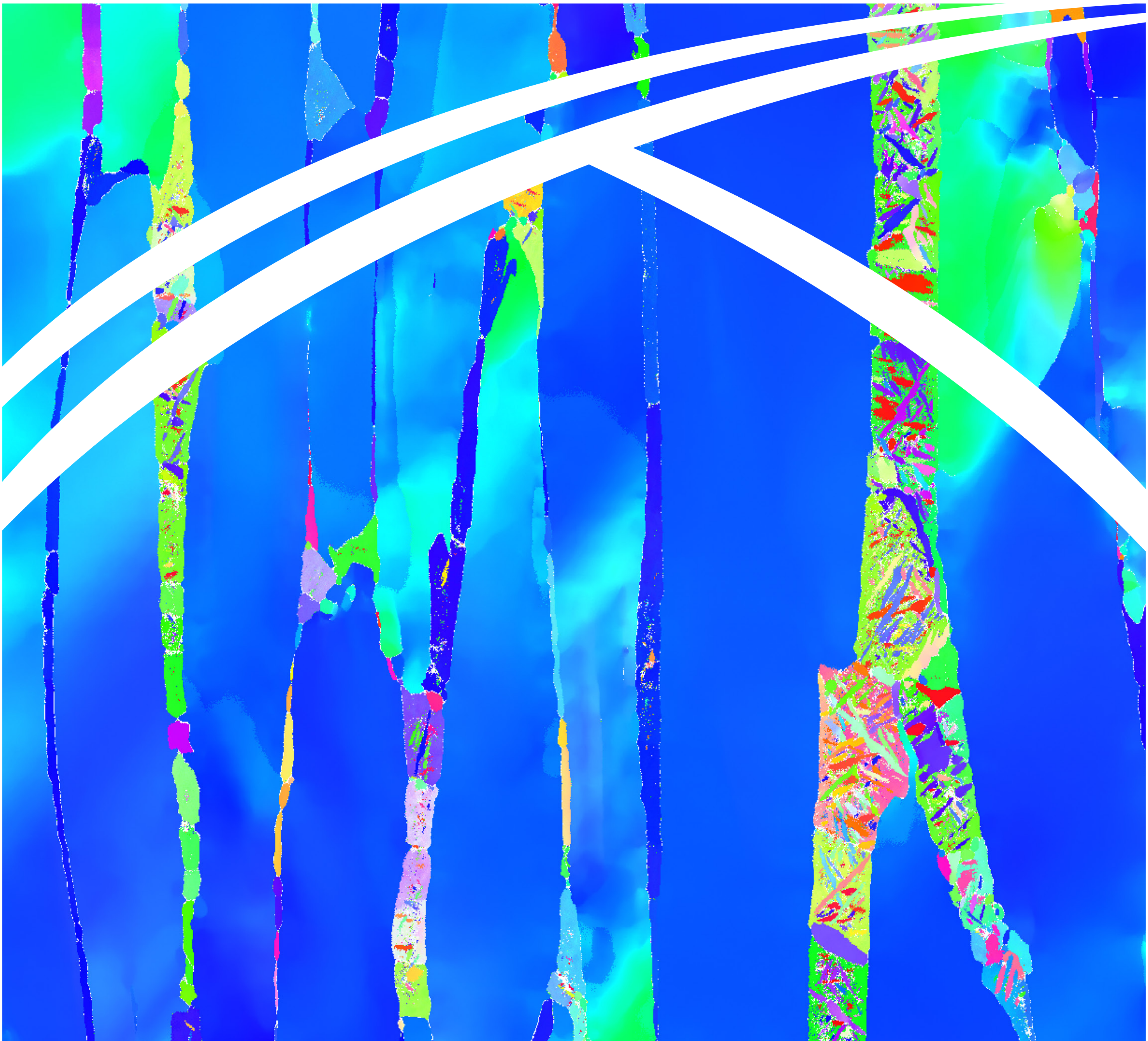
LIGHT FORM

2021 REPORT



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LIGHT FORM

MESSAGE FROM THE DIRECTOR

We are now past the midway point of the LightForm project, and despite the challenges imposed by the pandemic and associated lockdowns, we have continued to go from strength to strength. As we approach the end of the project, we are starting to see the fundamental work in LightForm being applied in several associated projects, both in the form of PhD projects but also new EPSRC and industrially funded projects. Our work on abnormal grain structures in titanium forgings is already being used to optimise forging processes and the research on fast ageing of HFQ formed parts, has also been adopted by industry.

