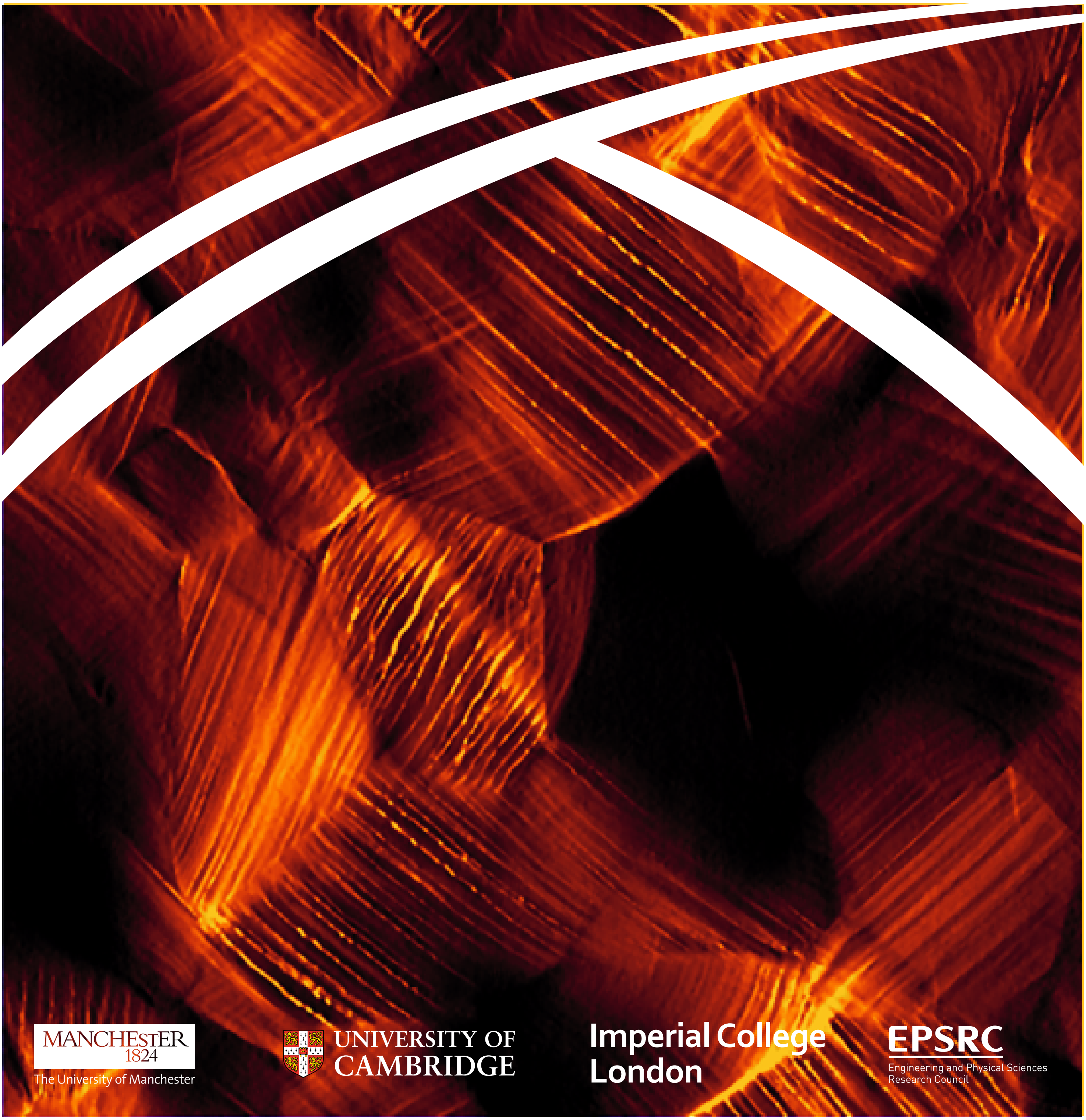
LIGHT FORM

YEAR ONE REPORT 2018



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LIGHT FORM

MESSAGE FROM THE DIRECTOR

These are important times for light alloys research with continuously increasing demand for lighter and more cost-effective solutions in the transport sector, in particular, to both reduce CO_2–emissions and increase the range of future electric vehicles. There is also increasing demand for higher performance materials, more efficient production processes, greater design flexibility and higher levels of end of life recycling, which present many challenges to materials engineering.

LightForm is a five-year multidisciplinary project with £4.8m (£5.9 FEC) in support from the EPSRC programme grant scheme, led by The University of Manchester with partners at the University of Cambridge and Imperial College, London. The overall objective of the research is to advance the enabling science (TRL 1-3) that will allow UK industry to compete internationally in developing the next generation of wrought, light-alloy, formed, components, by exploiting greater digital simulation in manufacturing and innovate in the move to a circular economy.

The philosophy behind the project is to adopt a more holistic approach to manufacturing and materials engineering of formed light-alloy components, and thereby exploit opportunities to increase performance and process efficiency through more intelligently embedding metallurgical design into the manufacturing cycle.

This will be facilitated within LightForm by promoting a deeper understanding of the dynamic behaviour of materials in forming and forging processes and the better integration of more physically based microstructure and texture simulation into engineering codes. This will allow embedded materials engineering to be more fully exploited by industry, by developing the capability to more accurately predict shape and properties.

Following our launch event at the end of October 2017, the academic team has been working hard on the ramp-up stage of the project. This has involved recruiting LightForm's core Post-Doctoral researchers and meeting with industry to organise our first phase PhD topics and discuss potential associated projects. We are pleased to report that we now have a full team of 7.5 talented researchers with skill sets across modelling, advanced electron microscopy, in situ real-time experimental simulation techniques, forming technology and environmental performance. In addition, we have been joined by Dr Pratheek Shanthraj from the Max Planck Institute Dusseldorf to take up the Airbus Research Fellowship at Manchester. Pratheek is an expert in phase field-crystal plasticity modelling and the prime developer of the 'DAMASK' code, which has been designed to simulate coupled microstructure evolution and mechanical behaviour responses in metals.

One of the novel aims of LightForm is to promote best practice in community access to research data and models developed within the project, so that they are fully documented.

We have therefore appointed a Computer Officer who will work with our researchers on cloud-based capture, storage, and public access of the large data sets and models, developed within the project.

The early stage work has focused on the core enabling science in Challenge Themes 1 and 2, which are reported on in more detail below. This has involved developing the research infrastructure, in terms of deformation simulation techniques and their appropriate modelling support, starting on the fundamental research into key mechanisms, and developing the modelling framework. Theme 3 is currently less advanced as it is designed to apply the core knowledge and modelling capability to industrial applications, as it becomes increasingly available. This Theme has thus started out by focusing on more mature forming technologies and in setting up leveraged associated projects, which will start to come on stream next year.

In the ramp up stage we have launched 22 new projects with industrial collaborators, including 17 PhD projects. These first round PhD projects are just getting started and we look forward to reviewing their progress next year, when we hope to launch our next set of year 2 projects. We already have direct leverage funding of £3,8M committed, which is excellent progress at this early stage, and includes several major projects and collaborations with:

Professor Phil Pragnell

- **Airbus** - Environmental performance of aircraft components
- **Innovate UK** - Combining deformation with high deposition rate additive manufacturing
- **BIAM** - Crystal plasticity modelling
- **Otto Fuchs** - Titanium and aluminium forgings
- **Impression Technologies** - HFQ sheet forming.

We have also been influential in defining the equipment requirements for the thermomechanical processing stream of the Advanced Metals Processing theme in the new Henry Royce Institute, which is being established at Manchester with its partner Universities.

The team have also been active in planning our outreach programme which will include hosting in Manchester a major international conference on light alloy metallurgy, LightMAT, and a workshop on modelling forming (Formed in the UK) in association with IOM3 in 2019.

If you would like to get involved in LightForm, please contact us through our Project Manager, Natalie Shannon (natalie.a.shannon@manchester.ac.uk). Please also visit our website for more detail on the project and news updates. **http://lightform.org.uk/**

LIGHTMAT

November 2019

LightMAT is an international conference on the science and technology of light alloys (aluminium, magnesium and titanium).

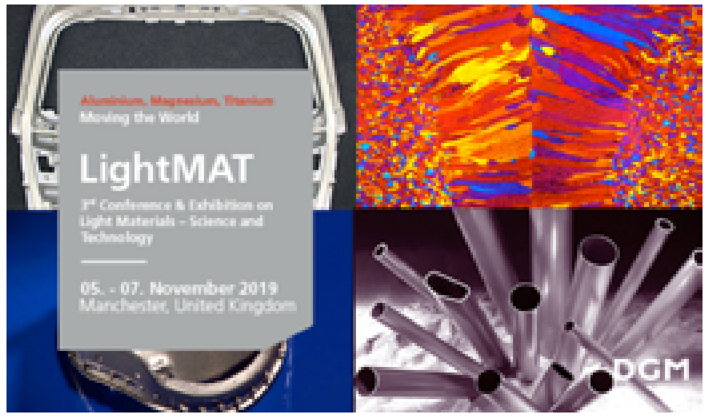
LightMAT 2019 will be the third conference held, and the first of these conferences to be held outside of Germany.

