
Quantifying Microstructure Heterogeneity and its Effect on Additive Manufactured Ti6Al4V Parts	On Track	06/15
Steel to Aluminium Laser Seam Welding	On Track	12/13
Stress Corrosion Cracking of Marine Alloys	On Track	12/13
Surface Integrity through Tomographic Reconstruction	On Track	09/14
Surface Treatment of Titanium and its Alloys for Adhesion Promotion	On Track	03/15
The Application of Taper Rolling to the Near-Net Shape Manufacture of Aluminium	On Track	09/15
The Effect of Alloying Elements on Deformation by Twinning in Alpha Titanium	On Track	06/14
The Effect of Macrozones in Crack Initiation and Propagation in Titanium Alloys	On Track	09/14
The Impact of Warm Forming on the Microstructure and Corrosion Behaviour of Recycled Aluminium Alloys	On Track	12/15
Thermo-Mechanical Processing of Advanced RE-Magnesium Alloys	On Track	08/14
Understanding Improved Formability in Mg Alloys Caused by Rare Earth Alloying Additions	On Track	09/14
Understanding the Formability of Titanium	On Track	01/16
EngD Research Projects		
Characterisation of Magnesium Castings Using X-Ray Tomography and Ultrasonic Inspection	On Track	12/13
Industrial Application of USW Aluminium Car Body Panels	Completed	03/12
Interrogation of the Manufacturing Route of Aluminium AA 1050 Alloy Used for Lithographic Application	Completed	02/13
Sol-Gel Coatings for Aerospace Alloys	Completed	09/12
MPhil Research Projects		
PEO of Magnesium	Completed	10/13
MSc Research Projects		
Accelerated Corrosion Testing by Electrochemical Noise Analysis	Completed	12/12
Anisotropy in Stretch Aged Al-Wing Skin Alloys	On Track	11/13
Anodizing of Aluminium in Chromic Acid	Completed	11/12
Anodizing of Aluminium in Selenate Solution	Completed	11/11
Anodizing of Al-W Alloys	On Track	11/13
Anodizing of Mg-Fe Alloy	On Track	11/13
Arc Welding of Titanium Pins to Manufacture Locking Features for Composite to Metal Joints	Completed	11/11
Corrosion and Electrochemical Behaviour of Friction Stir Welded Aluminium Alloy 7050-T7651	On Track	11/13
Corrosion Behaviour of A356 Alloy With Differing Iron Contents	Completed	11/12
Corrosion Control of Magnesium Alloys by PEO Coatings and Ionic Fluids	Completed	10/12
Effect of Voltage Ramp on PEO of Mg Alloys	Completed	11/12
Ennoblement of Magnesium Alloys	Completed	11/11
Galvanic Corrosion of GRPC/Aluminium Couples	Completed	11/11
Improving Adhesion of Polymer to Metal Joints by Advanced Anodizing	Completed	12/12
Influence of Ionic Fluids on the Growth Rate and Morphology of Anodic Film on Aluminium	Completed	11/12
Interface Reaction during Solid State Welding of Dissimilar Metals	Completed	10/10

Key: Completed | On Track | On Hold | Stopped

	Status	Target/actual End Date
MSc Research Projects (Continued)		
Interrogation of Composite/Aluminium Alloy Joints	Completed	11/11
Linear Friction Welding of Titanium/Stainless Steel	Completed	12/11
Nanotube Formation on Zirconium	Completed	11/12
Optimising Performance in High Speed Friction Spot Welding Dissimilar Materials	Completed	11/12
Severe Deformation Processing of Mg-Tri Calcium Phosphate (TCP) Composites for Biomedical Applications	Completed	11/12
Stationary Shoulder Friction Stir Welding of Aluminium Alloy 2014-T651	Completed	11/12
Study of Pore Formation in Anodized Aluminium	Completed	11/11
Systematic Investigation on Microstructural Evolution of CP-Ti and Ti-6Al-4V during Thermomechanical Processing	Completed	11/11
Texture Control in Wrought Magnesium Alloys Using Particles	Completed	11/12
The Effect of Friction Stir Processing on Microstructure and Properties of Aluminium Alloys	Completed	11/12
The Effect of Surface Treatment on the Anodizing Behaviour of Type - 5657 Aluminium Alloy	On Track	11/13
Understanding Strength Loss in Thin 2017 Aluminium Alloy Plate	Completed	11/11
Use of Arsenic Tracer for Study of Pore Growth	On Track	11/13
MEng Research Projects		
Dissimilar Refill Spot Welding of Al to Mg	Completed	06/13
Effect of Aluminium on Quasi Static Compression Behaviour of Cross-Rolled Alpha Titanium	On Track	06/14
Effect of Paint Bake Cycle on Friction Stir Spot Welding Of Aluminium Automotive Sheet	Completed	06/12
Effect of Tin and Zirconium on Twinning in Alpha Titanium	On Track	06/15
Fatigue in the Microstructure of Titanium	Completed	06/13
Interpretation of the Effect and Thermodynamics of Copper Interfacial Enrichments on A6111 Alloys	On Track	06/14
Strain Homogeneity of Titanium Alloy With and Without Macrozones	Completed	06/12
The Effect of Zirconium on Twinning in Alpha Titanium	Completed	06/13
Visitor Research Projects		
3-D Imaging of Rheocast Aluminium Alloy	On Track	02/14
Anodic Oxidation of Titanium for Energy Application	Completed	12/11
Anodizing of Titanium and Titanium Alloys	Completed	03/13
Antibacterial Properties of Coatings of Silanols	Completed	11/11
Characterisation of porous anodic films formed on aluminium	Completed	12/13
Coatings on Aerospace Alloys	Completed	12/12
Collaboration of Friction Stir Welding	Completed	09/13
Comparison of Ultrasonic Welding Variants for Al/Ti-Joints by Mechanical and Microstructural Analysis	Completed	07/12
Corrosion and Protection of Mg-RE Alloy	Completed	12/12
Corrosion Performance of Dissimilar Material Joints	Completed	04/12
Electroless Ni-P Coatings on Magnesium	Completed	11/11
Electroless Ni-B Coatings on Magnesium	Completed	11/11
Fatigue of PEO Coated Magnesium Alloy	Completed	11/12
Formation of Porous Films on Iron	Completed	03/12
Laser Shock Peening of Titanium Alloys	Completed	06/11
Low-Density Smart Polymers for Packaging Food	Completed	11/11
Nanoparticle Characterisation for Inhibition/Biocide Activity	Completed	04/11
Nanotube Film Formation on Titanium Alloy	Completed	10/12
Plasma Electrolytic Oxidation of Titanium for Photocatalysis and Energy Conversion Applications	On Track	01/14
Shock Peening of Aluminium Alloys	Completed	06/11
Sol-Gel Films	Completed	06/13
Suppression of the Formation of Fayalite (Fe_2SiO_4) By Antioxidant Composed of Refractory Powders for High Si Steel	On Track	10/14
TEM Observation of TiO_2 Films	Completed	09/12
Texture evaluation of Mg-based alloys during thermomechanical processing	Completed	12/13
Understanding the strength of sharply textured magnesium extrusions	Completed	08/13



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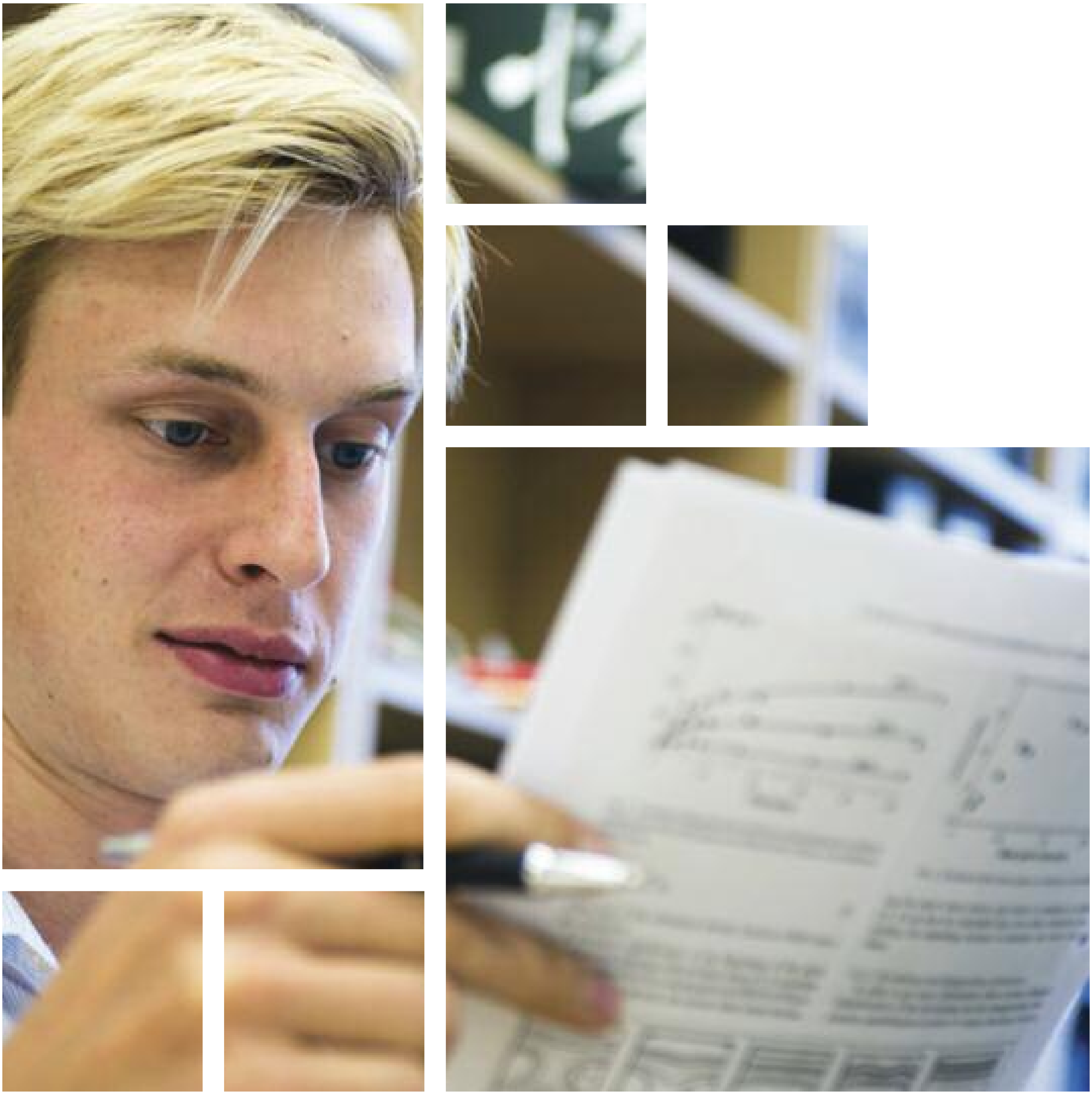

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17. "Environmentally-friendly anodizing of aluminium alloys", G. E. Thompson, M. Curioni, P. Skeldon, X. Zhou and E. Koroleva, 2nd International Conference on Surface Finishing of Light Aluminium, Paris (2011).
18. "In-situ observation and modelling of intergranular cracking in polycrystalline alumina", Materials Structure and Micromechanics of Fracture VI, Brno, Czech Republic (2011).
19. "Application of nuclear resonance analysis and narrow resonance profiling in understanding porous film growth on aluminium", A. Baron-Wiecheć, P. Skeldon, G. E. Thompson, J. J. Ganem and I. C. Vickridge, International Workshop on High-Resolution Depth Profiling, Paris (2011).
20. "Direct deposition of electroless Ni-P coatings on magnesium from basic and acid baths", A. Zuleta, E. Correa, M. Sepulveda, J. G. Castaño, F. Echeverría, P. Skeldon and G. E. Thompson. Presented at Eurocorr 2011, Stockholm, Sweden. (2011).
21. "Direct electroless nickel-boron plating on commercial purity magnesium", E. Correa, A. Zuleta, M. Sepulveda, J. G. Castaño, F. Echeverría, P. Skeldon and G. E. Thompson. (2011). Presented at Eurocorr 2011, Stockholm, Sweden. (2011).
22. "Contamination of surfaces in mass spectrometers", J. Doff, G. Jones, D. Douce, E.V. Koroleva, P. Skeldon and G. E. Thompson. Presented at Isranalytica, 14th Annual Meeting of the Israel Analytical Chemistry Society. Tel Aviv, Israel. (2011).

23. "Crystallographic pitting in 3XXX aluminium alloys", A. Laferrere, N. Parson, X. Zhou and G. E. Thompson. Presented at Eurocorr. Stockholm, Sweden. (2011).

24. "Hydrogen production from sodium borohydride on a Ni-Ru catalyst; an electrochemisal study", C. M. Rangel, V. R. Fernanded, M. J. F. Ferreira, A. M. F. R. Pinto, T. Hashimoto and G. E. Thompson. Presented at 4th World Hydrogen Technologies Convention. Glasgow. (2011).