Professor João Quinta da Fonseca

Just after the start of the pandemic we submitted our mid-term report to the EPSRC and received glowing reviews alongside valuable suggestions for maximizing the impact of our research. This was fed into a strategic plan for the second half of the programme, which includes enhancing our outreach activity, and the recruitment of a new communications and project manager, Doyin Mansell. Following the successful mid-term review, I became the director of the LightForm grant, taking over from Phil Prangnell. I am enjoying the challenge of looking after the project, which Phil did incredibly successfully, and for which we are all very grateful. We will continue to operate in the same collaborative manner with which Phil ran the project and we look forward to delivering on the ambitious objectives we have set ourselves and demonstrating the impact of the research carried out in LightForm. Unavoidably, lockdown took its toll on our research, with lab access impossible for most of 2020 and only limited access for most of 2021. This was particularly difficult for PhD students finishing their projects, but also for those starting, since opportunities for training and data acquisition were severely limited. Thanks to the unique way the modelling tools in LightForm have been created, it was possible to shift the emphasis onto computational work for many of the projects. MatFlow, the software framework developed in LightForm (see highlight), significantly lowers the barrier for those new to computational modelling, enabling researchers without any high-performance computing experience to carry out sophisticated workflows combining experimental results with advanced simulations. Several PhD students, most of whom had no background in computational modelling, used MatFlow to conduct computational experiments during lockdown, limiting the impact of the lack of lab access, while diversifying their skill set.

LightForm has continued to grow at pace and our activity now comprises of 54 research projects, 10 of which are already completed. This represents a total of £8.5M in leverage funding from industry and other research council funded projects. The team has expanded to include 9 postdoctoral researchers (6 of which are core funded) and 38 PhD students. We have published over 140 research articles to date, and 20 data-sets on our Zenodo repository. We have also had 3 major releases of software packages, including MatFlow and xrdfit, a package for automatic fitting of synchrotron x-ray diffraction data, developed to analyse the data from our in-situ synchrotron experiments.
It has also been extremely rewarding to see LightForm researchers move on to new posts and develop their careers. We have had 3 PhD students graduate and 4 postdoctoral research associates (PDRAs) moving on to new posts, three to academic positions and another to a career in research. This of course is testament to the calibre and industriousness of these researchers, but also evidence that the research environment in LightForm enables good people to thrive.

Despite the extensive COVID imposed disruption, progress was made in all challenge themes. Highlights include the understanding of the role of chemistry and microstructure on the stress corrosion cracking resistance of thick high strength aluminium plates, and the unravelling of the mechanisms responsible for abnormal grain structures in Ti64 forgings. Our computational modelling capability has also continued to develop at pace, with a new model capable of predicting precipitation kinetics in a crystal plasticity framework and new models for predicting the effects precipitate distribution on the strain localization in recycled aluminium alloys.

In 2021, the Manchester team moved into our new home at the state-of-the-art Royce Hub Building in Manchester, which also hosts our forming equipment, including our high-temperature sheet metal forming press, our Gleeble and deformation dilatometer and our latest addition, a new Fen rolling mill for rolling sheet metal.

Going forward, our plans are to continue to apply our new understanding to problems of industrial relevance and demonstrate the potential of the knowledge, tools and data produced in LightForm. We have ambitious aims to see our computational tools being used by the materials community and our industrial collaborators, and to showcase our newfound ability to predict the microstructure evolution during warm forming in both Al and Ti alloys. To enable us to deliver on these objectives with maximum impact, we have plans to apply for a no-cost extension with the EPSRC, moving the end date of the project to 2023. I will end by thanking all our collaborators and the advisory board members for their support and valuable input. I look forward to another successful year working together.

http://lightform.org.uk

LIGHTFORM AT A GLANCE

141 PUBLICATIONS

CONFERENCES ATTENDED 78

KEYNOTE INVITED 41

83 INDUSTRIAL ENGAGEMENTS

OUR TEAM

6 PDRA'S

ASSOCIATED PDRA'S 3

1 REPRODUCIBILITY AND DATA MANAGEMENT OFFICER

PHD'S ENGAGED IN INDUSTRY RELATED PROJECTS 29

38 PHD'S

LIGHTFORM OUTREACH

RESEARCH COMMUNITY OUTREACH EVENTS 3

SCHOOL OUTREACH PARTNERSHIP 2

CONFERENCES ORGANISED 12

LIGHTFORM PROJECTS

54 TOTAL PROJECTS

BREAKDOWN:

Al ALUMINIUM 36

Ti TITANIUM 13

LEVERAGE

TOTAL LEVERAGE £8.5 million

INDUSTRY £3 million

EPSRC/RESEARCH ORGANISATION £5.5 million

NEWS

Dr Alec E Davis Awarded Lectureship

Dr Alec E Davis has recently been awarded a lectureship in the Department of Materials at the University of Manchester. Alec obtained his PhD in Materials Engineering through the Advanced Metallics CDT at the University of Manchester, where he worked on the design of precipitation-hardenable wrought magnesium alloys. His post-doctoral research with the Open Architecture Additive Manufacturing (OAAM) and NEWAM projects has focused primarily on the development of high-deposition-rate additive manufacturing (AM) processes, and materials characterisation, development, and design of bespoke AM titanium aerospace components. This includes development of alloy-alloy composite parts, where multi-alloy AM technologies are utilised to deposited dissimilar alloys in different component locations for site-specific and tailored mechanical properties.

Vibration Assisted Incremental Sheet Forming Project

In 2022, LightForm is starting a new collaboration with Prof. Hui Long at the University of Sheffield, working on improving our fundamental understanding of the forming processes during Rotational Vibration Assisted Incremental Sheet Forming (RV-ISF). This project will be funded by the EPSRC under the Adventurous Manufacturing follow-up funding scheme,

Incremental Sheet Forming is a flexible, cost effective, energy and resource efficient forming process that requires a simple tool to deform the sheet material incrementally by moving the tool along a predefined tool path created directly from the CAD model of a product. Without using molds or dies, or heavy-duty forming machines, it is extremely well-suited to the manufacture of small-batch or customised sheet products, with complex geometries. In RV-ISF the tool rotates, which significantly improves the formability of many alloys.

In this follow-up project we will apply the modelling tools and characterisation techniques developed in LightForm to help understand the enhanced formability made possible by RV-ISF. This new understanding will then be used to optime the process window and apply it to other materials.

NEWS

LightForm Moves into Royce Hub Building

In October the LightForm team moved from its home in the historic Sackville Street Building to the brand-new Henry Royce Institute Hub Building at The University of Manchester.

The Royce Hub Building is the flagship building of the Henry Royce Institute, the UK's national institute for advanced materials research and innovation. It serves as a focal point of the Institute's national partnership with eight other leading institutions – the universities of Cambridge, Imperial College London, Liverpool, Leeds, Oxford, Sheffield, the National Nuclear Laboratory, and UKAEA.

The building hosts £45 million of new state-of-the-art equipment alongside existing facilities in Manchester for biomedical materials, metals processing, digital fabrication, and sustainable materials research. The hub houses 400 researchers, PhD students and professional services staff driving research and innovation in advanced materials. Alongside this is a variety of collaboration spaces for industry engagement, helping to accelerate the development and commercialisation of advanced materials.

New Capabilities Fenn Reversing Rolling Mill

LightForm's capability has recently been enhanced by the acquisition of a new rolling mill. The mill was supplied by Fenn and Torin and has been commissioned to improve our capability to roll sheet. The mill can roll 300 mm wide plate from a thickens of 10 mm, down to 0.7 mm. Although the rolls are optimised for cold rolling, it is capable of warm rolling up to 600 °C.

The new rolling mill is part of the thermomechanical processing suite at the Henry Royce Institute for advanced materials research and innovation, which also includes a Gleeble Hydrawege, a deformation dilatometer, a differential scanning calorimeter and two hydraulic test machines.
In combination with the casting facilities and hot rolling mill at the Royce Institute in Sheffield, we now have the capability of producing sheet with custom alloy compositions. The rolling mill will be used extensively in LightForm and future projects, and is also available for external use via the Henry Royce Institute.

New Students in LightForm

The LightForm team welcomed 8 new PhD students over the last year, two at Imperial College London and six at Manchester.

The students at Imperial will be carrying out research on creep forming and microstructure development during sideway extrusion of aluminium alloys. The students at Manchester will be working on topics such as the forming of aluminium alloys sheet with Novelis, modelling fatigue micro mechanics and cracking in aluminium in collaboration with Airbus, understanding dwell fatigue with Rolls-Royce, carrying out research on grain refinement in magnesium alloys with Luxfer, and carrying out advanced characterisation of lithium containing aluminium alloys.