By invitation, LightForm will be hosting LightMAT 2019, which will be organised in collaboration with DGM (Germany) and held at the Manchester Conference Centre from Tuesday 5 November to Wednesday 7 November 2019.

LightMAT 2019 provides a platform for academic and industrial researchers, scientists and engineers to present and discuss the recent development and progress made in aluminium, magnesium and titanium and their alloys and materials combinations. Additional sessions are organized beyond single metals and address common processes and main applications, intended to provide comparison and cross fertilization, giving a wide overview of individual advances, challenges and highlights, covering:

- Conventional and advanced light weight applications and products in automotive, aerospace and other relevant transport and lightweight applications
- Fundamental aspects of the three metallic lightweight materials and their alloys, their processing and (physical) metallurgy issues involved
- Microstructure evolution, related properties and advanced simulation
- Industrial fabrication, processing, joining and corrosion protection issues
- Additive manufacturing of metallic structures enabling novel lightweight designs
- Formability and advanced forming of light alloys to shape complex parts (LightForm special session)

LightMAT 2019 addresses industry as well as academia and intends to strengthen the link between the two. Furthermore, the conference promotes the participation and the networking of young engineers, scientists and students.



FORMED IN THE UK

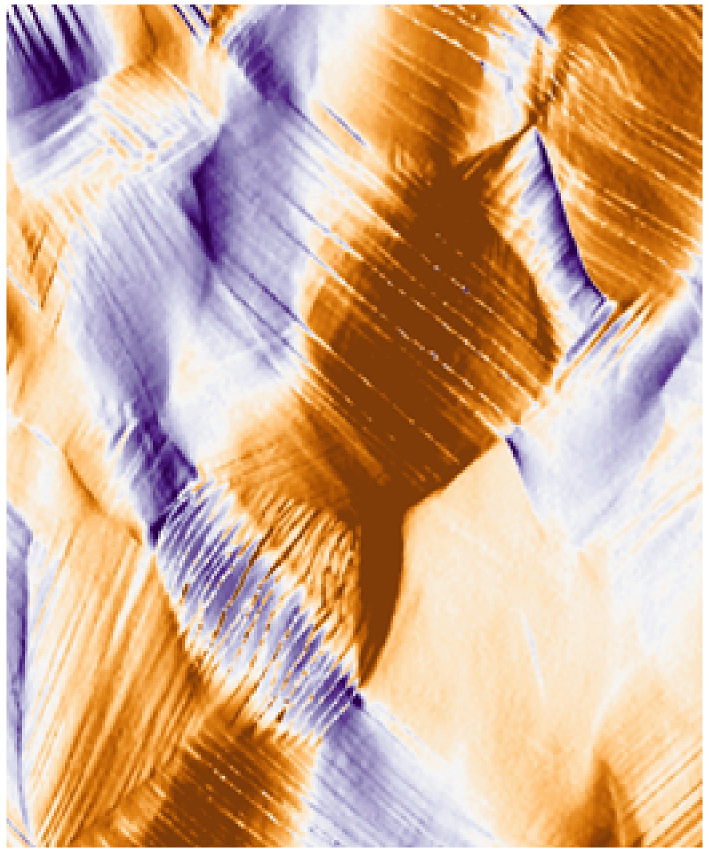
June 2019

Formed in the UK 2019, is a one-day workshop on Modelling of Materials and Processes in Forming, to be held at The University of Manchester and hosted by LightForm.

The meeting will be the latest of a series organised by IOM Communications Ltd on behalf of the Advanced Sheet Metal Forming Committee and the Bulk Metalforming Committee of the Institute of Materials, Minerals and Mining.

At the meeting, an international group of industrial and academic speakers will cover fundamental and applied research related to the modelling and simulation of material behaviour during forming, and the application to the simulation of forming processes. Industrial presentations will highlight existing challenges and opportunities in the areas of cold, warm and hot forming. The meeting will focus on modelling the forming of advanced lightweighting alloys including aluminium, magnesium, titanium and nickel and high strength steels. Processes covered will include extrusion, forging or rolling as well as superplastic and hybrid forming.

This meeting is an ideal networking opportunity for researchers and engineers from academia and industry who work in metal forming, but also group leaders from OEMs who have metal forming activities in their organisation, as well as Technical Directors and Senior Engineers from metal forming suppliers and other decision makers and advisors to major R&D funding bodies.



Challenge 1:

Enabling science for manufacturing with embedded materials engineering

Challenge Theme 1 is focussed on the fundamental science required to make embedding microstructural engineering in advanced forming a practical reality. The key objectives are to

- Develop 4D methods to study dynamic effects across length scales
- Inform physical model development and develop validation data for model testing
- Determine critical relationships between deformation, thermal exposure, microstructural evolution, and material response
- Understand how to exploit pre and post forming treatments to engineer microstructure and properties
- Understand effect of dynamic forming on surface microstructure and performance

Priority areas include exploiting dynamic precipitation effects in aluminium to produce both high formability and high final strength in aluminium alloy sheet, reducing cycle times and process cost for light metal forming, and increasing tolerance to impurities to enable closed-loop recycling.

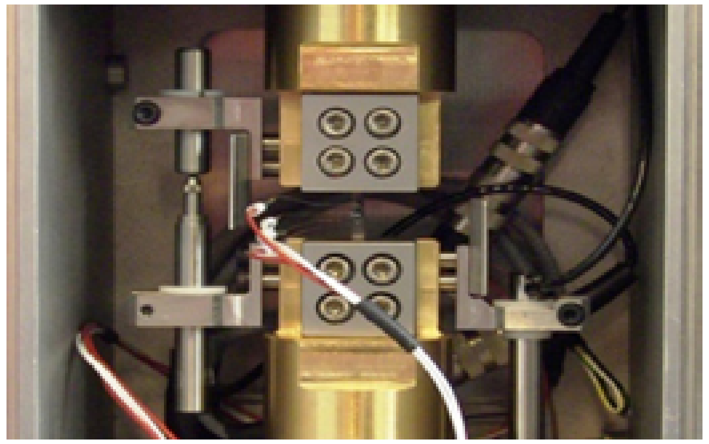
In magnesium, we seek to develop more formable alloys though microstructural control of local texture and twinning.

In titanium, we are developing the science required to produce reduced cost formed titanium sheet, and to enable better control of microstructure and texture through titanium forging.

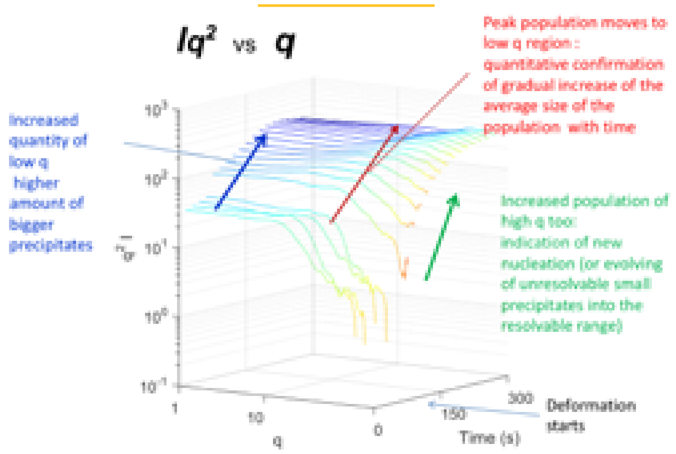
Dynamic interactions – fundamentals

One of the key concepts to be explored in LightForm is the potential to engineer the material properties during the forming process by dynamic control of the microstructure. An example of this would be using deformation induced defects to accelerate precipitation in aluminium alloys, thus reduce the need for a long post-form ageing treatment to achieve final properties.

To exploit this potential requires a better understanding of the dynamic interactions that occur between deformation and microstructural evolution. The details of these interactions can vary significantly from alloy to alloy, and our aim is to understand their nature and process windows under which they might be usefully exploited. To do this, novel in-situ techniques will be used to provide time-resolved datasets, enabling dynamic interactions to be measured at realistic forming strain rates. Work has already been completed to develop a test rig for such experiments at the DIAMOND beamline and apply it to understand dynamic precipitation in an automotive 7xxx alloy.



Heating/straining rig at DIAMOND I12 beamline, enables 1Hz acquisition of SAXS data to study dynamic precipitation in specimens up to 2mm in thickness.



Kratky plot showing evolution of precipitates during straining.

Development of adaptive materials

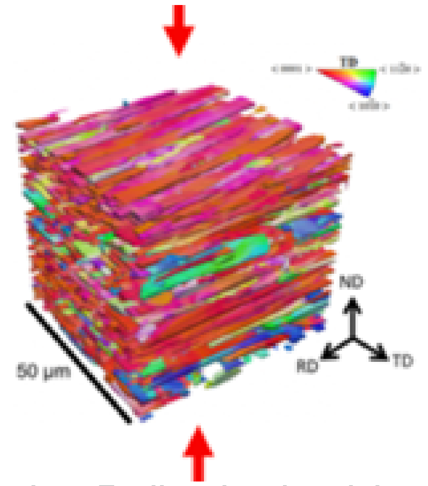
A better understanding of the dynamic interactions from F1 will enable us to design alloys optimized for dynamic engineering during forming. Our initial focus is on understanding the most promising dynamic process routes in aluminium for each alloy class, evaluating how to tailor the alloy composition and initial heat treatment to best exploit beneficial dynamic effects whilst minimizing those that may be detrimental.