25. "Polypyrrole films on aluminium from acid electrolytes: synthesis and characterisation", L. C. Scienza and G. E. Thompson. Presented at 27th World Congress of the Polymer Processing Society. Marrakech, Morocco. (2011).

26. "Characterisation of MEA degradation for an open air cathode PEM fuel cell", R. A. Silva, T. Hashimoto, G. E. Thompson. Presented at III Iberian Symposium on Hydrogen, Fuel Cells and Advanced Batteries. Zaragoza, Spain. (2011).

27. "Tomography of localised corrosion in AA2024 aluminium alloy", X. Zhou, C. Luo, T. Hashimoto, E. Koroleva, A. E. Hughes, G. E. Thompson and P. Withers. Presented at International Corrosion Congress. Perth, Australia. (2011).

28. "Tomography of localized corrosion in aluminium alloy", X. Zhou, C. Luo, T. Hashimoto, E. Koroleva, A. E. Hughes, G. E. Thompson and P. Withers. Presented at the 17th International Corrosion Congress. Perth, Australia (2011).

29. "On the impact of second phase particles on twinning in magnesium alloys", M. R. Barnett, N. Stanford, J. Geng, and J. D. Robson, 2011, in TMS 2011, 289-293 (2011).

30. "Effect of build geometry on texture and grain structure development in additive layer manufacture (ALM) of Ti-6Al-4V", A. A. Antonysamy, P. B. Prangnell and J. Meyer, Thermec, Quebec, Canada. (2011).

31. "Influence of build geometry on beta grain structure and texture during additive layer manufacture (ALM) of Ti-6Al-4V by electron beam selective melting", A. A. Antonysamy, P. B. Prangnell and J. Meyer, Titanium Conference (2011).

32. "Microstructure formability relationships in new generation high strength aluminium automotive alloys", R. A. Nolan, M-A. Kulas, J. Quinta da Fonseca and P. B. Prangnell, Euromat. (2012).

33. "Assessment by X-ray CT of the effects of geometry and build direction on defects in titanium ALM parts", F. Léonard, S. Tammas-Williams , P. B. Prangnell, I. Todd, P. J. Withers, in Symposium, Conference on Industrial Computed Tomography, Wels, Austria, (2012).

34. "Accelerated post-weld natural ageing in ultrasonic welding aluminium 6111-T4 automotive sheet", Y. C. Chen and P. B. Prangnell, In Symposium 13th International Conference on Aluminum Alloys (ICAA13) Edited by: H. Weiland, A. D. Rollett, W.A. Cassada, TMS, Pittsburgh, PA, (2012).

35. "Interfacial reaction during dissimilar joining of aluminum alloy to magnesium and titanium alloys", J. D. Robson, A. Panteli, C. Q. Zhang, D. Baptiste, E. Cai, P. B. Prangnell, In Symposium 13th International Conference on Aluminum Alloys (ICAA13) Edited by: H. Weiland, A.D. Rollett, W.A. Cassada, TMS, Pittsburgh, PA, (2012).

36. "Interface structure and bonding in rapid dissimilar FSSW of al to steel automotive sheet", Y. C. Chen and P. B. Prangnell, In Symposium 13th International Conference on Aluminum Alloys (ICAA13) Edited by: H. Weiland, A. D. Rollett, W. A. Cassada, TMS, Pittsburgh, PA, (2012).

37. "Optimization of anodizing cycles for enhanced performance", M. Curioni, T. Gionfini, P. Skeldon, E. Koroleva and G. E. Thompson, ASST 2012, Italy (2012).

38. "Application of electrochemical noise analysis to corroding aluminium alloys", M. Curioni, R. A. Cottis and G. E. Thompson, ASST 2012, Italy (2012).

39. "Measurement of electrochemical noise: Do we really need a zero resistance ammeter?", M. Curioni, ECG-COMON 2012, Petten, Netherlands (2012).

40. "Environmentally-friendly anodizing of aluminium alloys for aerospace", G. E. Thompson, M. Curioni, E. V. Koroleva, P. Skeldon, T. Hashimoto and X. Zhou, Corrosion and Prevention 2010, Adelaide, Australia (2010).

41. "Revealing the 3D internal structures of aluminium and its alloys", T. Hashimoto, X. L. Zhong, M. Curioni, X. Zhou, P. Skeldon, P. J. Withers and G. E. Thompson, ASST 2012, Italy (2012).

42. "Nanotomography for understanding the dealloying of second phase particles in aluminium alloys", T. Hashimoto, X. Zhou, M. Curioni, P. Skeldon and G. E. Thompson, ASST 2012, Italy (2012).

43. "Progress of galvanic corrosion in Elektron 21 magnesium alloy", J. Janiec-Anwar, G. E. Thompson, X. Zhou, M. Turski, T. Wilks and T. Hashimoto, 9th International Conference on Magnesium Alloys and their Applications, Vancouver, Canada (2012).

44. "Microstructure and corrosion resistance of eximer laser melted Elektron 21 rare-earth magnesium alloy", A. Shekhe, Z. Liu, P. Skeldon and G. E. Thompson, 9th International Conference on Magnesium Alloys and their Applications, Vancouver, Canada (2012).

45. "Thermal modelling of Al-Al and Al-steel friction stir spot welding", P. Jedrasiak, A Reilly, H. R. Shercliff, G. J. McShane, Y. C. Chen and P. B. Prangnell, In Mathematical Modelling of Weld Phenomena 10, Austria, (2012).

46. "Novel approaches to modelling metal flow in friction stir spot welding", A Reilly, H.R. Shercliff, G.J. McShane, Y. C. Chen and P. B. Prangnell, In Mathematical Modelling of Weld Phenomena 10, Austria (2012).

47. "Assessment of the advantages of static shoulder FSW for joining aluminium aerospace alloys", H. Wu, Y. C. Chen, D. Strong, and P. B. Prangnell, Thermec, Las Vegas, USA, (2013).

48. "Estudio del proceso de formacion de recubrimientos electroless Ni-P sobre el magnesio", A. Zuleta, E. Correa, M. Sepulveda, L. Guerra, J. G. Castano, F. Echeverria, P. Skeldon and G. E. Thompson, Congresso Internacional de Materiales, Medellin, Colombia (2013).

49. "Enhanced photo- and under X-ray luminescence from Xerogels embedded in mesoporous anodic alumina", N. Gaponenko, V. Kortov, V. Pustovarov, S. Zvonarev, A. Slesarev, M. V. Rudenko, L. S. Khoroshko, A. M. Asharif, I. Molchan, G. E. Thompson, A. Podhorodecki, J. Misiewicz, and S. Prislopskii, International Porous and Powder Materials Symposium, Turkey (2013).

50. "A study of mixed inhibitors for corrosion protection of AA2024 T3 aluminium alloy", A. C. Balsakas, M. Curioni, G. E. Thompson and G. Kordas, Eurocorr, Estoril, Portugal (2013).

51. "Corrosion testing of aerospace components by electrochemical noise analysis", M. Curioni, Z. Wang, A. C. Balaskas, E. Rahimi and G. E. Thompson, Eurocorr, Estoril, Portugal (2013).

52. "Reliability of noise resistance for the estimation of corrosion rate", M. Curioni and G. E. Thompson, Eurocorr, Estoril, Porugal (2013).

53. "Influence of galvanized coatings on abrasion circle friction stir spot welding aluminium to steel for automotive applications", Y. C. Chen, S-F Liu and P. B. Prangnell, Thermec, (2013).

54. "Mechanical and microstructural characterization of percussive arc welded hyper-pins for titanium to composite metal joining, in LMT2013", R. J. Oluleke, D. Strong, O. Ciuca, J Meyer, A. De Oliveira and P. B. Prangnell, 6th Int. Symp. on Light Metals Technology, (2013).

55. "The effect of temperature on the formability of a high strength aluminum automotive", R. A. Nolan, M-A. Kulas, P. B. Prangnell, J. Quinta da Fonseca, MS&T 2013, Materials Science and Technology 2013, Montreal, Canada (2013).

56. "Grain structure evolution in alumnium to steel ultrasonic spot welding", F. Haddadi, P. B. Prangnell, MS&T 2013, Montreal, Canada (2013).

57. "Advanced aluminium extrusion technology", McCool, N. S. Malone, J. O'Connor, P. Howe, S. Mills, G. E. Thompson, Y. Liu, X. Zhou, M. Curioni, E. McAlpine, G. Scamans, C. Butler, Aluminium International Today, (2013).

PRESTIGE, AWARDS AND INVITED LECTURES

Prestige

Professor G.E.Thompson
Description of Membership: International Organising Committee Member for ASST Conference 2014.
Date Applicable: 2013

Professor M. Preuss
Description of Membership: Member of the ILL Scientific Council
Date Applicable: Annually

Professor M. Preuss
Description of Membership: Chair of the Science and Technology Advisory Panel a New Engineering Instrument at the European Spallation Source, Lund, Sweden
Date Applicable: Annually

Professor M. Preuss
Description of Membership: Member of the ILL Sub-Committee for the Upgrade Endurance Programme
Date Applicable: Annually

Dr J. D. Robson
Description of Membership: International Advisory Panel, 9th International Conference on Magnesium Alloys and their Applications, Vancouver, Canada
Date Applicable: 2012

Dr X. Zhou
Description of Election: Elected Fellow for the Institute of Corrosion
Date Elected: April 2012

Dr X. Zhou
Description of Election: Elected Fellow for the Institute of Materials
Date Elected: August 2012

Dr J. Quinta Da Fonseca
Description of Election: Election to ISIS Beam Time Access Panel
Date Elected: August 2012 for 2 years

Dr J. D. Robson
Description of Membership: ICAA14 International Organizing Committee Member
Date Applicable: 2012 - 2014

Dr X. Zhou
Description of Membership: Ontario Centre of Excellence Assessment Panel
Date Applicable: 2012

Dr J. D. Robson
Description of Membership: Co-chair and Organizer of Magnesium Technology Symposium, EuroMat
Date Applicable: 2011

Professor M. Preuss
Editorial Role: Section Editor of Encyclopaedic for Aerospace Engineering covering High Temperature Materials
Date Applicable: Dec 2011 - ongoing

Dr J. D. Robson
Description of Membership: Manchester Metallurgical Society (Vice President)
Date Applicable: 2011 - Present

Dr J. D. Robson
Description of Membership: EPSRC College Peer review
Date Applicable: Annually

Professor P. B. Prangnell
Description of Membership: Thermec Conference Organisation
Date Applicable: Annually

Professor M. Preuss
Description of Membership: EPSRC College for Reviewing Proposals
Date Applicable: 2010 - Present

Professor M. Preuss
Description of Membership: Titanium Information Group (TIG) Member
Date Applicable: 2009 - Present

Dr J. D. Robson
Description of Membership: Light Metals Board, IOM3
Date Applicable: 2005 - Present

Professor G. E. Thompson
Description of Membership: Editorial Board Member of Electroplating and Finishing
Date Applicable: 2005 – Present

Professor G. E. Thompson
Description of Appointment: Officer of the Order of the British Empire (OBE) for research activities of relevance to the defence industries June 2000

Professor G. E. Thompson
Description of Membership: Editorial Board Member of Anti Corrosion Methods and Materials
Date Applicable: 1997 – Present

Professor G. E. Thompson
Description of Membership: Editorial Board Member of Corrosion Science
Date Applicable: 1992 – Present

Professor G. E. Thompson
Description of Membership: Fellow, Institute of Metal Finishing (FIMF)
Date Applicable: Anually

Professor G. E. Thompson
Description of Membership: Fellow, Institution of Corrosion (FICorr)
Date Applicable: Anually

Professor G. E. Thompson
Description of Membership: Fellow, Institute of Materials, Minerals and Mining (FIMMM)
Date Applicable: Anually

Professor G. E. Thompson
Description of Membership: Fellow, Electrochemical Society, New Jersey, USA (FECS)
Date Applicable: Anually

Professor G. E. Thompson
Description of Membership: Fellow, Royal Academy of Engineering (FREng)
Date Applicable: Anually

Awards

Professor M. Preuss
Description of Award: IOM3 Grünfeld Memorial Award and Medal 2013
Awarding Body: IOM3
Date Awarded: March 2013

Dr M. Curioni, Professor P. Skeldon and Professor G. E. Thompson
Description of Award: Co-recipients of the Jim Kape Memorial Medal of the Institute of Metal Finishing 2013
Awarding Body: IOM3
Date Awarded: August 2013

Ms B. Liu
Description of Award: 1st Prize in The University of Manchester PGR Conference Poster Competition 2013
Awarding Body: The University of Manchester
Date Awarded: May 2013

Mr C. Zhang
Description of Award: 2nd Prize in The University of Manchester PGR Conference Poster Competition 2013
Awarding Body: The University of Manchester
Date Awarded: May 2013

Ms J. Janiec-Anwar
Description of Award: 3rd Prize in The University of Manchester PGR Conference Poster Competition 2013
Awarding Body: The University of Manchester
Date Awarded: May 2013