All these projects build on the fundamental characterisation and modelling tools developed during the first half of LightForm, and apply them to pressing problems of relevance to our industrial collaborators. We wish them all the best in their studies and look forward to hearing more about their research soon.

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.

Over the past year, Theme 1 activity has grown substantially. We have appointed a new postdoctoral research associate (PDRA) in corrosion characterization and control. Three new PDRAs have also joined the team (1 at Imperial, 2 at Manchester) replacing staff who have left and bringing both experimental and modelling expertise to LightForm.

There has also been increase in the number of associated PhD projects to 19, over 70% of whom are part supported by industry funding. Consistent with the LightForm plan, projects are distributed across all three material classes, with 60% aluminium focussed, 25% titanium and 15% magnesium.

A key feature of the last year has been more intensive cross-theme collaboration. This has enabled fundamental understanding gained in Theme 1 to be translated into application in Theme 3. In addition, data from Theme 1 is being used to inform the models developed in Theme 2, with the modelling activity in turn being used to help interpret fundamental experimental observations. To enhance these collaborations, we have established cross-theme and institution groups focussed on topics such as dynamic effects in aluminium, high recycled content alloys, and titanium fundamentals. These groups have been meeting virtually and have proved a successful addition to our previously established material and theme-based clusters.

Research Summary

A summary of the key research activities in Theme 1 is given below, grouped by material. The research highlights provide further details of some of the most significant developments in the past year.

Aluminium

To exploit synergies between deformation and precipitation to reduce cycle times and enhance formability requires an improved understanding of the fundamentals of dynamic effects in high strength aluminium alloys (AA7075). Using a combination of small angle X-ray scattering (SAXS) and electron microscopy, we have performed dynamic experiments at higher strain rates than previously studied, making them more relevant to industrial forming operations. As strain rate increases, the duration of deformation necessarily decreases, and we have explored the interplay of these effects. This has required utilizing synchrotron X-rays to obtain the necessary size resolution to differentiate small differences in precipitate distribution. We have shown how the balance between greater kinetic enhancement, but shorter time, plays out for higher strain rates (Figure 1a-c). These results have been used to inform the modelling activity (Theme 2) and incorporate non-uniform dynamic precipitation into crystal plasticity models (Figure 1).

Other highlights in aluminium include further advances in the understanding of environmentally assisted cracking (EAC) of high strength 7xxx alloys, which includes in-situ studies of EAC growth. This work, carried out in collaboration with the University of Manchester Airbus partnership, has attracted strong international attention, with a recent publication being in the top 5 most highly cited papers in Corrosion Science.

Titanium

In titanium research, work has continued using in-situ methods to understand the fundamentals of deformation, texture, and microstructural evolution during thermomechanical processing. This has led to advances in the understanding of industrially important phenomena such as the formation of abnormal coarse grain structures (further details given in research highlights). Work has also progressed on the hot stamping of titanium sheet, with new insights gained into the flow behaviour and its relationship to texture distribution in Ti64.

Magnesium

Work has progressed in understanding the fundamental factors necessary to improve formability of magnesium alloys. A novel process path involving cryogenic rolling has been developed that enables a refinement of the microstructure through twinning and manipulation of texture, producing an attractive combination of strength and ductility. Work to understand the improved formability of ZEK100 alloy compared to AZ31 has shown that the strain localization behaviour in the two alloys is different (Figure 2), and this can be related to local micro-texture and the ease of slip transfer. This work is being extended to understand the role of strain path effects.

Future Plans

Uncreasingly, the fundamental work in Challenge 1 is being transferred to applications in Challenge 3 and this trend will continue. For example, there are now 4 new industry supported PhD projects applying the fundamental work on abnormal coarse-grained structures in titanium to industrial use cases.

Areas of growth include an increased focus on recycling tolerant aluminium alloys. We now have 3 PhD projects in this area, looking at fundamental science to enable higher levels of impurities that accompany increasing recycled content. This work is closely linked to related modelling activities in Challenge Theme 2.

Finally, the work on dynamic precipitation in aluminium is now being implemented in a fully coupled crystal plasticity framework (Challenge 2), which will enable the effect of complex forming operations on dynamic effects to be understood and exploited.
formability, along with understanding the effects of local micro-texture on deformation and failure.