We have already demonstrated that a very different approach is needed for 6xxx and 7xxx aluminium alloys due to the difference in their response to dynamic ageing. We have also explored the potential to introduce accelerated ageing heat treatments after hot forming (HFQ™) to reduce cycle times and process cost. An understanding of how accelerated ageing influences the microstructure will be used to develop materials optimized for best response under such conditions.

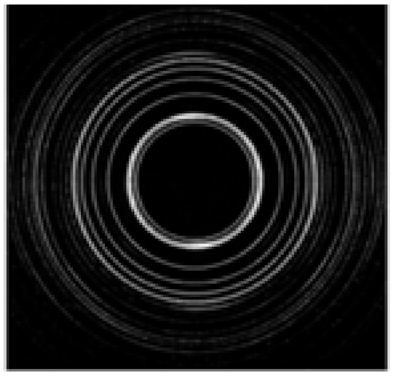
Formability through microstructural engineering

Our objective is to satisfy two goals through dynamic microstructural engineering that are often in conflict during conventional processing; high formability and high final strength. To develop high formability, we will engineer a desired work hardening response into the material through exploiting dynamic effects, guided by modelling.

In titanium, the interaction of the two phases in the most common alpha and beta titanium alloys (e.g. Ti64) is critical to optimize the post-formed microstructure. We have performed in-situ diffraction experiments to measure texture evolution and micromechanics during deformation of Ti64 to understand how the influence of the fraction and distribution of the alpha and beta phases. Ongoing work includes developing a new test rig to enable such experiments to be performed under industrially relevant plane-strain conditions.



Alpha-beta Zr alloy showing alpha-phase grain structure subject to in-situ diffraction study during compressive deformation as indicated by the arrows.



Example snapshot of diffraction pattern captured during in-situ testing.

Dynamic engineering of surface structures

Surfaces play a critical role in controlling properties such as corrosion performance. The near surface microstructure in formed metal components can often be different from that in the bulk, and it is thus essential to understand how to control and engineer surfaces. We will use a range of corrosion tests and surface analysis techniques to understand how novel dynamic forming processes influence the surface microstructure and thus surface performance. Initially, this work has focussed on evaluating the effect of novel hot forming processes (HFQ™) influence on the surface microstructure and corrosion performance of automotive aluminium body sheet. We have demonstrated that HFQ™ material performs well when subject to a range of corrosion testing.

Challenge 2:

Computationally efficient material and process modelling

The aim of Challenge Theme 2 is to develop an efficient computational modelling framework for modelling material behaviour, including microstructural evolution, and embedding it into forming process models.

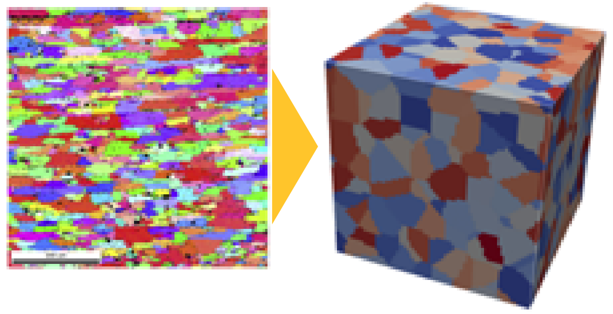
The main objectives of challenge 2 are to:

- Develop material sub-models that capture key aspects of the evolution of deformation structures
- Develop new models for sub-transus deformation of dual phase titanium alloys
- Couple microstructure evolution models with crystal plasticity codes to produce 'virtual microstructure simulations' that can predict dynamic forming limits and yield surfaces
- Validate the models against rich data sets generated in Challenge 1, and inform and reduce experimental effort
- Develop accurate engineering process models for new flexible forming technologies (e.g. for property tailoring)
- Explore computationally efficient routes to integrate microstructurally informed simulations into engineering forming codes.

Hardening models for dynamic microstructural evolution and during forming

The formability of materials depends strongly on the hardening behaviour of the material during forming. In the current paradigm, models must be calibrated through extensive, and sometimes prohibitively expensive, empirical testing. In LightForm we will develop a modelling framework for carrying out virtual dynamic material simulations, which will use microstructural parameters and data from a reduced set of mechanical tests to simulate material behaviour for different strain paths and temperature histories.

Work on Challenge Theme 2 started in Manchester in late June with the development of a crystal plasticity framework for modelling microstructural effects on yield surface evolution. The framework consists of modelling pipelines for producing virtual microstructures from texture data and carrying out virtual tests from which yield surfaces can be determined. Future work will extend the framework to predict dynamic forming limit diagrams using both strain and stress based limits.



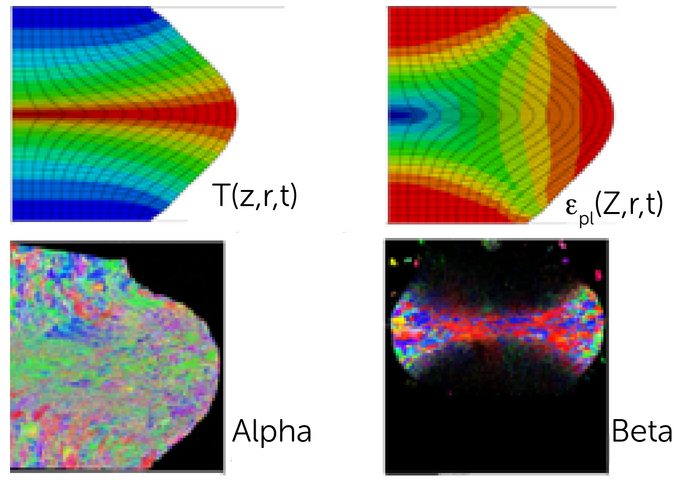
The virtual modelling framework will use experimental microstructural data to create virtual material models from which yield surfaces can be determined.

Process models for dynamic materials engineering

Although engineers often assume that the microstructure remains unchanged during forming, in reality it evolves continuously, particularly in the warm and hot forming regimes of interest in LightForm. In aluminium alloys this involves texture evolution, strain hardening, recovery and the dynamic precipitation and dissolution of strengthening particles. During the hot forming of titanium alloys, phase transformations and recrystallization are also important.

Research during the first year, led by Cambridge University and supported by Manchester, has focused on modelling lab-scale upsetting tests, containing thermal gradients and linking it to microstructure evolution.

Finite element modelling has been used to model the effects of friction and heat transfer boundary conditions, during the testing of two different titanium alloys, Ti64 and Ti407. Initial results have shown that the macroscopic behaviour measured during these tests can be relatively insensitive to severe local deformation variations. As a result, microstructures produced during these tests are often not truly representative of the conditions assumed in tests.



Integrating microstructure -informed modelling codes across length scales

Ultimately, the materials models developed in LightForm will be used in process models, using efficient parametrisations of microstructure evolution. This integration of microstructure informed models into forming codes will not only improve the predictions of shapes and forming limits but also provide much desired information about the microstructure and therefore properties after forming.

Initial efforts in this area, led by Imperial College London, are focused on modelling the effects of plastic strain on the precipitation kinetics consequently on the hardening behaviour of aluminium alloys during ageing after cold and warm forming. The objective is to be able to predict the property variation in a process like HFQ™, where the deformation and temperature histories vary with position.

Challenge 3:

Process innovation – Manufacturing with embedded Materials engineering (meme) Implementation

Challenge Theme 3 aims to exploit the fundamental materials engineering knowledge, developed in Challenge 1, and the modelling and simulation tools, developed in Challenge 2, to advance novel forming processes that will extend manufacturing technology and the ability to form more difficult materials.

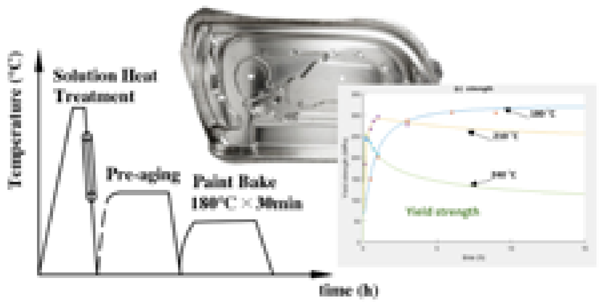
Initially, research in Theme 3 has focused on more mature forming technologies and working to set up leveraged associated projects, which will start to come more on stream next year. This currently involves the following main topics:

Rapid post forming ageing

The aim of this project, led by Imperial College, is to investigate the viability of reducing the artificial ageing cycle traditionally used post forming to achieve T6/8 peak strength in heat treatable aluminium alloys.

Conventionally, this requires 9 to 12 hour aging treatments, which for large scale automotive production is too expensive to implement. Results to date are very encouraging and have demonstrated that, by control of the thermal cycle, in standard automotive materials like AA6082, it is possible to reduce the time to less than 20 minutes and still achieve a yield strength that is 95% of that of the standard T6 temper.