Ms B. Liu
Description of Award: 3rd Prize in Young Lecture Competition 2013
Awarding Body: IOM3
Date Awarded: March 2013

Dr C. Zhang
Description of Award: 1st Prize in the EPSRC LATEST2 Researcher Symposium Poster Competition 2012
Awarding Body: The University of Manchester
Date Awarded: October 2012

Dr A. Lafferrere and Mr J. Smith
Description of Award: IOM3 Colin Humphrey's Education Award 2012
Awarding Body: IOM3
Date Awarded: March 2012

Dr K. Li
Description of Award: 3rd Prize in Young Lecture Competition 2012
Awarding Body:IOM3 North West
Date Awarded: March 2012

Dr A. Němcová
Description of Award: 1st Prize in the 15th International Corrosion and Corrosion Protection of Metals Conference Poster Competition
Awarding Body: ICCPM
Date Awarded: October 2012

Dr J. D. Robson
Description of Award: IOM3 Grunfeld Memorial Award and Medal 2011
Awarding Body: IOM3
Date Awarded: March 2011

Dr A. Antonysamy
Description of Award: Winner of the Best Research Poster at the 'National Level Conference on Technology Developments in Titanium'
Awarding Body: Titanium Information Group TIG-UK
Date Awarded: April 2011

Dr K. Li
Description of Award: 1st Prize in The University of Manchester PGR Conference Poster Competition 2011
Awarding Body: The University of Manchester
Date Awarded: May 2011

Dr J. Wang
Description of Award: 1st Prize in the EPSRC LATEST2 Symposium Poster Competition 2011
Awarding Body: The University of Manchester
Date Awarded: May 2011

Dr Alphons Antonysamy receiving his award for best research poster at the 'National Level Conference on Technology Developments in Titanium', on behalf of the Chairman of the Titanium Information Group

Invited Lectures

Dr X. Zhou
Invited Lecture: "Electrochemical Methods and Surface Analysis in Corrosion Research", Vrije Universiteit Brussel, Belgium (September 2013)

Dr X. Zhou
Invited Lecture: "Grain Boundary Precipitation and Corrosion Behaviour of Al-Li alloy", Constellium, Grenoble, France (September 2013)

Dr X. Zhou
Invited Lecture: "Environmentally-Friendly Surface Treatment for Al-Li Alloy", Beijing Institute of Aeronautical Materials, Beijing, China (August 2013)

Dr J. D. Robson
Invited Lecture: Light Metals Technology Conference, Windsor, UK (July 2013)

Professor G. E. Thompson
Plenary Lecture: "Development of Environmentally-Friendly Anodizing Conditions", Italian Metallurgical Society, Naples, Italy (July 2013)

Dr J. Quinta da Fonseca
Invited Lecture: Constellium, Grenoble, France (June 2013)

Dr X. Zhou
Plenary Lecture: "New Development in Research for Corrosion Resistant Film on Aluminium Alloys", The 3rd International Conference, Aluminium 21-Coatings, St Petersburg, Russia (June 2013)

Dr J. D. Robson
Invited Lecture: Magnesium Technology Workshop, Madrid, Spain (May 2013)

Professor M. Preuss
Invited Lecture: "Variant Selection in Ti Alloys", BARC seminar series, Mumbai, India (February 2013)

Dr J. D. Robson
Invited Lecture: Constellium CRV, Grenoble, France (January 2013)

Dr J. Quinta da Fonseca
Invited Lecture: IOM3, Surrey, UK (December 2012)

Dr X. Zhou
Invited Lecture: "Nanotomography of Localized Corrosion in Aluminium Alloys", China State Key Laboratory for Marine Corrosion and Protection, Beijing, China (November 2012)

Dr J. Quinta da Fonseca
Invited Lecture: IOM3, Surrey, UK (October 2012)

Dr X. Zhou
Invited Lecture: "New Observation of Intergranular Corrosion in Aluminium Alloy", The 16th Asian Pacific Corrosion Control Conference, Kaohsiung, Taiwan (October 2012)

Dr J. Quinta da Fonseca
Invited Lecture: IMR, Shenyang, China (September 2012)

Professor M. Preuss
Invited Lecture: "Ti and Related Research - Materials Performance", Bao steel and IMR, Shenyang, China (September 2012)

Dr X. Zhou
Invited Lecture: "Initiation and Propagation of IGC in AA2xxx Aluminium Alloys", Airbus, UK (August 2012)

Dr J. D. Robson
Invited Lecture: Welding Summer School, Leicester, UK (August 2012)

Dr J. D. Robson
Invited Lecture: Magnesium Technology Conference, Canada (July 2012)

Professor G. E. Thompson
Invited Lecture: "Revealing The Three Dimensional Internal Structure of Aluminium Alloys", Aluminium Surface Science and Technology Symposium (ASST VI), Sorrento, Italy (May 2012)

Professor G. E. Thompson
Invited Lecture: "In-SEM Tomography (Nano- and Micro-Tomography with 3View and XuM Capabilities)", FESI-UK Forum for Engineered Structural Integrity Conferences and Related Continuing Professional Development, Manchester, UK (April 2012)

Dr X. Zhou
Invited Lecture: "Corrosion Control of Aluminium Alloys for Aircraft Application", The 2nd International Symposium on Aeronautical Engineering, Santiago, Chile (March 2012)

Professor M. Preuss
Invited Lecture: "Variant Selection in Ti Alloys", Ti European Conference, Bristol, UK (March 2012)

Dr J. D. Robson
Invited Lecture: The Minerals, Metals and Materials Society (TMS), Florida, USA (March 2012)

Dr X. Zhou
Invited Lecture: "Near-Surface Microstructure and Anodic Film Growth on Aluminium Alloys", Sapa Technology Centre, Sapa Group (February 2012)

Professor G. E. Thompson
Plenary Lecture: "Fundamental Studies to Assist Development of Environmentally-Friendly Coatings on Aluminium Alloys", Materials Science and Engineering Symposium, Doha, Qatar (February 2012)

Professor M. Preuss
Invited Lecture: "So you think you understand deformation in metals?" Imperial College London, UK (January 2011)

Dr X. Zhou
Invited Lecture: "Electron tomography of Aluminium Alloys", Constellium, Grenoble, France (December 2011)

Professor G. E. Thompson
Plenary Lecture: "Fundamental Studies to Assist Development of Environmentally-Friendly Anodizing Treatments on Aluminium Alloys", China (Ningbo) International Forum on Advanced materials and Commercialization, Ningbo (December 2011)

Professor G. E. Thompson
Plenary Lecture: "Environmentally-Friendly Anodizing of Aluminium Alloys for Aerospace", Corrosion and Prevention Conference, Adelaide, Australia (November 2010)

Dr X. Zhou
Invited Lecture: "Nanotomography of Localised Corrosion in Aluminium Alloys", The Australian Research Council (ARC) Centre of Excellence for Design in Light Metals Annual Conference, Melbourne, Australia (November 2011)

Professor G. E. Thompson
Invited Lecture: "Environmentally-Friendly Anodizing of Aluminium Alloys", 2nd International Conference on Light Metal Surface Finishing, Paris, France (November 2011)

Professor G. E. Thompson
Invited Lecture: "Reducing the Energy Cost of Anodizing", Australasian Corrosion Association, Melbourne, Australia (November 2010)

Dr J. D. Robson
Invited Lecture: European Conference on Aluminium Alloys (ECAA), Germany (October 2011)

Dr J. D. Robson
Invited Lecture: MagNet Conference, Canada (October 2010)

Dr J. D. Robson
Invited Lecture: EuroMat Conference, France (September 2011)

Dr J. D. Robson
Invited Lecture: OPTIMoM Conference, Cambridge, UK (September 2010)

Professor P. B. Prangnell
Invited Lecture: "Effect of Build Geometry on Texture and Grain Structure Development in Additive Layer Manufacture (ALM) of Ti-6Al-4V", Thermec, Quebec, Canada (August 2011)

Professor P. B. Prangnell
Invited Lecture: "Friction Spot Welding Dissimilar Materials with Rapid Cycle Times", Thermec, Quebec, Canada (August 2011)

Dr J. D. Robson
Invited Lecture: Thermec Conference, Quebec, Canada (August 2011)

Dr J. D. Robson
Invited Lecture: PRICM Conference, Cairns, Australia (August 2010)

Dr J. D. Robson
Invited Lecture: IPSUS Summer School, Germany (August 2010)

Dr Xiaorong Zhou delivering an invited lecture on "Nanotomography of Localised Corrosion in Aluminium Alloys".

FINANCIAL INVESTMENT SUMMARY

The financial support for the EPSRC LATEST2 Programme has continued to grow year on year since its inception in July 2010 with the cumulative added value funding now standing at £8.65 million which exceeds the target to match the initial core funding of £7.5 million provided by the EPSRC and The University of Manchester set at the outset of the programme, as illustrated below in Figure 1.

The LATEST2 Team are committed to continue to strive to attract added value funding to the Programme in order to optimise the outputs and impact of the research.

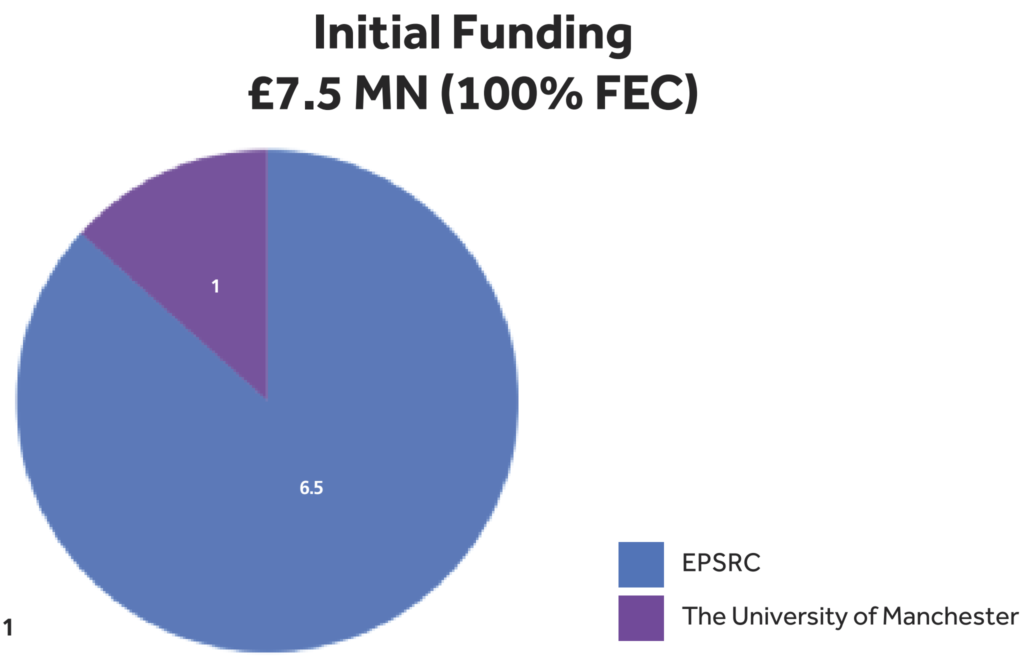


Figure 1

The added value funding achieved to date originates from a variety of sources including industry as a major contributor given the importance of research being undertaken in this field, Research Councils both national and international and international governments as illustrated in Figure 2 below. The funding comprises new associated research grants, sponsorship of Postdoctoral Researchers or Students, collaborative projects, value in kind etc.

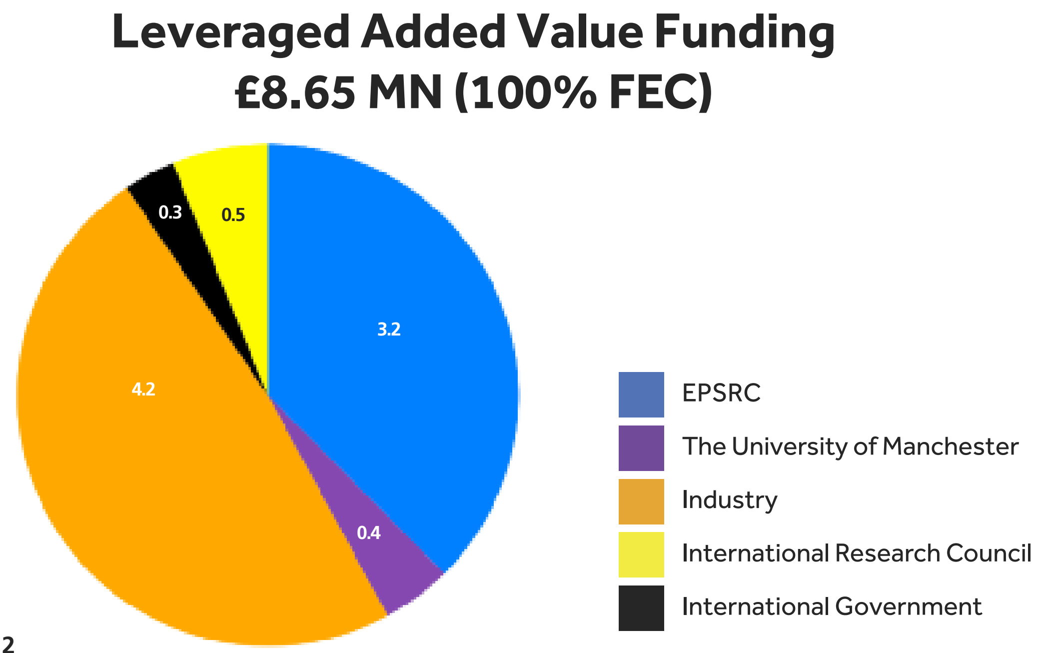


Figure 2

HUMAN CAPITAL IMPACT

A high priority for the EPSRC LATEST2 Programme Grant is to help address the skills gap in metallurgical and corrosion science training, to contribute to the future generation skills base for academia and industry and to help provide globally competitive and innovative materials engineers needed by the UK manufacturing sector.