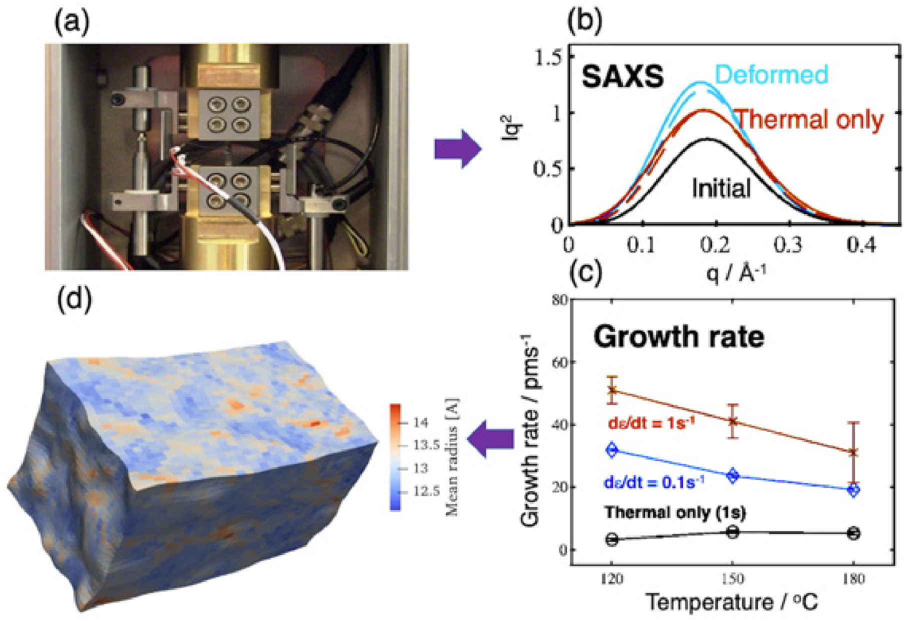

Figure 1 (a) Warm deformation experiments combined with synchrotron X-ray small angle X-ray scattering (SAXS) measurement (b) show the effect that deformation has on the growth rate of strengthening precipitates in AA7075 (c). These experimental results are used to validate coupled crystal plasticity/dynamic precipitation models being developed in Theme 2 (d).

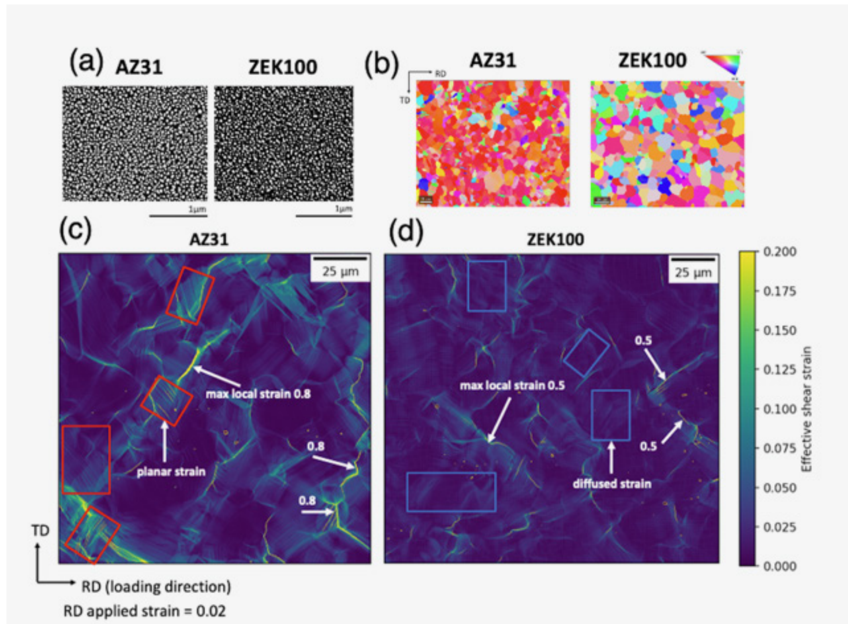

Figure 2 Digital image correlation (DIC) and electron back-scattered diffraction (EBSD) is being used to understand strain localization behaviour in AZ31 and ZEK100 to explain their different forming performance. (a) Gold speckle pattern used for DIC, (b, c) EBSD maps and DIC strain maps from the same area. AZ31 shows stronger planar slip and higher maximum local strain levels, which can be correlated with the local texture environment.