A process model is being developed to predict the material response in the rapid ageing regime. Future work will also incorporate more in-depth microstructural analysis of potential, detrimental effects from heterogeneous precipitation, whilst exploring the impact on other important properties such as corrosion performance.



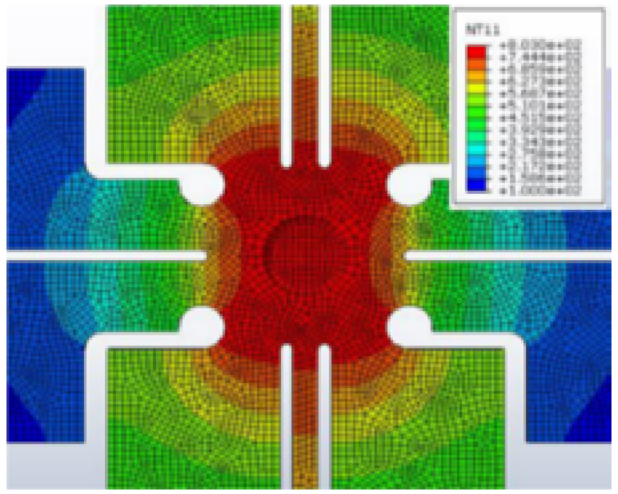
Rapid post forming aging of heat treatable aluminium-automative alloys has the potential to reduce the cycle time from 12hrs to 20mins.

Generating rapid forming limit data under hot sheet forming Conditions

A small scale testing technique is being developed by Imperial College London for rapid measurement of hot formability under biaxial conditions that can be used with rapid heating and cooling cycles.

A test method to obtain such essential data does not currently exist.

The technology being developed has already been demonstrated in a first iteration design, which has attracted interest from a commercial equipment manufacturer (Gleeble).



A small scale test technique being developed in LightForm of rapid measurement of warm forming limits in biaxial conditions.

CHALLENGE UPDATES

Tailoring sheet materials

A PhD project with Primetals Technology has been instigated and a student recruited to begin looking at the issues associated with forming aluminium sheet with tailor rolled blanks.

Low cost forming of difficult materials – titanium and magnesium

Two PhD projects have also just started to explore low cost sheet forming of difficult hexagonal crystal structure titanium and magnesium based alloys. This involves exploring more rapid hot forming techniques as well as optimising the materials for formability by controlling their microstructure and texture though pre-processing.

New generation high strength wrought aluminium-alloys

This year Airbus has launched a large LightForm associated project aimed at obtaining a better understanding of the factors that control the in-service life of new generation high strength aluminium, zinc, magnesium and copper alloys. This work will benefit from the 3D multi-scale imaging and in–situ testing techniques being developed at Manchester, as well as atomistic and phase field approaches to modelling complex coupled problems.

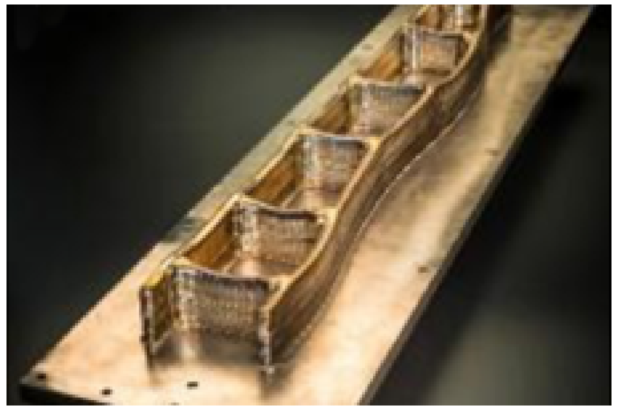
Open Architecture AM(OAAM)

Additive manufacturing within process deformation:

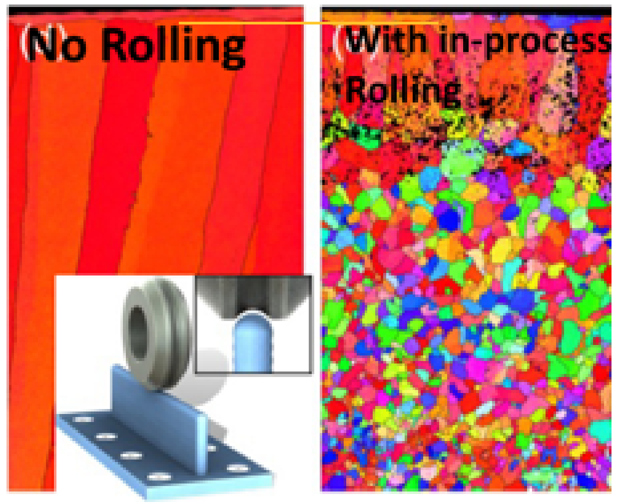
A project associated to LightForm, that is benefiting from the core expertise in forging titanium, forms a substantial work package in an Innovated UK programme - Open Architecture Additive Manufacturing.

The aims of this project are to help industry qualify a hybrid AM process which includes in-process deformation whilst building large structural airframe components, through layer wise addition, using wire fed EBEAM and Plasma-Arc AM technologies.

The work to date has used simulations to develop a process map for determining the process window required to obtain a uniform β- grain structure, as well as research to establish the mechanism of grain refinement that results from the deformation step and techniques to measure the strain distribution introduced to each layer.



Typical titanium part produced by high deposition rate AM



Reconstituted EBSD maps showing improved grain structure

LightForm Research Team

Dr Paloma Hidalgo-Manrique

Started: December 2017 – Full time
Research Stream: aluminium

Dr Paloma Hidalgo-Manrique completed a PhD at the Complutense University of Madrid, focusing on the processing of fine-grained microstructures by accumulative roll bonding, and how it can be used to produce material that can be super-plastically formed more easily. Since then she has worked on the fundamental deformation mechanisms in magnesium alloys as part of LATEST2 and project MAGMAN. Paloma's work in LighForm will extend and optimise the Hot Form Quench process in aluminium alloys, involving a systematic analysis of the effect of different processing parameters on the resulting microstructures and performing detailed characterization of the latter, by a combination of complementary techniques including scanning and transmission electron microscopy.

Dr Alex Cassell

Started: February 2018 – Dedicated 50% LightForm

Research Stream: titanium and aluminium

Dr Alex Cassell has worked on several research programmes since completion of a PhD on the environmentally assisted degradation mechanisms in light alloys. Working in the Corrosion and Protection Centre he has expertise on the multi-scale characterisation of high performance aluminium alloys. His research has included the study of hydrogen embrittlement (HE) and stress corrosion mechanisms in light alloys, the development of new corrosion protection systems for high performance aerospace aluminium alloys, as well as research on forming techniques for integration of light weight alloy systems into land transport vehicles. Alex's work in LightForm aims to improve our understanding of the degradation mechanisms in high performance light alloys formed using existing and new processes, and their behaviour in demanding environments.

Dr. Nicolas Gruel

Research Software Engineer
Dedicated 50% LightForm
Research Stream: modelling and data

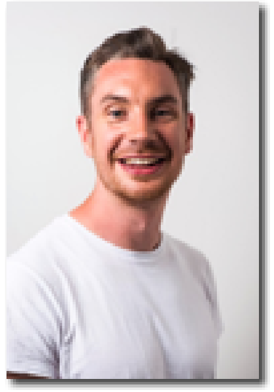
Dr Nicolas Gruel completed a PhD in astrophysics and a Post-Doc in software development for data acquisition, analysis and simulation of astronomical images. As the lead developer for the Centro de Estudios de Física del Cosmos de Aragón, Nicolas was accountable for creating the data pipeline to analyse 1.4 TB of data per day, moving then to the University of Sheffield where he led the Insigneo Institute Computer Science engineering team. As a Research Software Engineer at The University of Manchester, Nicolas' supports research by managing software development and/or optimization as well as data management. Nicolas's work in LightForm will be to create a multi-platform data infrastructure to which LightForm data can be uploaded, shared and managed.

Dr Adam Plowman

Started: June 2018 – Full time
Research Stream: modelling and data

Dr Adam Plowman has recently completed a PhD at The University of Manchester, using first principles atomistic simulation to study zirconium grain boundaries, with the aim of understanding the pellet-cladding interaction in the fuel rod cladding tubes of light water nuclear reactors. In LighForm, Adam will create a framework to improve modelling capabilities in assessing the formability of light alloys. This will include exploring crystal plasticity methods and phase field modelling and applying them to predict microstructure development during warm forming and forging.

Dr Christopher Stuart Daniel



Started: February 2018 – Full time
Research Stream: titanium and aluminium

Dr Christopher Stuart Daniel recently obtained his EngD from the University of Manchester with a thesis on the development of crystallographic orientations (textures) during hot-rolling of dual-phase zirconium alloys. In LightForm, Christopher leads the in-situ characterisation of light alloys and is working to develop in-situ characterisation capabilities for studying the micro-mechanics of deformation at elevated and hot and warm forming temperatures in titanium, aluminium and magnesium alloys, including the development and building of bespoke rigs for use with synchrotron diffraction, neutron diffraction and electron microscopy. Christopher's work is intended to broaden knowledge of the dynamic mechanisms, active during forming, that contribute to the micro-structural evolution and precipitate formation during forming of advanced light alloys.