Over the period of the award, there has been continued intake, development and progression of both students and researchers. Specifically one of our Co-Investigators has been awarded an EPSRC Leadership Fellowship and promoted to Professor of Metallurgy. A second has been promoted to Reader, a third has been promoted to Senior Lecturer, and one of our Post Doctoral Researchers has been promoted to LATEST2 Research Fellow, in recognition of their achievements, high quality research and leadership qualities.

The EPSRC LATEST2 Programme Grant has successfully attracted high quality students and researchers, some of whom are now progressing with their careers either within academia or within industry.

Here are some examples of profiles of LATEST2 students and researchers, there are already many real success stories for the EPSRC LATEST2 Programme Grant.

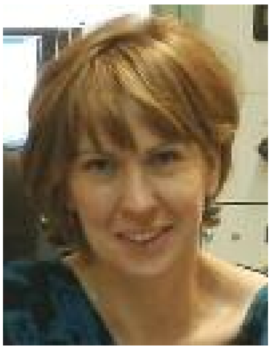
Dr. Alphons Anandaraj ANTONYSAMY
Materials Lead at GKN Aerospace Filton, UK

During my Bachelors degree in metallurgical engineering at Periyar University in India, I developed an interest in metallurgical engineering. After graduating I began my working career as a 'Metallurgical Process and Quality Control Engineer' at TVS Brakes India Ltd, Foundry Division, Tamilnadu. After 2 years of Foundry experience, I had the opportunity to pursue my Masters degree at IIT kharagpur with sponsorship from the Ministry of Human Resource Development of India, where I gained an in-depth understanding of Metallurgical and Materials Sciences. I was awarded a DAAD scholarship to complete my one year master's research project at the Technical University-Dresden, Germany as a Sandwich programme between IIT-India and Germany Universities. After completing my Masters degree, I worked at Renault-Nissan Technology and Business Centre, India as a Materials Engineer/Specialist. After working to standards and specifications set by material scientists, I realised that I still lacked knowledge of what factors define and restrict metallic materials in real time engineering applications. This in fact, stimulated me to pursue a research course focused on advanced manufacturing processes and materials and hence I chose to pursue my PhD in the reputed University of Manchester on the fast growing technology of Additive Manufacturing of Ti6Al4V alloys which was sponsored by the EPRSC LATEST Programme Grant, and EADS Innovations Work, UK.

Specifically, my thesis was focused on 'Microstructure, Texture and Mechanical Property Evolution during Additive Manufacturing of Ti6Al4V Alloy for Aerospace Applications'. I enjoyed the research environment, technical advice and experimental help offered by my Professor/Advisor, laboratory technicians, and more importantly the advanced facilities which were made available to me within the School of Materials at The University of Manchester. I worked utilised the SEM-EBSD, high resolution 3D x-ray tomography, high resolution Megellam SEM (which could replace high resolution TEM imaging capability), x-ray diffraction for residual stress and texture analysis, tensile testing, etc. During my PhD I had the opportunity to work closely with key industrial partners such as EADS-Airbus (collaborator for PhD work), Bombardier Aerospace, TWI, Timet, etc. I also had the opportunity to collaborate with other universities such as Cranfield University (via RUAM Project-Ready to Use Additive Manufacturing) and University of Sheffield (AMRC) in the field of AM in the UK with unique multidisciplinary experiments on the leading edge of advanced technology development. These collaborations helped me to share my thoughts and gain knowledge on the latest advances in research and development in this area. I was very pleased with the guidance received and the quality of my 'PhD Thesis' which I submitted to The University of Manchester and has been downloaded more than 600 times within a year from all around the world (the top 10 countries to download it include the USA, India, Germany, Japan, China, Iran, France, Vietnam, Belgium and Singapore). In addition, 7 journals and conference papers have been published out of this research on microstructure and mechanical properties of TiAl4V alloys using AM.

After completing my PhD in May 2012, I obtained a position as Materials Lead at the Additive Manufacturing Centre, GKN Aerospace, Filton, UK in June 2012. Where I am now attempting to industrialise the research topic that I worked on during my PhD, where Ti6Al4V parts are manufactured through an additive manufacturing route for real-time use in aerospace applications. This work is being carried out under an ecoHVP project (ecologically High Value Parts) with a £10 million investment from GKN and EADS (50-50 % collaboration) including £2 million from the BIS-UK Government. Since Additive manufacturing offers complete design freedom and approximately 30% overall weight reduction of existing parts. I am enjoying being part of big ecoHVP team as Materials Lead and, also since joining I have been involved with 4 other projects as materials advisor and, currently working towards a project leader/managerial position in near future at GKN Aerospace, UK for materials related projects. I am also representing GKN Aerospace as a part of the ASTM F42 Committee working on establishing, reviewing and approving the new standards for additive manufacturing.

I would certainly recommend any industrial researchers or Materials Science and Engineering students to pursue high end research on advanced characterization and manufacturing technologies at The University of Manchester.



Dr Aleksandra Baron-Wiecheć
Physicist in Culham Centre for Fusion Energy (UKAEA), UK

After completing my PhD, my scientific career began when I obtained a position as assistant professor at the Silesian University of Technology in Gliwice, Poland in 2005. I was involved in a project focused on an investigation of the relationship between structure and thermal crystallization processes of amorphous soft magnetic Fe-based alloys as well as their magnetic features and corrosion behavior.

I first joined the School of Materials at The University of Manchester in 2008 as a Marie Curie Fellow (IEF for Career Development, FP7). During my time at Manchester I was a frequent user of the Van de Graaff accelerator at the Université Pierre et Marie Curie in Paris, where I used a wide range of Ion Beam Analytical techniques to study the mechanism of anodizing. Thanks to the project I got an opportunity to perform unique multidisciplinary experiments at the edge of electrochemistry and nuclear physics.

After finishing my Marie Curie fellowship in 2010 I was privileged to join the EPSRC LATEST2 Programme Grant and continued my scientific adventure within a vibrant environment created by the LATEST2 Team. Thanks to the project's research plan and availability of a variety of equipment I gained invaluable hands-on experience in conducting experiments in electrochemistry and materials/surface science. Thanks to the great knowledge of my supervisors and very helpful colleagues within the LATEST2 team, I have gained not only hands-on experience but also new, and more importantly, transferable skills. I feel fortunate to take these important lessons with me. This combined experience gave me a very important confidence for moving to Culham Centre for Fusion Energy (CCFE) and being successful as an independent scientist in a demanding environment.

The Culham Centre for Fusion Energy (CCFE) hosts the world's largest magnetic fusion experiment JET (Joint European Torus), on behalf of its European partners. The JET facilities are operated for scientists from around Europe, co-ordinated by the EFDA-JET Close Support Unit (under the European Fusion Development Agreement). I work in the R&D Experimental Department and my work includes responsibility for a wide range of surface analysis techniques applied to materials extracted from JET tokamak, development of links with UK and overseas Universities to encourage participation in exploitation of JET data and also assistance in operation of some of JET diagnostic during plasma campaigns.

Dr. Kasra Sotoudeh
BEng. MSc, PhD, CSci MIMMM
Section Manager
Stainless Steel and Non-Ferrous Alloys Section
Materials Group
TWI Ltd. Cambridge

I joined TWI in 2011 and currently work in Cambridge as the Section Manager of Stainless Steel and Non-Ferrous Alloys Section, Materials Group.

My position requires me to lead a wide range of projects, from rapid turn-round failure investigations to long-term R&D programmes for individual companies, consortia of companies and Governmental programmes in oil and gas, power generation, heavy engineering and transport sectors. I am also involved with consultancy work, including failure analysis and managing and conducting single and joint industrial and research projects with main areas of focus related to materials assessment/selection, microstructure property relationships, welding metallurgy (similar and dissimilar joints) and fabrication cracking, combined with expertise in service performance and failure including corrosion, creep, fracture and resistance to environmentally assisted cracking of metallic materials with particular interest in improving materials qualification and design of duplex stainless steels, titanium, aluminium and nickel alloys.

Before joining TWI, I studied and worked at The Materials Science Centre, The University of Manchester more than 7 years. After completing my MSc in 2005, I pursued a PhD in Mechanical Metallurgy of Light Alloys with the thesis title of 'Fundamental Superplasticity of Aluminium Alloys'. During the course of my PhD, I challenged widely held views on superplasticity, namely grain boundary sliding and slip, and quantitatively demonstrated that superplasticity is primarily a result of diffusion creep. After finishing my PhD I stayed on as a Research Associate with my main areas of focus relating to advance metal forming of a wide range of ferrous and non-ferrous alloy sheets.

Throughout these years, the EPSRC funded Light Alloys Towards Environmentally Sustainable Transport (LATEST) Programme Grants, 1st and 2nd Generation, provided me with financial support and also gave me the opportunity to work with a number of knowledgeable academics based at the School of Materials and collaborate with a number of prominent industrial partners. The experience has indeed had a significant and positive effect on my personal development and has helped me develop a successful career.

Dr Lexi Panteli
Consultant in Materials Science for Clean Energy – Europe
Amec, UK

Having completed my Masters degree in Biomedical Materials Science at The University of Manchester, I spent three years working for BAE SYSTEMS developing and assessing Radar Absorbing Materials using various Composite and Elastomeric materials. I rejoined the School of Materials in 2009 to study for a PhD in Metallic Materials as part of the Light Alloys Towards Environmentally Sustainable Transport (LATEST2) Research Programme of work, funded by EPSRC.

Within the LATEST2 framework I was able to work with knowledgeable supervisors, researchers, students and technicians within the university, and collaborated with many people from other organisations, such as Cranfield University and the Beijing Institute of Aeronautical Materials. I was fortunate to have the opportunity to present my work at conferences in the UK and the USA which, coupled with the diverse backgrounds of my LATEST2 peers, has enabled me to build an international network of fellow metallurgists. The facilities available to me during my PhD allowed me to conduct in depth research into Solid State joining of aluminium to magnesium, the issues facing joining these two materials, and finding potential solutions. I enjoyed working on a project that had genuine focus on both the advancement of scientific knowledge and its application to a real world issue; successful joining of aluminium to magnesium could result in a significant reduction in automotive emissions. Ultrasonic welding, friction stir welding, scanning electron microscopy, x-ray diffraction and electron backscatter diffraction were amongst the techniques I used, and there were many other advanced facilities available as well. To date, the research I conducted within my PhD has directly resulted in three published academic papers, with a fourth having been accepted.

I currently work for AMEC, Clean Energy – Europe in Warrington, a focused supplier of consultancy, engineering and project management services to its customers in the world's oil and gas, mining, clean energy, environment and infrastructure markets. My role is as Task Manager for a large project researching the Effect of a Heat Flux on the Corrosion of Zirconium in Nuclear reactors, and I also work as a Structural Integrity Consultant providing safety advice to a naval plant. My PhD developed many of the skills that are necessary in my current job: oral and written communication skills, communicating technical content effectively and undertaking independent research are all essential, as are some of the technical skills I learnt during my studies, such as microscopy.

Dr. Leo Prakash D.G
Senior Lecturer
Materials Research Center,
School of Engineering,
University of Swansea, UK

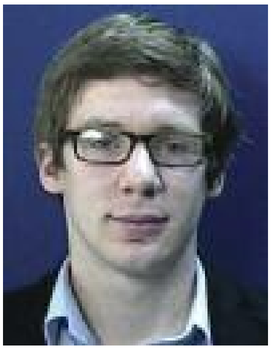
After completing my Dr.-Ing. in OvG Universität Magdeburg, Germany and postdoctoral research tenure in University of Oxford. In 2008 I joined the School of Materials, The University of Manchester, as a Research Associate. I have been working on hexagonal metals with a special emphasis on light metals (titanium and magnesium) in close association with the LATEST2 investigators, Dr. João Quinta da Fonseca and Professor Michael Preuss. One of the main aspects of my research has been characterizing and modeling the heterogeneous nature of hexagonal metal deformation and investigating its effects on materials performance. The encouraging support of Joao and Michael, and the vibrant research environment in the LATEST2/School of Materials offered me the motivation to become an expert in hexagonal metals (titanium, magnesium and zirconium), texture evolution, thermomechanical processing, phase transformations and in a wide range of the state-of-the-art analytical tools, such as EBSD, image correlation, in-situ neutron and X-ray synchrotron diffraction and crystal plasticity finite element modeling. Furthermore, this also provided me with an opportunity to work on Nuclear Materials (zirconium), with other research groups (Professor Phil Withers), Universities (Sheffield and Birmingham) and Industries (Rolls-Royce plc, Serco and Timet UK).

Rotimi Joseph Oluleke
Metallurgist at Rawwater Engineering Company Limited

After completing my Bachelors degree in Metallurgical and Materials Engineering in Obafemi Awolowo University, Nigeria, I came to the U.K. to study for a Masters in Materials for Industry in Loughborough University. By this stage, I had developed a strong interest in engineering materials and wanted to undertake a PhD at a world renowned institution.

I decided to come to The University of Manchester as it had a great reputation worldwide in the field and also beyond this, and on a personal note, I had a strong recommendation from my mentor who had studied at The University of Manchester in the 1970s in a similar field. On this basis, I accepted an offer to undertake a research PhD on a project titled the "Metallurgical performance of hyper joints in composite to metal joining" which was sponsored by EPRSC LATEST2 Programme Grant and EADS Innovations Work, UK. I was particularly interested in the project because it offered me the unique experience of direct collaboration with industrial partners like EADs and TWI on a novel means of composite to metal joining. The project involved investigating the use of titanium alloys for making hyper-joint features via different manufacturing routes such as additive layer manufacturing and arc-percussive welding. The project also involved conducting series of mechanical testing to ascertain the performance of such hyper-joints features and modelling using Abaqus FE to simulate experimental observations. I was able to achieve the aims and objectives of the project in part due to the wide range of research facilities provided by the university and most importantly because of the technical advice and assistance offered by both my academic and industrial supervisors.

I currently work with Rawwater Engineering Company Limited (RECL) as a Metallurgist. RECL is an oil industry flow-assurance company providing specialist testing and consultancy in the fields of well technology, water management, materials science and improved oil recovery. In my role as a Metallurgist for RECL, I am responsible for leading the materials section in alloy development that is being considered for metal to metal sealing in oil well abandonment process. In the short period of time that I have being working for RECL, I have come to appreciate all the skills and knowledge I have gained during the course of my PhD from materials testing, characterisation using the SEM and even reviewing FEA models. Being in a small team, I have been given high level responsibilities including liaising with external product qualification agencies, decision making and project management. For this and many more, I am deeply grateful to The University of Manchester, EPRSC LATEST2 Programme Grant for giving me the opportunity to undertake my PhD degree successfully which has now given me the right platform to begin my career in engineering and materials science at RECL.



David Mackie MSc BEng(Hons)
Materials Engineer
Amec Oil and Gas, UK

While at The University of Manchester I studied for an MSc in Advanced Engineering Materials which complimented my previous industrial experience and undergraduate Mechanical Engineering degree. After completing my MSc I was offered the opportunity to study for an EngD sponsored by Magnesium Elektron and contributing to the EPSRC LATEST2 Research Programme at The University of Manchester.

This combination of industrial and academic working environments made for a very interesting and rewarding research project. Working on the inspection of cast light alloys I frequently used the facilities of the Manchester X-ray Imaging Facility and electron microscope suite. Combined with the support of the academic staff and fellow students the research degree was a positive experience which has enabled me to secure employment in the UK.

Since leaving Manchester I worked as an alloy development metallurgist for Oil and Gas Well Abandonment applications. I was able to undertake this role thanks to the skills I learnt both technical and professional during my studies. Indeed the reputation of The University of Manchester helped me to secure my current position as a Materials Engineer for Amec Oil and Gas, UK. Since commencing this role I have been responsible for carrying out an audit on a forge in Italy and working as part of a multi-disciplined team on maintenance projects for North Sea production platforms.

IMPACT - SCIENCE COMMUNICATION

EPSRC LATEST2 SCIENCE COMMUNICATION PROGRAMME

The LATEST2 Team are committed to delivering an effective science communication programme to engage with a wide range of target audiences and have delivered strong growth in contact numbers. The key goals are to raise awareness of the EPSRC, the engineering and physical sciences in general and to share the research being undertaken by the EPSRC LATEST2 Programme and its value to society. To develop collaborations both academic and industrial, to facilitate effective knowledge transfer and to help address the skills gap by attracting high quality students and researchers into the engineering and physical sciences by engaging with schools and colleges.

The outreach activities are carried out by a dedicated science communication officer, supported by the LATEST2 academic champion, academic staff, students and external industrial collaborators. The activities are specifically developed to effectively reach a wide range of target audiences.

OUR "IMPACT" STRATEGY AIMS TO REACH THE FOLLOWING AUDIENCES:

- **I**NDUSTRY
- **M**ATERIAL SCIENTISTS
- **P**UPILS
- **A**CADEMIA
- **C**OMMUNITY
- **T**EACHERS AND CAREER ADVISORS

Events for Schools and Colleges

LATEST2 runs a wide variety of events aimed at school and college students, and their teachers. The key aims of the activities are to engage students with materials science and to raise awareness of the subject, to introduce them to some of the research taking place in this area, and to highlight the range of careers and courses available.

There are a number of different ways in which we engage with students. Our researchers visit schools to deliver lectures and workshops, we host work experience students and we also run practical activities for students and visit days at The University of Manchester.

The programme of activities for schools and colleges has grown in strength each year, in the period July 2010 – June 2011 we engaged with over 1500 people, but in the period July 2012 – June 2013, this number increased to over 2300 people.

A number of our events take place just once a year such as the Dragonfly Day, which is aimed specifically at female students and aims to increase the number of women in engineering. Other events take place throughout the year such as our programme of schools workshops.

We are always looking to develop new activities or work in conjunction with other organisations to run events. Organisations we have engaged with in the past include the Nuffield Foundation, IOM^3, and The Smallpeice Trust.

One of our most successful activities is the EPSRC LATEST2 Engineering Materials Residential Summer School.

EPSRC LATEST2 Engineering Materials Residential Summer School

2013 is the 6th year the annual LATEST and, more recently, LATEST2 Engineering Materials Summer School has taken place. This event has grown in success and popularity year on year, and in 2013, due to the overwhelming demand for places, for the first time we ran two Summer Schools.

The Summer Schools are attended by students in Years 10 and 11 (aged 14 – 16 years old), and students come from across the country to attend the course.

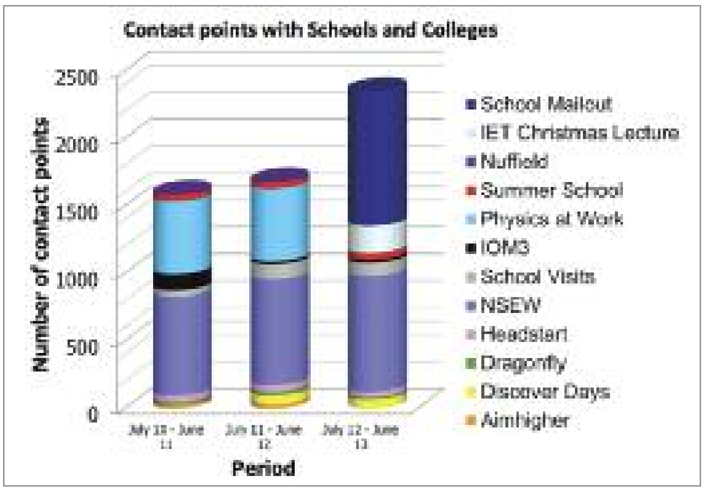
During the course, students stay at the University for 4 days and take part in a wide variety of talks, practical workshops and social activities, all of which aim to ignite their interest in engineering and physical sciences, give them an introduction to the different aspects of materials science and a taster of University life.

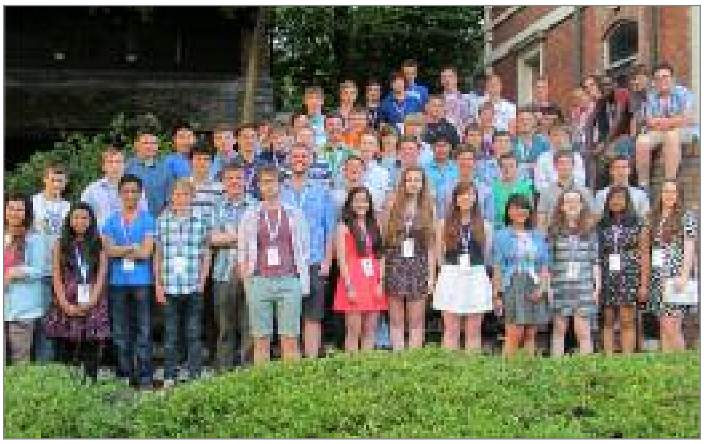
Activities include a practical workshop in which students try to identify materials using a range of techniques such as microscopy, impact and tensile testing and X-Ray diffraction. The aim of this workshop is to introduce students to some of the practical techniques commonly used by materials scientists, and also to explore different material properties.

Students are also given talks from a range of academics within the School of Materials and external speakers from industry, and topics that have been covered in the Summer Schools include the LATEST2 research programme, cutting-edge work taking place in the field of nanotechnology and graphene, and how scientists design materials for medical applications.

During each Residential Summer School, students also visit a transport manufacturer, and in the past we have visited the Jaguar Land Rover manufacturing centre in Halewood and Airbus, Broughton. These visits enable students to see industrial applications of materials science and to hear more about different careers that are available.

The Residential Summer Schools are always a great success and comments made by students who have attended the course include; "It was not only a great experience, but also a very inspiring week which really got me interested in materials science, engineering and sciences in general." And "I thoroughly enjoyed it and would love to do it again! It was an amazing experience."





Students attending the EPSRC LATEST2 Engineering Residential Summer School 2013

Events for the Community

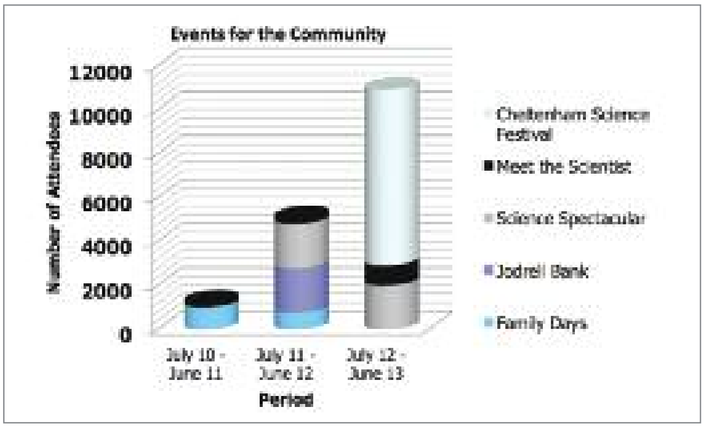
LATEST2 is committed to delivering a programme of activities aimed at the community, including both family and adult audiences. Each year we are involved in a variety of different events, ranging from taking part in large science festivals such as the Jodrell Bank Science Festival, to hosting our own Meet the Scientist Days at the Museum of Science and Industry.

Our community events are often focused on running hands-on activities which aim to raise awareness of materials science and to showcase some of the research taking place within the EPSRC LATEST2 programme. These activities are designed to be suitable for a variety of audiences, and encourage people to engage with the science in a fun and practical way. A number of our PhD and Post-doctoral researchers have been involved with helping to run these activities, and they are also an opportunity for them to speak to the public about the research they are carrying out.

Our community events have been a huge success, and each year we are looking to develop the programme further and reach new audiences, and take part in different events. For example 2013 was the first year that we have been involved with the Cheltenham Science Festival. The large growth in this programme of activities can be seen in the graph below, as in the period July 2010 – June 2011 our events were attended by 1,200 people, however in the period July 2012 – June 2013, this number has increased significantly with events now attended by over 10,000 people.

Community events take place throughout the year, e.g. the Science Spectacular at The University of Manchester as part of the Manchester Science Festival, which is usually held once a year. We have taken part in events across the country reaching as wide an audience as possible.

An event which we have now run for a number of years, and which is an effective way of reaching a large and diverse audience is a Meet the Scientist Day.



Meet the Scientist at the Museum of Science and Industry

Meet the Scientist Days are aimed at a family audience and usually take place at the Museum of Science and Industry, Manchester. At these events the EPSRC LATEST2 team and the School of Materials, take over a section of the museum and run a wide variety of practical activities.

Activities that have been run in the past include chocolate impact testing, in which participants investigate which is the toughest chocolate bar using a miniature impact tester, and through this are given an introduction to mechanical testing and modes of fracture and why different materials fracture in different ways. Other activities include electroless copper plating, in which the concepts of corrosion and electroplating are explored through the participant taking part in an experiment in which copper is plated on to steel. We also run activities which demonstrate the power of microscopy and the different microstructures of materials.