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Dr Sumeet Mishra

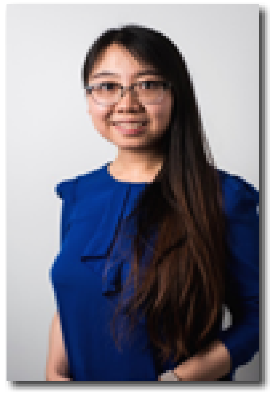
Started: September 2018 – Full time
Research Stream: aluminium and modelling

Dr Sumeet Mishra recently completed his PhD from Indian Institute of Technology Kanpur with a thesis on experimental and theoretical investigations of the effect of precipitates on mechanical behaviour and deformation texture of an aluminium-magnesium-silicon alloy.

Prior to joining The University of Manchester, he was a post-doctoral fellow at Indian Institute of Science Bangalore. In LightForm, Sumeet is involved in understanding the deformation response in the two phase regime of Ti-6Al-4V alloy by carrying compression tests at different temperature under constant true strain rate to simulate experimental processing conditions.

A special emphasis will be placed on developing a detailed understanding of texture and microstructure evolution and other mechanisms such as globularization, dynamic recrystallization and dynamic recovery. Apart from titanium alloys, Sumeet will also be developing a model based on Kampmann-Wagner numerical framework to understand precipitation kinetics in age hardenable Al alloys with special focus on dislocation assisted nucleation and growth.

Dr Jinghua Zheng



Started: January 2018 – Full time
Research Stream: aluminium

Dr Jinghua Zheng completed a PhD in Mechanical Engineering at Imperial College London, during which she developed a constrained ageing technique for residual stress reduction in aluminium aircraft components. She also established and validated physically-based constitutive equations and for FE models of residual stress and yield strength distributions in components. Based at Imperial College London, Jinghua's work in LightForm focuses on optimizing and modelling the age hardening response in the HFQ process. This includes an examination of the age hardening properties and considering the effects of prior dislocations. Jinghua will also develop a phenomena-based model to capture the basic ageing mechanisms (i.e. nucleation, growth, coarsening, dissolution of the precipitates) and the interactive relations between ageing and dislocation evolution. Crucially this model is expected to be implemented into FE simulations of the HFQ process modelling

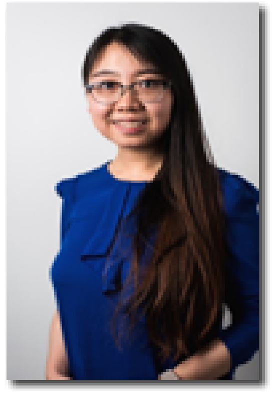
Dr Patryk Jedrasiak

Started: October 2017 – Full time
Research Stream: titanium, aluminium and modelling

Dr Patryk Jedrasiak completed an MPhil in Engineering and a PhD in numerical modelling of friction welding at the University of Cambridge, where he is now a Research Associate. Patryk's research experience includes a fellowship at Harvard University, focusing on a novel Eulerian numerical method for simulating elastoplastic solids, 3 years part-time at the industrial sponsor of his PhD, The Welding Institute, as well as undergraduate research placements at Imperial College London and fka Aachen (part of RWTH Aachen). Patryk has also completed internships with Centro Ricerche Fiat, McKinsey & Co. and NATO, working on major engineering challenges: electric vehicles, energy strategy and autonomous systems. Patryk's work with LightForm focuses on microstructure-informed, computationally efficient thermomechanical finite element modelling of innovative forming processes, for light alloys.

LightForm Research Spotlight: Dr Jinghua Zheng

Development of compressed HFQ processing routes

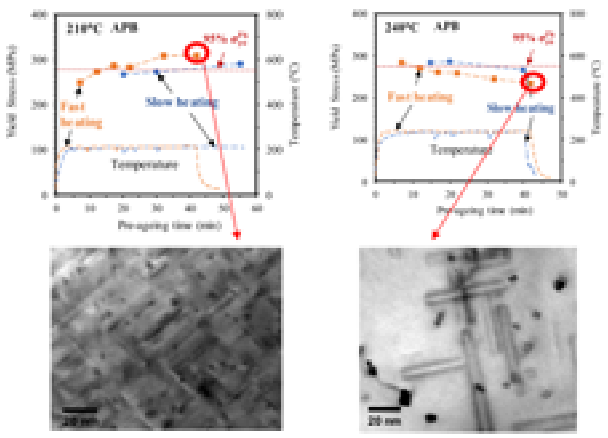


Solution heat treatment, Forming and cold die Quenching (HFQ®) is a technique that enables mass production of high strength aluminium panel parts with unprecedented shape complexity. HFQ is being used to reduce the mass of components by using high-strength aluminium grades, such that HFQ panels are delivering >50% weight reduction comparing to conventional steel ones, or >20% compared to some conventionally pressed aluminium grades. The key potential concerns relating to the current development are the processing cost and the lead time, which are two important factors, particularly for the car manufactures. Therefore, gaining a deeper understanding of the microstructure evolution, particularly the precipitate, during HFQ is vital to enable a more energy-efficient HFQ processing routes to be developed for the industrial application.

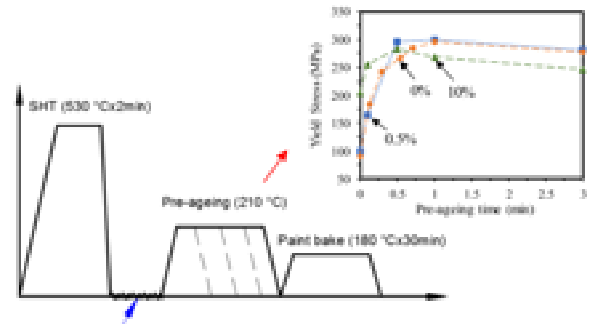
The project aims to establish compressed HFQ processing routes by developing rapid ageing and solution heat treatment, considering the microstructure evolutions, while maintaining or further improving the required post-form shape and mechanical properties.

Methodologies

- Gleeble tests will be performed, simulating the HFQ procedure, to specimens to examine the optimum (cost-effective) HFQ processing parameters for solution heat treatment, quenching and ageing individually. The processing variables include heating rates, soaking time, soaking temperature, strain rates, etc.
- Mechanical tests (e.g. tensile, hardness tests, fatigue, etc.) will be conducted to examine the post-formed properties.
- Microstructure examination (e.g. SEM, EBSD, etc.) will be performed to enable insight into the HFQ mechanism.
- A typical car body component (e.g. B-pillar, etc.) will be processed using the determined parameters to validate the effectiveness of the newly established HFQ processing route.



Fast ageing experimental examination



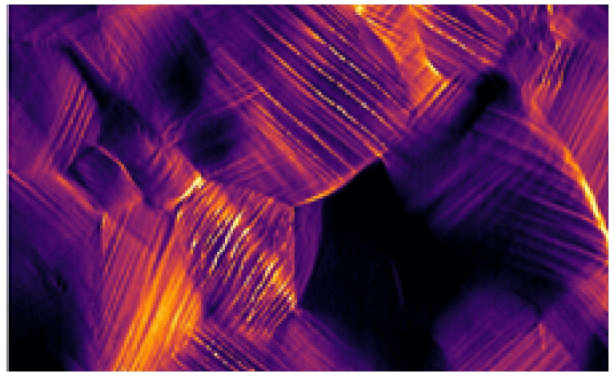
Dislocation effects on age hardening properties

LightForm Research Projects

- Computationally efficient modelling for manufacturing with embedded materials engineering
- Prediction of yield surface evolution using crystal plasticity simulations
- Performance testing for materials produced by novel production routes for automotive light-weighting
- In-situ characterisation of the high temperature deformation micro-mechanics in dual-phase Ti alloys
- Datalight - Reproducibility and data management
- Improving the Hot Form Quench process in Al alloys
- Lab scale simulation for thermo-mechanical processing of dual-phase Ti alloys

Associated LightForm Research Projects

- **Understanding EAC in wrought aerospace plate** Airbus
- **Crystal plasticity of abnormal beta grain structures** Otto Fuchs
- **Coupled-phase field crystal plasticity modelling of Ti forgings**
- **Designing SCC resistant forging alloys**
- **Phase field modelling of Al alloys**
- **OAAM** Innovate UK



LightForm PhD Research Projects

- Effects of accelerated ageing of hybrid-hot formed Al automotive panels on corrosion resistance
- Novel pre-age deform and re-age processing route for tailoring properties in Al alloys
- Control of abnormal grain structures in Ti forgings
- Slip localisation in forming high strength / warm Al forming of 7xxx alloys
- Tailored properties in Al automotive body sheet with taper-rolled geometry
- Generating forming limit curves at hot sheet forming conditions - Formability assessment for metallic sheet materials under hot stamping conditions
- Low cost rolling of Mg-alloy sheets - A novel and cost effective method to manufacture Mg alloy sheets
- Novel hot stamping of Ti alloy panel components - Development of novel hot stamping process of Ti alloy