The aim of all of these activities is to introduce people to materials science in a fun and exciting way, and to discuss with them some of the research taking place and the importance of this work. Events are attended by people ranging from young children right up to adults, and are usually attended by between 200 – 500 people.

We also offer our PhD students the opportunity to design their own activities to be run at these events, and a number of creative activities have been developed in the past including a practical activity which uses Play-Doh to explore different methods of manufacturing including 3D printing!

PhD students on the exhibition stand at the Jodrell Bank Science Festival 2013

School pupils taking part in some of the hands on interactive activities during the LATEST2 Engineering Residential Summer School 2013

Events for Industry and Academia

The LATEST2 Team are committed to delivering a variety of events for colleagues working in industry and academia, in order to help to establish and build long-term strategic partnerships with leading industrial and other research institutions and, facilitate networking and knowledge transfer.

There are a range of ways in which we engage with industry and academia and events that have taken place include conferences, seminars and technical workshops. The dissemination activities are further supported by the LATEST2 website and newsletter. In addition the LATEST2 Team encourage visits to and from industry and to and from other academic institutions.

The programme of events for industry and academia has developed each year, and we have seen a significant increase in the number of people reached from the period July 2010 – June 2011, when our events were attended by over 300 people, to the period July 2012 – June 2013, where events were attended by over 1,100 people, a nearly fourfold increase in numbers. This is due to the development of our programme of events, with new events taking place each year.

Significant events that have taken place include an EPSRC LATEST2 hosted conference on the “Challenges for Joining Light Weight Dissimilar Materials for Automotive Applications,” and the hosting of the Titanium Information Group Meeting. LATEST2 has also exhibited at large scale and significant events including the EPSRC Manufacturing the Future event, and the Cenex Low Carbon Vehicle event.

The LATEST2 Guest Seminar series has shown significant growth in the period July 2012 – June 2013, and LATEST2 have been pleased to host seminars including Professor Vadim V. Silberschmidt from the Wolfson School of Mechanical and Manufacturing Engineering Loughborough University, discussing “Advanced Hybrid Turning Techniques for Aerospace Alloys”. Also Professor Matthew R Barnett of the ARC Centre of Excellence for Design in Light Metals Institute for Frontier Materials, Deakin University, Geelong, Australia who talked about “Magnesium Alloys for Efficient Extrusion”. These seminars are always very well received, and are attended by external delegates as well as colleagues from across The University of Manchester.

We are always looking to build on our programme of events, and to work with our partnering organisations to co-host conferences and workshops. One recent example of a successful co-hosted event is the Light Metals Technology workshop:

Light Metals Technology Workshop

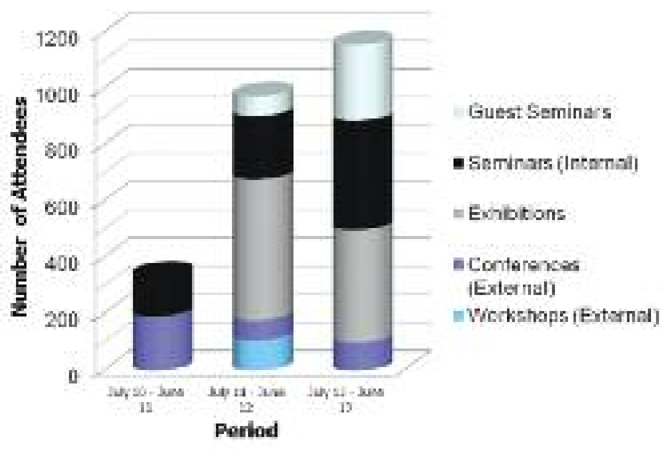
The Light Metals Technology workshop took place in April 2013 at Brunel University, and was co-hosted by the Centre for Innovative Manufacturing Liquid Metal Engineering (LIME) and LATEST2.

This workshop attracted a wide audience including industrial leaders, technical managers and researchers from across the UK. The event included presentations from academics from both research activities and topics discussed included the joining and formability of advanced light alloys, and an overview of UK research in aluminium and magnesium.

Panel-led discussions took place in the afternoon which gave ample opportunity for discussion and debate on future industry needs and research opportunities for transport applications with a particular emphasis on end-of-life recovery and recycling. Discussion topics included: the future of alloy design; the need for more magnesium research; UK car recycling and high pressure die-casting research.

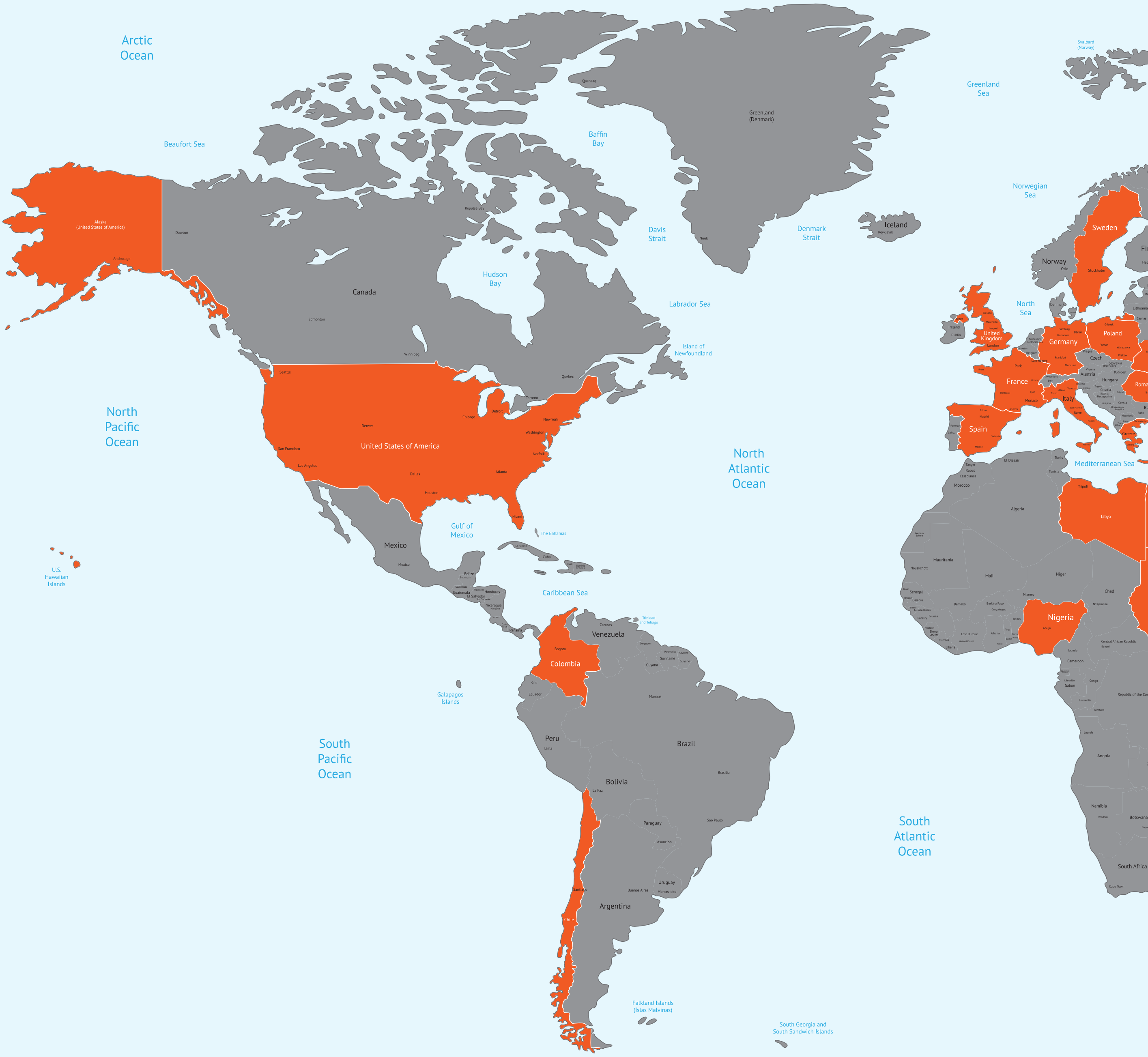
The workshop was very successful with the EPSRC Portfolio Manager, Dr Tony Chapman, commenting that he “found the workshop very interesting and useful. It was good to see the activities going on in the Centre and see good progress being made in the research programme, as well as lots of interest from industry”.

Events for Industry and Academia



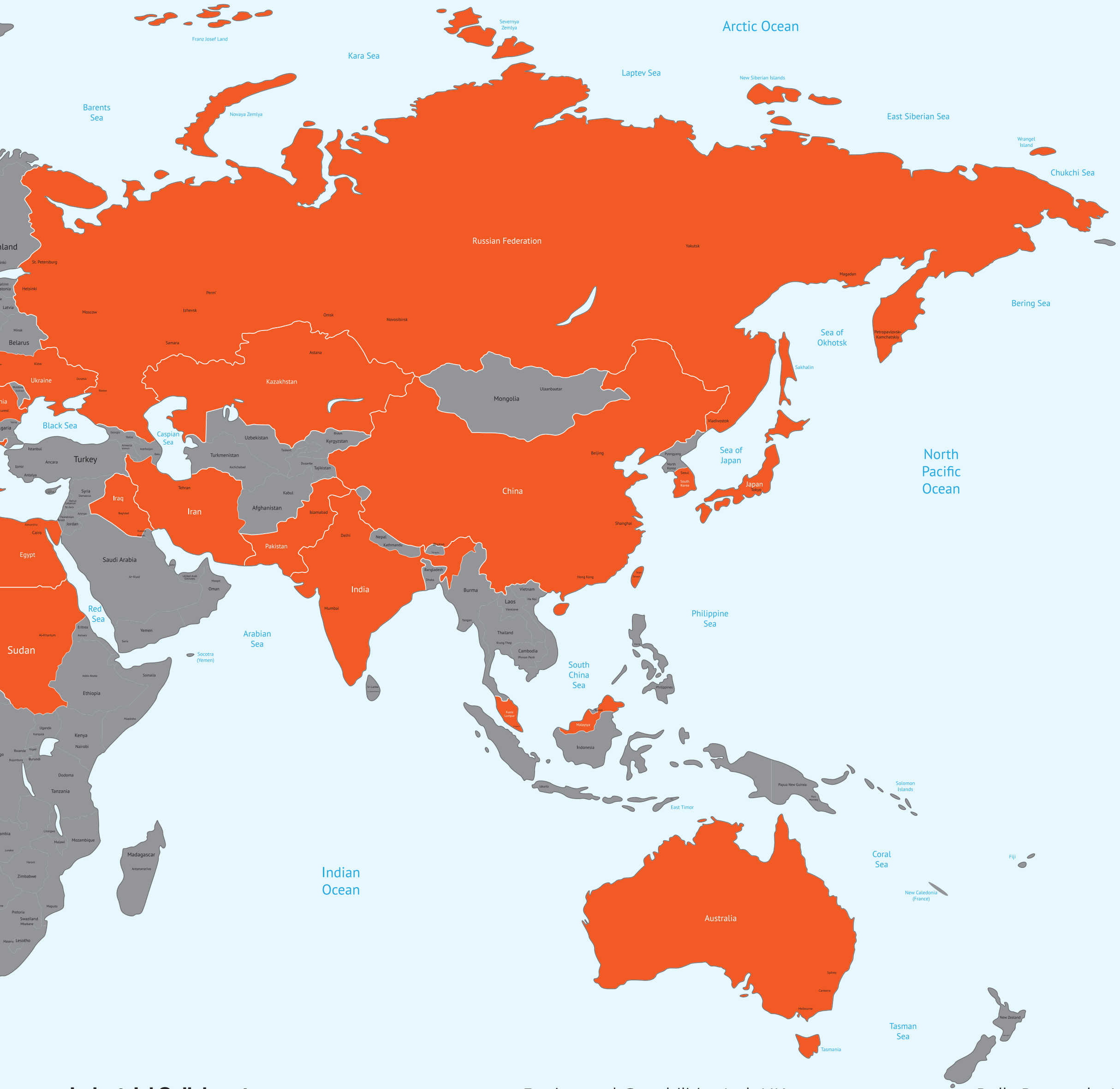
Presentations from researchers from the EPSRC LATEST2 Programme and EPSRC – Centre LIME