Associated LightForm PhD Research Projects

- **Novel Al alloys for defence applications** DSTL
- **EAC of new generation 7xxx al-aerospace alloys: 4D imaging of initiation processes** Airbus
- **The influence of combined oxidation and fatigue conditions on the endurance of Ti alloys** Airbus
- **Atomistic simulation of hydrogen embrittlement mechanisms in 7xxx series Al alloys** Airbus
- **Chemo-mechanical modelling of hydrogen diffusion and fracture in wrought 7xxx series Al alloys** Airbus
- **The effect of microstructure on the ductility of Ti alloys** Rolls-Royce and TIMET
- **Development of novel corrosion testing methods for anticorrosion performance evaluation of treated light alloys**

LightForm Investigators

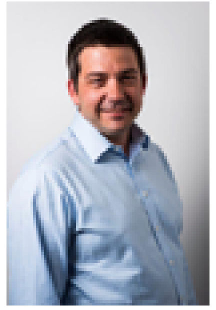
Principal Investigator
Professor Phil Prangnell

The University of Manchester
- Co-Investigators

Dr João Quinta da Fonseca

Professor Joseph Robson

Dr Michele Curioni



Professor Xiaorong Zhou

Dr Sarah Haigh

Dr Christopher Race

Dr Pratheek Shanthraj

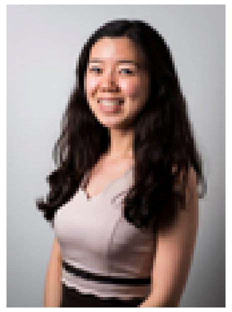
Cambridge University
- Co-Investigator

Dr Hugh Shercliff

Imperial College London
- Co-Investigators

Professor Jianguo Lin

Dr Nan Li



Dr Jun Jian

LightForm Structure

Professor Phil Prangnell
Principal Investigator

University of Cambridge	Manchester 1824 The University of Manchester	Imperial College London
Dr Hugh Shercliff *Co-Investigator*	Dr João Quinta da Fonseca *Co-Investigator*	Professor Jianguo Lin *Co-Investigator*
	Professor Joseph Robson *Co-Investigator*	Dr Nan Li *Co-Investigator*
	Dr Michele Curioni *Co-Investigator*	Dr Jun Jian *Co-Investigator*
	Professor Xiaorong Zhou *Co-Investigator*	

Operations Team Members

Natalie Shannon - Project Manager	Professor Phil Prangnell	Dr João Quinta da Fonseca
Professor Joseph Robson	Dr Michele Curion	Professor Xiaorong Zhou

Challenge Theme Leaders

Theme 1	**Theme 2**	**Theme 3**
Professor Joseph Robson	Dr João Quinta da Fonseca	Professor Jianguo Lin/Dr Jun Jiang

Management Team members:

Professor. Phil Prangnel	Dr João Quinta da Fonseca	Professor Joseph Robson
Professor Xiaorong Zhou	Dr Michele Curioni	Dr Sarah Haigh
Professor Jianguo Lin	Dr Nan Li	Dr Jun Jiang
Dr Hugh Shercliff	Dr Christopher Race	Dr Pratheek Shanthraj
Natalie Shannon		

LightForm International Advisory Board – Steering Committee members

Dr Michael Clinch (Chair)	Innoval Technology	Dr Cyrille Bezencon	Novelis
Professor Paul Blackwell	University of Strathclyde	Dr Richard Hunt	Impression- Technologies
Dr Benjamin Dod	Airbus	Mark Dixon	Rolls-Royce Plc
Professor Trond Furu	Nord Hydro	Professor Bjorn Holmedal	Norwegian University of Science and Technology
Dr Mark Turski	Luxfer		

Engineering & Physical Sciences Research Council

Dr Laura Finney EPSRC Portfolio Manager

LightForm Structure

Operations team

Meeting every 4 weeks approximately, the Operations Team execute actions from the Management meetings, review progress to date, report and discuss project milestones, administration and project management. The Operations Team meetings provide a transparent and current overview of the project, which is disseminated to all team members.

Management team

Responsible for developing LightForm's rolling strategic vision, implementation and delivery of research, against objectives and milestones.

Comprised of the Programme Director and Deputy Director, Challenge Theme Leaders, Lead Investigators from all partner institutions and the LightForm Project Manager, the Management Team meet in person twice yearly.

An in-depth review of project work packages and research landscape is undertaken, in order to:

- Inform our vision
- Develop our technology transfer plan
- Modify and/or set new objectives

Each meeting includes:

- Progress reviews to date
- Technical presentations from the entire PDRA team
- Planning and content for IAB

LightForm International Advisory Board – Steering Committee

The Independent Advisory Board (IAB) meets annually. The IAB comprises industrial specialists, representing a range of industrial sectors relevant to LightForm, with additional academic representation, both UK and international, and one Catapult Centre (AFRC) representative.

The IAB provide expert advice and recommendations to the management group and research team in relation to:

- Direction of research, methodology and research plan
- Strategy for outreach and industrial engagement
- Progress of research against milestones and deliverables
- Efficient utilisation of resources
- Bench-marking in relation to research quality and research outputs
- Approval of annual report

LightForm International Advisory Board - September 2018

Our most recent meeting was held at Cambridge University on Monday 24 September 2018 where we were delighted to welcome our newly appointed Chair, Dr Michael Clinch, and thank his predecessor Professor Trond Furu.

Professor Phil Prangnell started the day's proceedings by restating LightForm's core aims and objectives, providing a comprehensive overview of the current and future landscape, and headline project news.

Project Manager, Natalie Shannon, delivered a detailed review of project progress to date, incorporating resourcing, progress against key performance indicators, project spend, communications, LightForm website and Researcher Code of conduct.

Professor Joseph Robson, LightForm Outreach Champion, outlined future activities including the LightMAT conference, which will take place in Manchester in November 2019. This is the first occasion that this prestigious conference will be hosted outside of Germany. Dr Hugh Shercliff provided teacher and pupil feedback, regarding his newly developed secondary school and college resource, which encourages students to explore and consider the selection of materials in the design process.

Our three Theme Leaders, Dr João Quinta da Fonseca, Professor Joseph Robson and Dr Jun Jian, presented updates on their work packages and key theme challenges within LightForm. This generated positive, beneficial dialogue and considered discussion amongst the LightForm Team and Steering Committee members.

At the close of the day, EPSRC Portfolio Manager, Dr Sinead Balgobin provided initial verbal feedback to the Management Team. Positive feedback highlighted the Researcher Code of Conduct as an example of best practice, LightForm's professional outreach plan as a highly effective approach and strategy, KPI's as clearly defined and managed and the approach to data management as impressive, pioneering and interesting. Feedback provided points for consideration moving forward, and confirmation that LightForm is on track after one year.

Verbal feedback from Steering Committee Chair, Dr. Michael Clinch, was also extremely positive and insightful, presenting the LightForm team with several opportunities to consider for future development and encouraging us to keep up the good work!

For our evening meal we were extremely fortunate to receive a Cambridge University dining experience. The Queens' College Dining Hall dates as far back as the 15th Century, steeped in history and tradition, this was a unique experience enjoyed and appreciated by all.

The Queens' College Dining Hall

LightForm Events

The LightForm Research Showcase 2018 took place on Tuesday 25 September the day after the International Advisory Board. Our first, LightForm Research Showcase, presented to the entire Steering Committee the culmination of LightForm research to date.

Steering Committee Chair, Dr Michael Clinch, observed that the Showcase demonstrated an impressive volume of work for the first year of the programme, with project presentations of high technical quality, demonstrating detailed scientific understanding.

We were fortunate enough to have in attendance, academics and students from Cambridge University who also benefited from the Showcase's varied range of presentations which comprised of:

Michael Atkinson
The University of Manchester
Simulating strain path reversal using full-field crystal plasticity modelling

Kai Zhang
Imperial College London
Microstructure evolution in the thermal-mechanical behaviours of alloys

Dr Jinghua Zheng
Imperial College London
Investigation of fast ageing method for AA6082

Dr Alex Cassell
The University of Manchester
Recent developments in the characterisation of aluminium alloy microstructures by electron microscopy - microchemistry in 7xxx aluminium alloys the non-uniform distribution of elements

Nick Byres
The University of Manchester
Investigating grain size distribution abnormalities in Ti-6Al-4V

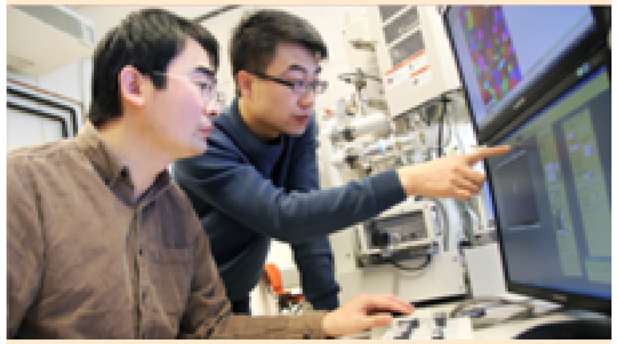
Dr Christopher Daniel
The University of Manchester
High temperature deformation micromechanics in dual-phase titanium alloys

Dr Hugh Shercliff & Dr Patryk Jędrasiak
Cambridge University
Modelling of hot deformation testing

Dr Nicolas Gruel (assisted by Nick Byers)
The University of Manchester
LightForm data management and data sharing application

Our outreach activities are targeted at four main stakeholder groups; the research community, industry, the general public, and schools. Our outreach delivery strategy involves working with appropriate outreach partners to maximize the impact of our activities. This includes the Centres for Doctoral Training (in particular, Advanced Metallic Systems), the Sir Henry Royce Institute, and the existing outreach teams at The University of Manchester, Imperial College London, and Cambridge University.