COLLABORATORS



Academic Collaborators

Advanced Metallic Systems Centre for Doctoral Training (CDT), UK
Brno University of Technology, Czech Republic
Brunel Centre for Advance Solidification Technology (BCAST), UK
Brunel University London, UK
Cranfield University, UK
Deakin University, Australia
Diamond Light Source, UK
Engineering and Physical Science Research Council (EPSRC), UK
EPSRC Centre for Innovative Manufacturing in Liquid Metal Engineering (LiME), UK
Helmholtz-Zentrum Geesthacht Centre for Materials and Coastal Research, Germany
Hokkaido University, Japan
Imperial College London, UK
Institut Laue-Langevin (ILL), France
Iowa State University, USA
ISIS, UK
Materials Performance Centre (MPC), UK
Monash University, Australia
National Centre of Scientific Research (DEMOKRITOS), Greece
Ohio State University, USA
Politecnico di Milan, Italy
RWTH Aachen University, Germany
Universidad Complutense de Madrid, Spain
Universidad de Santiago de Chile (USACH), Chile
Universitié Pierre et Marie Curie, France
University of Antioquia, Colombia
University of Birmingham, UK
University of Cambridge, UK
University of Kaiserslautern, Germany
The University of Manchester Aerospace Research Institute (UMARI), UK
The University of Manchester, Manchester X-Ray Imaging Facility, UK
University of Milan, Italy
University of Naples Federico II, Italy
University of Nottingham, UK
University of Sheffield, UK
University of Strathclyde, UK
Warwick Manufacturing Group (WMG), UK
Xi’an Technology University, China



Industrial Collaborators

Airbus, an EADS Company, UK
Akzo Nobel N. V., the Netherlands
Alcoa Inc., UK
Aston Martin Lagonda Ltd, UK
Australian Government Department of Defence, Australia
BAE Systems plc, UK
Beijing Aeronautical Manufacturing Technology Research Institute (BAMTRI), China
Baosteel Group, China
Beijing Institute of Aeronautical Materials (AVIC), China
BMW, UK
BP, UK
Bridgnorth Aluminium Limited, UK
Constellium, France
Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia
EADS Innovation Works, UK
European Synchrotron Radiation Facility (ESRF), France
Engineered Capabilities Ltd, UK
FEI Company, UK
Goodrich, UK
Heat Trace Ltd, UK
Innoval Technology Ltd, UK
Institute of Materials, Minerals and Mining (IOM3), UK
Jaguar Land Rover (JLR), UK
Magnesium Elektron, UK
Michell Instruments, UK
National Metals technology Centre (NAMTEC), UK
The National Center for Metallurgical Research (CENIM), Spain
Novelis Inc., USA
Northwest Aerospace Alliance (NWAA), UK
Northwest Automotive Alliance (NAA), UK
Otto Fuchs KG, Germany
Poeton Industries Ltd, UK
POSCO Engineering & Construction Ltd, South Korea
Rio Tinto Group, UK
Rolls-Royce plc, UK
Sapa AS Group, Sweden
Siemens VAI – Metals Technologies Ltd, UK
Tata Steel Europe Limited, UK
Technology Strategy Board (TSB), UK
The Welding Institute (TWI), UK
Titanium Metals Corporation (Timet), UK

Outreach Collaborators

Engineering Development Trust (Headstart), UK
Institute of Materials, Minerals and Mining (IOM3), UK
Jodrell Bank Centre for Astrophysics, UK
Museum of Science and Industry (MOSI), UK
Nuffield Foundation, UK
Royal Academy of Engineering, UK
Science, Technology, Engineering and Mathematics Network (STEMNET), UK
Smallpeice Trust, UK
The University of Manchester Widening Participation, UK
Women's Engineering Society (Dragonfly), UK

Mr Rodney C. Jones
EPSRC LASTEST2
International Advisory Panel Chairperson

Rod Jones worked in the metals industry for almost 50 years and is now an independent consultant.

Having graduated in Metallurgy following a sandwich degree course at Aston University with industrial sponsorship from Henry Wiggin & Company Limited he did research initially into high temperature material for aircraft engine applications at British Non-Ferrous Metals Research Association.

Following the transition of the company into BNF Metals Technology Centre he specialised in the field of process development and control of fabrication processes in the copper- and aluminium alloy industries. He then moved to Alcan International to continue process developments primarily in the aluminium rolling industry.

After a period as Programme Director at the Banbury Laboratories he moved into operations having responsibilities for technology in the U.K. fabrication plants and subsequently across Europe as Technical Director. Whilst retaining a senior technology position in Europe he returned to Alcan International at Banbury as Laboratory Director.

Following Alcan's merger with Alusuisse he moved to Switzerland to lead the application of aluminium in automotives followed by obtaining the position of VP Technology for Alcan's Engineered Products division. This position expanded further following Alcan's acquisition of Pechiney with global responsibility for the research laboratories and critical technology teams becoming based in Paris.

Key responsibilities of this position became the technology aspects of the spin-off of major rolled products businesses as Novelis and, following the purchase of Alcan by Rio Tinto, the sale of Engineered Products to private equity (now known as Constellium). Following completion of this sale he established RJInnTech Limited, an independent consultancy.

The International Advisory Panel stand as international experts in the areas of the EPSRC LATEST2 Programme Grant. The Panel is made up of both national and international, academic and individual members with many years experience. The role of the Panel is to advise the Management Team on Strategic directions to benchmark the quality and progress of our research against our objectives and on the international stage

Professor Paul O'Brien
EPSRC LATEST2
International Advisory Panel Member

Paul O'Brien graduated from the University of Liverpool in 1975 and took a Ph.D. in Inorganic Chemistry under the supervision of Professor R. D. Gillard at University College Cardiff in 1978. He is at present the Chair of Inorganic Materials Chemistry in the Schools of Chemistry and of Materials and Head of School of Materials at The University of Manchester.

He was Research Dean (The University of Manchester 2000-2002), Head of Chemistry (2002-2004), then formed Chemistry in the new University of Manchester (2004-2009). He has worked in London at Chelsea (1978-84), Queen Mary (1984-94) and Imperial Colleges (1994-99), and was a visiting Professor at Georgia Institute of Technology (1995-99).

His research centres on new chemical processes for thin films and nanoparticles; especially of chalcogenide containing materials. In 2002 he founded Nanoco, an AIM listed company that manufactures nanoparticles.

He led the Materials Forum (Royal Society of Chemistry 2001-2006), was a Trustee (2001-2012) and Vice-President (2010-2012). He works extensively in Africa running on capacity building programmes in Zululand, Ghana and Tanzania.

He was Chemistry President of the British Association (2004), and is a frequent presenter at Café Scientifique, he has lectured widely to the public eg at The Royal Society, The Victoria and Albert Museum, The Institute of Contemporary Arts and The Manchester Literary and Philosophical Society (McCurdy Lecture 2012). In 2011 he received the Sir Colin Humphries Medal (IOM3) for his outreach work in materials science.

He is the recipient of distinguished alumni awards from Liverpool (Potts Medal) and Cardiff (A.G. Evans Memorial Medal). He received the Kroll Award (IOM3) and the first Peter Day Award of the RSC for Materials Chemistry in 2009. He has been awarded honorary D.Sc degrees by the University of Zululand South Africa and his alma mater the University of Liverpool. He was a visiting Fellow at Magdalen College Oxford (2009) and a Distinguished Fellow (2010) at the Institute for Advanced Studies Durham University. In May 2013 he was elected a Fellow of the Royal Society London.

Professor Bevis Hutchinson
EPSRC LATEST2
International Advisory Panel Member

Professor Bevis Hutchinson has a long association with The University of Manchester where he received his B.Sc. in 1965 and his D.Sc. in 1984. In between these he was successively doctoral student, lecturer and senior lecturer at the University of Birmingham where his Ph.D. and research centred mainly on textures and anisotropy in metals.

In 1982 he moved to the Swedish Institute for Metals Research (now SwereaKIMAB) in Stockholm where he headed the department of Physical Metallurgy.
This involved research into processing, microstructures and properties of a wide range of ferrous and non-ferrous materials. The work in Stockholm is carried out exclusively in collaboration with industrial companies and has included many studies of aluminium alloys in the form of extruded profiles and flat rolled products. He was also responsible for establishing and maintaining advanced experimental methods in metallography including EBSD and laser-ultrasonics and has published some 200 papers in these areas.

Since 2006 he has held the position of Senior Scientific Advisor at SwereaKIMAB but has also travelled widely with extended periods as a visiting researcher at the Universities in Sheffield, Manchester, Delft, Aachen and at Deakin University in Australia where he was awarded the title of Honorary Professor as well as the Geoff Wilson Medal.

He was awarded the title of professor by the Swedish state in 1991. He is a Fellow of the Royal Academy of Engineering and a Member of the Swedish Academy of Engineering Sciences. In addition to his role on the International Advisory Panel of LATEST2 he is a consultant for Gränges Aluminium in Sweden and for Nippon Sumitomo Steel Corporation in Japan.

Professor Dorte Juul Jensen
EPSRC LATEST2
International Advisory Panel Member

Dorte Juul Jensen is educated in solid state physics and since 1980 she has been working in materials science. She completed a PhD in 1983 and became a Doctor of Science (Dr. Techn.) in 1997.

Her scientific interests cover a wide range including the development of advanced characterization techniques, microstructure and texture development during recrystallization covering experimental characterization and modeling, microstructure and texture development during plastic deformation, nanometals and the relationships between microstructure and physical properties. During her career to date she has published more than 300 papers on these research topics.

She is currently Professor, Dr. Techn. and Head of Section for Materials Science and Advanced Characterization, Department of Wind Energy, Risø Campus at the Technical University of Denmark.

As well as a member of the LATEST2 Advisory Panel, her present honorary positions include memberships of European committees, e.g. COST Technical Committee on Materials, Physics and Nanosciences and EERA, joint programme on Advanced Materials and Processes for Energy Application, as well as advisory positions, e.g. for NSF (USA) on advanced characterization. She is a member of both the Danish Academy of Technical Sciences and the Royal Danish Academy of Sciences and Letters.

Dr Floris Kooistra
EPSRC LATEST2
International Advisory Panel Member

Floris Kooistra was born in 1979 in the city of Amersfoort in the Netherlands. After finishing his high school degree he attended high school in the United States for one year. After returning to the Netherlands he started his studies in chemistry at the University of Groningen. During his studies he specialised in organic chemistry. After completing his masters degree in 2003, he started a PhD at the University of Groningen titled: Fullerenes for Molecular Electronics.

After successfully defending his thesis in 2007, he started his career working for AkzoNobel Aerospace Coatings as a coating specialist working on super absorbant coating technology for Land Defense vehicles.

Currently he works in the RD&I organization as Groupleader Innovation leading a small team responsible for the R&D Innovation program within AkzoNobel Aerospace Coatings based in the Netherlands. The main topics of interest in his group include protection of new substrates, adhesion, non-hazardous coating technology and chrome free corrosion protection.

Mr John Ferguson
EPSRC LATEST2
International Advisory Panel Member

John Ferguson gained a degree in Chemistry and an MSc in Analytical Chemistry through part time studies at Bristol University and is now a Fellow of the Royal Society of Chemistry.

He worked for Airbus and it's predecessor companies in Bristol for 45 years. His career began as an Apprentice Trainee Chemist and through progressive promotions eventually finished his time as Laboratory Manager within the Materials and Process Laboratory at Airbus UK at Filton, Bristol.

He is a specialist in aerospace coatings, analytical chemistry and laboratory accreditation and won an Aerospace Innovation award for suggesting an environmentally friendly solvent for sealant promoters. In 2010 he gained an Airbus Award for Excellence as part of a team who carried out research on a chromate free anodizing procedure. The new process is now widely used throughout the world by numerous Airbus suppliers. The University of Manchester was a major team player in this research.

In his spare time he helps to run a flight training school and gained his Private Pilots License in 2000.

Dr Ian Norris
EPSRC LATEST2
International Advisory Panel Member

Ian Norris trained as a metallurgist at Sheffield University and completed a PhD in The Application of Laser Welding to Pipeline Production before joining TWI in 1985 as a Project Leader in the Laser Section. In this role, he proposed and ran a wide variety of projects involving laser processing of metallic materials. He became Section Leader for Laser Applications in 1988 leading a team in the development of laser processes for industrial applications.

Following a period in industry working for an industrial laser manufacturer in a variety of roles including applications development, service support and sales, he returned to TWI in 1999 in a business development role in the Manufacturing Support Group.

Subsequently, he has worked as a Technology Group Manager overseeing TWI's friction and electron beam processing activities as well as working to establish new centres across the UK including TWI's facility in Rotherham, South Yorkshire which is dedicated to friction stir welding, laser welding, powder based near net shape manufacturing and cold spray. He has also been involved in establishing TWI's position as a founding research partner at the Manufacturing Technology Centre near Coventry and assisting in the specification of the building and initial equipment for the MTC. He is now Business Group Manager – UK Programmes involved in equipment specification and procurement for the National Structural Integrity Research Centre, a joint initiative between TWI and a variety of academic and industrial partners which will see a new facility established at TWI's headquarters near Cambridge.

Dr Mark White
EPSRC LATEST2
International Advisory Panel Member

Mark White was born in Dunfermline, Scotland in 1960 and after being awarded an honours degree in Automotive Design at Coventry University he then continued his studies at Brunel University where he was awarded a Doctorate in Engineering.