Researchers



- Publications and presentations
- Conference and workshop organisation
- Data standards and sharing

Industry

- Industry focussed workshops
- Trade magazine publication
- Professional standard code sharing

Our launch event was held in Manchester on October 19 2017. There were 62 attendees (32 industry, 30 university or research organisation), representing 22 companies and 10 universities/research organizations.

The morning session comprised an introduction to LightForm from the research team and three industrial scene-setting talks from Constellium, Impression technologies, and Rolls Royce spanning both the supply chain and alloy type aluminium, titanium and magnesium. The need for a paradigm shift to integrate materials technology into the manufacturing with light alloys was a recurring theme across industries and sectors and is central to the vision of LightForm.

The afternoon session comprised a workshop where ideas and input from industry and research organisation delegates were sought on industry specific research topics, on effective routes to collaboration, and on areas for cross-industry collaboration.

General public

- Science fairs and festivals
- Local societies
- Public events (eg Café Scientifique)

Schools

- Summer school events
- Resources for teachers
- Science fairs and festivals

64 inputs were received, comprising potential PhD projects, general comments on the research programme, and suggestions for collaborative workshops.

Of the 11 workshop topics identified, 6 had a modelling focus and this led to us initiating a workshop on simulation of metal forming, to be held in 2019 in conjunction with the IoM3 (Formed in the UK).

Outreach activities to the general public have included

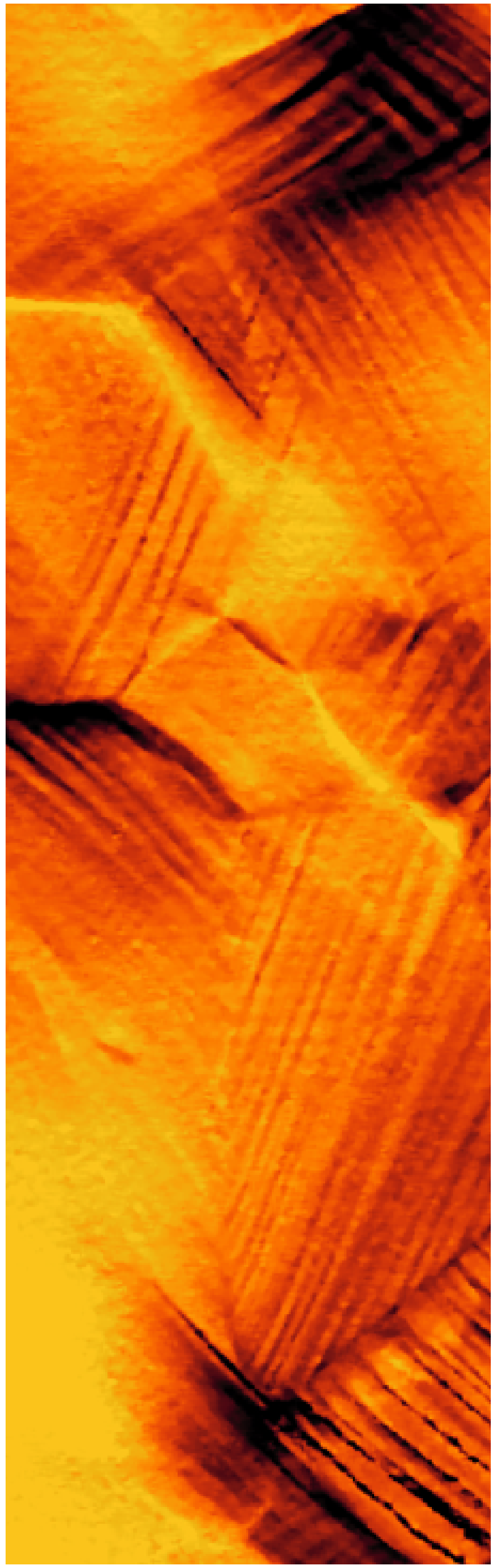
Outreach

hands on demonstrations in collaboration with The Sir Henry Royce Institute. Major outreach events planned for 2019 also include the LightMAT conference.

LightForm launch event
October 2017

Of the 11 workshop topics identified, 6 had a modelling focus and this led to us initiating a workshop on simulation of metal forming, to be held in 2019 in conjunction with the IoM3 (Formed in the UK).

Outreach activities to the general public have included participation in the BlueDot science festival delivering hands on demonstrations in collaboration with The Sir Henry Royce Institute. Major outreach events planned for 2019 also include the LightMAT conference.



Code of Conduct

A LightForm Code of Conduct has been developed in collaboration with LightForm colleagues and described by our EPSRC Portfolio Manager as an example of outstanding practice.

Our Code of Conduct is intended as a guide and support to all LightForm colleagues, defining how the LightForm team will operate, in order to foster an inclusive work environment, in which to successfully deliver our project goals.

It sets out standards of practice which the team are expected to follow when within, or representing LightForm.

Roll-out for the Code of Conduct incorporated a briefing for all existing team members, and inclusion in the new starters induction programme and can be viewed here at the **LightForm website**.

Headline successes

Headline successes in our first year include the publication of 41 journal papers (see page 22), with others in preparation.

In addition to our core industry partners, we have already established new collaborations with industry partners, including aligned PhD projects with Otto Fuchs and Airbus. To date a total of 36 industry and academic engagement activities have taken place.

LightForm has already attracted £3.8M direct leverage funding.

Our Research Team have been engaging in activities around the globe, which include 13 invited keynotes, with 28 activities at national and international events including conferences in UK, France, China and the USA.

We are also happy to celebrate the successes of the Imperial College London Team, who have made two patent applications and received two prestigious recognition awards.

Dr Nan Li
Imperial College London

Rowbotham Medal - Institute of Materials, Minerals and Mining (IOM3) Recognition of outstanding contribution to the development of the innovative use of materials for automotive applications

Dr Jun Jiang
Imperial College London

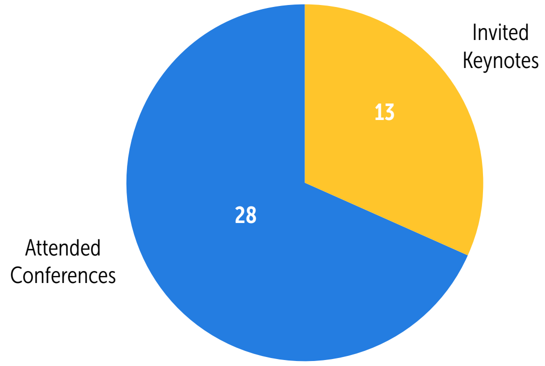
President Award, Imperial College London
- Outstanding early stage researcher

Professor Jianguo Lin

A method for forming curved lengths of extruded profiles/sections in metal alloys
UK Application No. GB 1707519.3

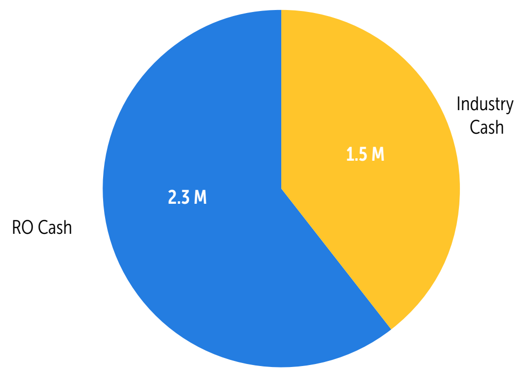
Professor Jianguo Lin & Dr Nan Li

A Method for Forming Sheet Material Components
UK Application No. GB 1713483.4



Conferences

Our Senior Academics are regularly invited as keynote speakers, and commit to attending those conferences which increase visibility, strengthened links with industry, and raise and promote the LightForm profile, during our critical early development stage.



3.8M Direct Support

Leveraged activity will continue to be essential, in order to maximise the Impact on UK Plc from the core EPSRC investment.

Publications

A measured selection of journal outputs for Year 1, combined with journal outputs for ongoing projects across our partnership institutions, have enabled us to surpass our initial year 1 target.

D. Esqué-de los Ojos, C.-T. Nguyen, A. Orozco-Caballero, G. Timár, J. Quinta da Fonseca
Back-stresses and geometrical hardening as competing mechanisms enhancing ductility in HCP metals, Materials Science and Engineering: A. 729 (2018) 37–47.

D. Lunt, X. Xu, T. Busolo, J. Quinta da Fonseca, M. Preuss
Quantification of strain localisation in a bimodal two-phase titanium alloy, Scripta Materialia. 145 (2018) 45–49.

A. Orozco-Caballero, D. Lunt, J.D. Robson, J. Quinta da Fonseca
How magnesium accommodates local deformation incompatibility: A high-resolution digital image correlation study, Acta Materialia. 133 (2017) 367–379.

J.F. dos Santos, P. Staron, T. Fischer, J.D. Robson, A. Kostka, P. Colegrove, H. Wang, J. Hilgert, L. Bergmann, L.L. Hütsch, N. Huber, A. Schreyer
Understanding precipitate evolution during friction stir welding of Al-Zn-Mg-Cu alloy through in-situ measurement coupled with simulation, Acta Materialia. 148 (2018) 163–172.

L. Xu, J.D. Robson, L. Wang, P.B. Prangnell
The Influence of Grain Structure on Intermetallic Compound Layer Growth Rates in Fe-Al Dissimilar Welds, Metallurgical and Materials Transactions A. 49 (2018) 515–526.

D. Griffiths, B. Davis, J.D. Robson
The Influence of Strain Path on Rare Earth Recrystallization Textures in a Magnesium-Zinc-Rare Earth Alloy, Metallurgical and Materials Transactions A. 49 (2018) 321–332.

Y. Wang, P.B. Prangnell
Evaluation of Zn-rich coatings for IMC reaction control in aluminium-magnesium dissimilar welds, Materials Characterization. 139 (2018) 100–110.

Y. Wang, B. Al-Zubaidy, P.B. Prangnell
The Effectiveness of Al-Si Coatings for Preventing Interfacial Reaction in Al-Mg Dissimilar Metal Welding, Metallurgical and Materials Transactions A. 49 (2018) 162–176.

Y. Liu, M. Curioni, Z. Liu
Correlation between electrochemical impedance measurements and corrosion rates of Mg-1Ca alloy in simulated body fluid, Electrochimica Acta. 264 (2018) 101–108.

R. Elaish, M. Curioni, K. Gowers, A. Kasuga, H. Habazaki, T. Hashimoto, P. Skeldon
Effect of fluorozirconic acid on anodizing of aluminium and AA 2024-T3 alloy in sulphuric and tartaric-sulphuric acids, Surface and Coatings Technology. 342 (2018) 233–243.

F. Yu, L. Camilli, T. Wang, D.M.A. Mackenzie, M. Curioni, R. Akid, P. Bøggild
Complete long-term corrosion protection with chemical vapor deposited graphene, Carbon. 132 (2018) 78–84.

M. Curioni, L. Salamone, F. Scenini, M. Santamaria, M. Di Natale
A mathematical description accounting for the superfluous hydrogen evolution and the inductive behaviour observed during electrochemical measurements on magnesium, Electrochimica Acta. 274 (2018) 343–352.

Y. Yang, F. Scenini, N. Stevens, M. Curioni
Relationship between the inductive response observed during electrochemical impedance measurements on aluminium and local corrosion processes, Corrosion Engineering, Science and Technology. (2018) 1–9.

J.M. Torrescano-Alvarez, M. Curioni, X. Zhou, P. Skeldon
Effect of anodizing conditions on the cell morphology of anodic films on AA2024-T3 alloy, Surface and Interface Analysis. (2018).

M. Curioni, L. Salamone, F. Scenini, M. Santamaria, M. Di Natale
A mathematical description accounting for the superfluous hydrogen evolution and the inductive behaviour observed during electrochemical measurements on magnesium, Electrochimica Acta. 274 (2018) 343–352.

J.M. Torrescano-Alvarez, M. Curioni, P. Skeldon
Effects of oxygen evolution on the voltage and film morphology during galvanostatic anodizing of AA 2024-T3 aluminium alloy in sulphuric acid at –2 and 24 °C, Electrochimica Acta. 275 (2018) 172–181.

Q. Luan, J. Lee, Z. Zheng, J. Lin, J. Jiang
Static recrystallization study on pure aluminium using crystal plasticity finite element and phase-field modelling, Procedia Manufacturing. 15 (2018) 1800–1807.

Y. Li, Z. Shi, J. Lin, Y.-L. Yang, P. Saillard, R. Said
Effect of machining-induced residual stress on springback of creep age formed AA2050 plates with asymmetric creep-ageing behaviour, International Journal of Machine Tools and Manufacture. 132 (2018) 113–122.

Publications

J.-H. Zheng, R. Pan, C. Li, W. Zhang, J. Lin, C.M. Davies
Experimental investigation of multi-step stress-relaxation-ageing of 7050 aluminium alloy for different pre-strained conditions, Materials Science and Engineering: A. 710 (2018) 111–120.

W. Zhou, J. Lin, T.A. Dean, L. Wang
Feasibility studies of a novel extrusion process for curved profiles: Experimentation and modelling, International Journal of Machine Tools and Manufacture. 126 (2018) 27–43.

K. Zheng, J. Lee, W. Xiao, B. Wang, J. Lin
Experimental Investigations of the In-Die Quenching Efficiency and Die Surface Temperature of Hot Stamping Aluminium Alloys, Metals. 8 (2018) 231.

T.-F. Chung, Y.-L. Yang, B.-M. Huang, Z. Shi, J. Lin, T. Ohmura, J.-R. Yang
Transmission electron microscopy investigation of separated nucleation and in-situ nucleation in AA7050 aluminium alloy, Acta Materialia. 149 (2018) 377–387.

Y. Li, Z. Shi, J. Lin, Y.-L. Yang, P. Saillard, R. Said
FE simulation of asymmetric creep-ageing behaviour of AA2050 and its application to creep age forming, International Journal of Mechanical Sciences. 140 (2018) 228–240.

W. Zhou, Z. Shi, J. Lin
Upper bound analysis of differential velocity sideways extrusion process for curved profiles using a fan-shaped flow line model, International Journal of Lightweight Materials and Manufacture. 1 (2018) 21–32.

W. Zhou, J. Lin, T.A. Dean, L. Wang
Analysis and modelling of a novel process for extruding curved metal alloy profiles, International Journal of Mechanical Sciences. 138–139 (2018) 524–536.

J.-H. Zheng, J. Lin, J. Lee, R. Pan, C. Li, C.M. Davies
A novel constitutive model for multi-step stress relaxation ageing of a pre-strained 7xxx series alloy, International Journal of Plasticity. 106 (2018) 31–47.

D. Tsivoulas, J.Q. da Fonseca, M. Tuffs, M. Preuss
Measurement and modelling of textures in flow formed Cr-Mo-V steel tubes, Materials Science and Engineering: A. 685 (2017) 7–18.

X. Hong, A. Godfrey, W. Liu, A. Orozco-Caballero, J.Q. da Fonseca
Effect of pre-existing twinning on strain localization during deformation of a magnesium alloy, Materials Letters. 209 (2017) 94–96.

G. Timár, M.R. Barnett, J.Q. da Fonseca
Discontinuous yielding in wrought magnesium, Computational Materials Science. 132 (2017) 81–91.

T. Sun, A.S. Tremsin, M.J. Roy, M. Hofmann, P.B. Prangnell, P.J. Withers
Investigation of residual stress distribution and texture evolution in AA7050 stationary shoulder friction stir welded joints, Materials Science and Engineering: A. .

D.B. Mitton, A. Carangelo, A. Acquesta, T. Monetta, M. Curioni, F. Bellucci
Selected Cr(VI) replacement options for aluminum alloys: a literature survey, Corrosion Reviews. 35 (2017).

Y. Wang, P.B. Prangnell
The significance of intermetallic compounds formed during interdiffusion in aluminum and magnesium dissimilar welds, Materials Characterization. 134 (2017) 84–95.

S. Tammas-Williams, P.J. Withers, I. Todd, P.B. Prangnell
The influence of porosity on fatigue crack initiation in additively manufactured titanium components, Scientific Reports. 7 (2017).

A. Orozco-Caballero, D. Lunt, J.D. Robson, J. Quinta da Fonseca
How magnesium accommodates local deformation incompatibility: A high-resolution digital image correlation study, Acta Materialia. 133 (2017) 367–379.

D. Lunt, T. Busolo, X. Xu, J. Quinta da Fonseca, M. Preuss
Effect of nanoscale α 2 precipitation on strain localisation in a two-phase Ti-alloy, Acta Materialia. 129 (2017) 72–82.

D. Lunt, J.Q. da Fonseca, D. Rugg, M. Preuss
Microscopic strain localisation in Ti-6Al-4V during uniaxial tensile loading, Materials Science and Engineering: A. 680 (2017) 444–453.

B.I. Rodgers, R.J. Cinderey, P.B. Prangnell
The Influence of Extended and Variable Pre-Stretching on the Strength of AA2195 Alloy Taper-Rolled Plates, Materials Science Forum. 877 (2016) 205–210.
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Industry Partners & Collaborators

AECC BIAM
AFRC ADVANCED FORMING RESEARCH CENTRE UNIVERSITY OF STRATHCLYDE
AIRBUS
Constellium
DD DONCASTERS
FUCHS
esi get it right®
HYDRO
Impression TECHNOLOGIES
JAGUAR
LAND ROVER
Magnesium Elektron SERVICE & INNOVATION IN MAGNESIUM
ADITYA BIRLA NOVELIS
PRIMETALS TECHNOLOGIES
ROLLS ROYCE Rolls-Royce
LUXFER GROUP
TIMET®
innoval technology Part of Danieli Group
NTNU
University of Strathclyde Glasgow