After working for four years as a free lance design engineer, he began his career at Jaguar Cars Ltd in 1987 as a Body Design Engineer for Sports models and was part of a team responsible for development of XJ-S derivatives including the convertible. In 1990 he was promoted to Manager for sports models and led the team responsible for the design and development of XJ-S coupe and convertible facelift and XK8 body.

He continued to progress his career within Jaguar and in 1998 he became Manager for Body structures, all Jaguar models. Responsible for design and development of all sedan and sports body structures, including feasibility, CAE analysis, CAD design and release, design verification test and launch support. His responsibilities were then further expanded in 2002 to include all Jaguar & Land Rover models and he was responsible for designand development of all Jaguar & Land Rover new Body Structures, including new platform development and light weight vehicle (LWV) development.

In 2004 he was made Chief Technical Specialist, Jaguar & Land Rover Body Engineering responsible for body engineering related system strategy and research and advanced projects, with focus on body structures, including light weight vehicle (LWV) development.

In 2012 he took up his current role as Chief Engineer – Body Complete Business Unit, JLR Body Engineering where he is responsible for all body structures, sheet metal and closures design and release, as well as technical specialist lead for research and advanced projects, with focus on body structures, and closures including light weight vehicle (LWV) development.

Dr Neil Calder
EPSRC LATEST2
Advisory Panel Member

Through his consultancy company Engineered Capabilities Ltd, Neil provides services as a technical specialist in advanced manufacturing to a range of clients, including industrial organisations at all points of the value chain, universities, and government departments and agencies. With a Bachelors degree from Edinburgh University, and a Doctorate from Liverpool University, both in Mechanical Engineering, his background includes 15 years of developing advanced manufacturing processes for combat aircraft with BAE SYSTEMS and doctoral research in laser welding of airframe alloys within this context. He spent three years with the North West Aerospace Alliance facilitating innovation across the regional sector, with much of this in metallics materials and processing.

In addition to work with advanced engineering sector supply chain companies, Neil fulfills roles as a technical expert in advanced manufacturing for the Technology Strategy Board, Ministry of Defence and European Commission. He is also Technical Editor for Aerospace Manufacturing magazine and Congress Director for the UK Advanced Engineering Show.

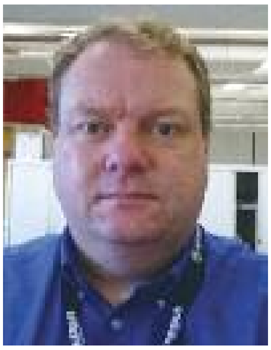
Neil is also recognised as an expert in composites, broadening the scope beyond lightweight metallics.

Ms Carol Holden
EPSRC LATEST2
Advisory Panel Member

Carol Holden commenced work in the truck industry as a Leyland Truck and Bus student apprentice. She graduated from the University of Bath with a degree in Mechanical Engineering and returned to Leyland Vehicles to a permanent position in Test Operations in the power-train group for 5 years before leaving and joining Eaton Corporation, Truck Components Division. She was with Eaton for 25 years in an assortment of roles, from Project Engineering, Project Management, Chief Engineer and finally as European Engineering Manager, with staff based in Manchester, Poland and Korea. Across the years she had a broad range of management as well as technical responsibilities in the development of truck transmissions; including the formation of a European Hybrid team. During this time she also obtained her MBA from The University of Manchester. She is a Fellow of the Institution of Mechanical Engineers and continues to be committed to supporting the training and development of engineers.

Her expertise is varied and covers, new product introduction, project management, engineering management, technical and business bid applications combined with project delivery, business leadership and organisational change and development.

She joined NAA as the Chief Executive in April 2010 and immediately faced the challenge of the changing shape of cluster organisations in the NW; with the need to take the NAA from a funded body of the NWDA to a wholly independent not-for-profit organisation. This has been achieved and she represents the NW automotive community both nationally and locally across the NW.



Dr Simon Gardiner
EPSRC LATEST2
Advisory Panel Member

Simon Gardiner is the Manufacturing Research & Development Manager for Airbus based in Filton, Bristol, UK with direct responsibility for developing and delivering new technological solutions directly into the manufacturing business.

He graduated from The University of Manchester in Materials Engineering and joined "Airbus" (BAE Commercial Aircraft) in 1991. He has worked on a number of metallic, surface and environmental programmes with the main theme being development of metallic material processing such as Super Plastic Forming, Creep Forming, Welding Process Development, Friction Stir welding, Laser Processing, etc.

Simon was instrumental in the introduction of Additive Layer Manufacturing (ALM) technology into Airbus in 2001 being involved in the benchmarking and acquisition of SLA rapid prototyping for wind tunnel models and has since been involved in the development of the ALM capability within Airbus from selective laser sintering of thermoplastics through to the ALM capability development for aerospace metallic materials (titanium and aluminium). Currently he is responsible for a development portfolio in excess of 1M€ transnationally across Airbus and tasked with the alignment of EADS and Airbus roadmaps for Freeform Fabrication the major element of which is ALM.

Professor Stefan Zaefferer PD Dr. Dipl.-Ing.
EPSRC LATEST2
Advisory Panel Member

Stefan Zaefferer studied physical metallurgy at the University of Clausthal-Zellerfeld, Germany. At the same university he also pursued his PhD studies in the institute for metal physics lead by Professor H. J. Bunge and Professor R. Schwarzer. In his PhD work he developed algorithms for electron diffraction analysis in TEM and SEM and applied them to study deformation mechanisms of Titanium alloys.

Following this he worked as a post doc at the Université Paris-Sud (France) and at Kyoto University (Japan) studying deformation and recrystallization of metallic materials and continuing to develop electron diffraction techniques.

In 2000 he took up his current role as leader of the research group "Microscopy and Diffraction" at the Max-Planck-Institute for Iron Research (MPIE) in Duesseldorf, Germany. The group has between 10 and 15 members studying mechanisms of microstructure formation in metals and intermetallic materials mainly by electron microscopy. One of the current main interests of research is the development of electron diffraction tools for the scanning electron microscope (EBSD and ECCI). These tools are employed to study the nature of crystallographic defects like grain and phase boundaries, dislocations and residual stresses.

He passed the habilitation at the University of Aachen, Germany, where he works as lecturer for the subjects metallic microstructures and microscopy techniques.

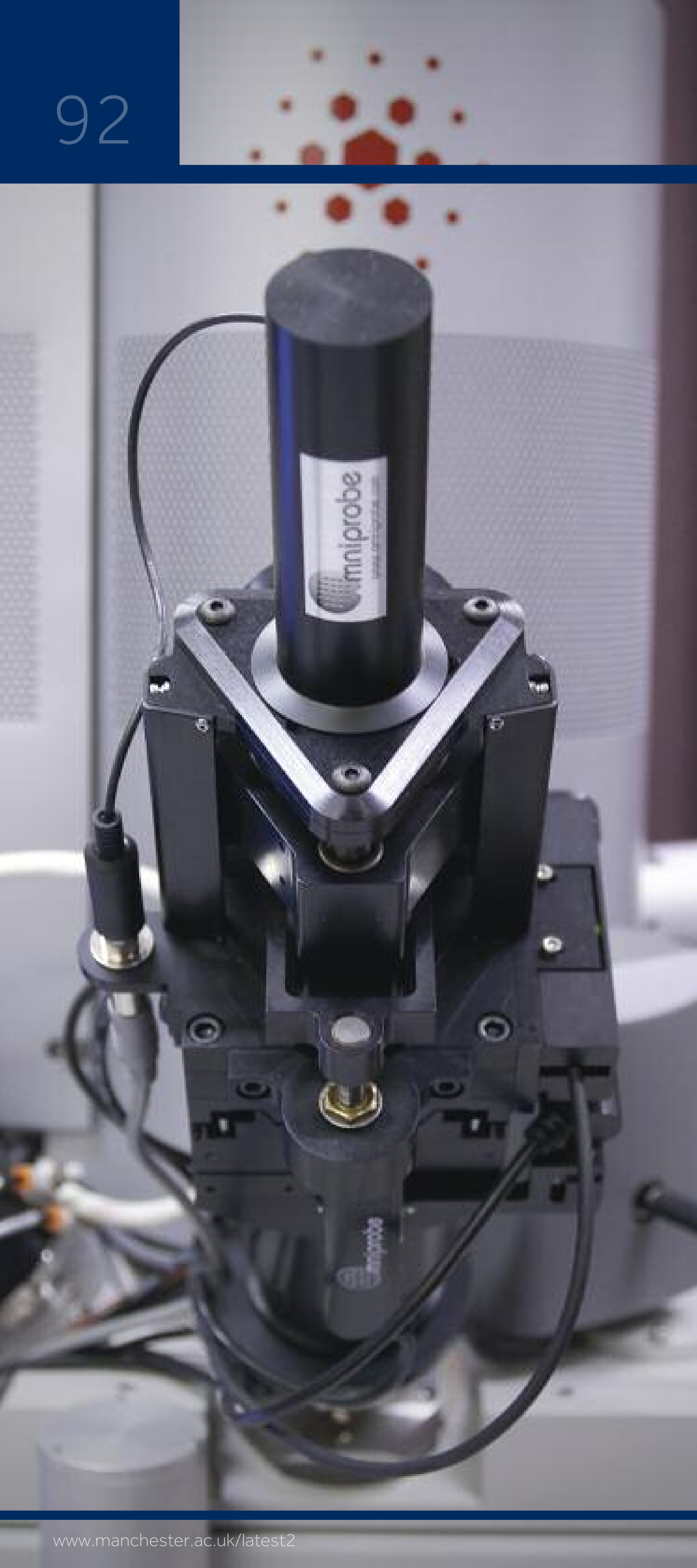
Professor Warren Poole
EPSRC LATEST2
Advisory Panel Member

Professor Warren Poole received his PhD from McMaster University which was followed by a NSERC Post Doctoral Fellowship at the University of Cambridge, UK.

He has published over 125 journal and conference papers related to the deformation, fracture and microstructure evolution in light alloys and steels. He works closely with leading industrial companies in the world to transfer the knowledge gained from his research to industrial receptors.

In addition, he serves on the international scientific committee for the two most important conferences on light metals and is on the advisory board of the EPSRC LATEST 2 Research Programme at The University of Manchester. He has won numerous best paper and poster awards, the 2013 Canadian Metal Physics Award, a Killam Research Fellowship, given over 20 invited conference papers and was a recipient of the Alan Blizzard Award for excellence in teaching.

Currently, he is the Head of the Department of Materials Engineering at The University of British Columbia and the Scientific Director of the NSERC Strategic Research Network (MagNET). The network involves a team of 20 Professors from McGill, Ecole Polytechnique, Waterloo, McMaster and UBC and currently supports 30 projects for graduate students and post doctoral fellows.



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D = Departed

OPPORTUNITIES TO ENGAGE WITH LATEST2

The LATEST2 team is committed to establishing and building long-term strategic partnerships with leading industrial and other research institutions. We believe in creating mutually beneficial collaborations that provide access to research facilities and expertise for industry together with opportunities to work on real-world problems in the transport sector for academics. Collaboration also enhances our capacity to educate and train the next generation of researchers and highly skilled, knowledgeable professionals for industry.

The LATEST2 multidisciplinary research team is drawn from the School of Material's Corrosion and Protection, Materials Science and the Materials Performance Centres. Collectively the team has extensive experience of processing, modelling, microstructure and texture control, surface engineering, corrosion control, joining and forming of light alloys and related materials for transport applications. Supported by an extensive suite of state-of-the-art facilities, the team can respond rapidly to new innovations and industry needs and is supported by colleagues within the School of Materials, enabling new expertise to be drawn in as required.

Your company or institution could become a partner in the LATEST2 research and benefit by taking advantage of the expertise available in the university and its partners.

Sponsor a LATEST2 Student

Your company could take the opportunity to work with experienced graduates who can provide cutting edge research focused on your business needs. By sponsoring a LATEST2 student you would have the opportunity to fund the work of an exceptional student and to encourage research relevant to your industry. The LATEST2 team of Investigators will work with you to match a student with the appropriate skills and interest in your specific industry sector.

You have the option to sponsor a full PhD or a Masters student through their course or to sponsor a dissertation project, lasting five months, during which time an MSc student will carry out academic research on a specific project in your business.

Sponsor a LATEST2 Postdoctoral Researcher

Your company could take the opportunity to work with an experienced Postdoctoral Researcher who can provide cutting edge research focused on your business needs. By sponsoring a LATEST2 Postdoctoral Researcher you would have the opportunity to fund the work of an exceptional researcher and to encourage research relevant to your industry. The LATEST2 team of Investigators will work with you to match a suitable Postdoctoral Researcher with the appropriate skills and expertise in your specific research sector.

LATEST2 Collaborative Research Project

Your company or academic institution could enter into collaborative research with LATEST2, working together on a specific project. Such a collaborative project would combine the expertise of your company or academic institution with that of the LATEST2 team to benefit both parties. Various funding streams may be available to support collaborative research projects and we can provide guidance on tapping into suitable funding streams.

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