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 embed it into forming process models. The theme's main objectives are:

- Develop material sub-models that capture key aspects of the evolution of deformation structures
- Develop new models for sub-transus deformation of dual phase Ti 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.

Over the past year, research activity has focused on further development of the LightForm virtual materials testing framework MatFlow, developing sub-models for the effects of deformation on precipitation in aluminium alloys and modelling the thermomechanical processing of titanium alloys. This is highlighted by the increased collaboration across the challenge themes, building on foundational data generated in Theme 1 and translating them into mature models for exploitation in Theme 3.

We have appointed two new postdoctoral research associates (PDRAs) within the theme, replacing existing staff vacancies, to ramp up activity in the core research areas. There have also been 11 new associated PhD projects, funded by our partners, that aim to maximise the industrial impact of this activity.

Research Summary

A summary of the key research activities in Theme 2 is given below. The research highlights provide further details of some of the most significant developments in the past year.

Computational formability predictions using MatFlow

One of the core research objectives in LightForm is to be able to perform "virtual materials testing" to predict material behaviour such as forming limits. With MatFlow we have developed the computational framework that will make these simulations possible (see MatFlow research highlight). Using a MatFlow computational pipeline that integrates basic experimental characterisation (EBSD) and testing (uniaxial tension) data with full-field crystal plasticity (CP) and finite element (FE) simulations, using DAMASK and Abaqus, respectively, we can generate forming limit curves (FLCs) and other formability predictors for a given material (Figure 1a). We applied this workflow to Surfalex HF (AA6016A) aluminium as a case study material and produced upper and lower limit bounds on its forming limit. These were compared to experimental FLCs obtained from Nakazima testing. The intermediate steps of this workflow included fitting single-crystal parameters to the experimental testing data, for use within the CP simulations,

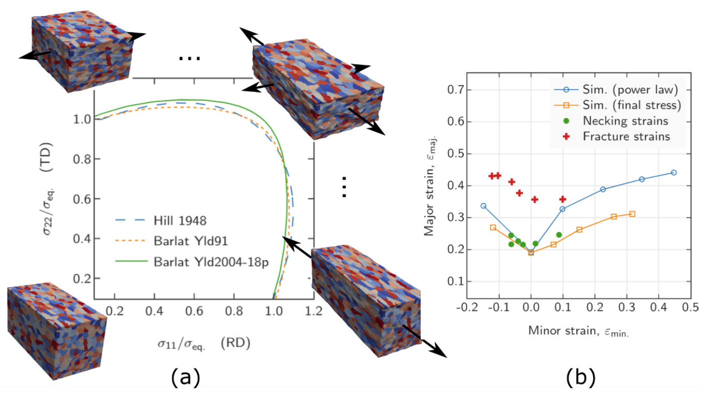

Figure 1: (a) Yield functions were fitted to different criteria using many multiaxial CP simulations; the deformed representative volume elements for three of these loading directions are shown, and (b) Simulated and experimental forming limit curves. Necking strains were calculated using the "first derivative" criterion. "Power law" and "final stress" refer to the hardening model used for strains above 30%.

and fitting, from CP simulation data, anisotropic yield functions, which, in turn, we used within the FE simulations. The computational FLCs were derived from FE models based on the Marciniak-Kuczynski approach to strain localisation, and upper and lower bounds were found by considering distinct hardening models for the large strain regions, which we found to be a significant factor in the FLC predictions. Our computed and experimental FLCs are shown in Figure 1b. The flexibility of our workflow allows us to easily perform sensitivity analyses, or repeat the analysis using different models (e.g. yield functions, necking criteria) or different materials, which we are currently exploring.

Modelling dynamic precipitation in aluminium alloys

The nucleation and growth of strengthening precipitates during carefully controlled heat treatments is the basis for age-hardened aluminium alloys. While it is well established that plastic deformation significantly accelerates precipitation formation, to control and exploit the response of aluminium alloys during warm forming operations (120-250 °C), an improved understanding of the coupling between deformation and precipitation kinetics is needed. In this temperature range, dynamic precipitation is mainly controlled by the production of excess vacancies, induced by the non-conservative

movement of screw dislocation jogs. We have developed a model describing precipitation kinetics under warm deformation conditions using the Kampmann-Wagner (KWN) framework. The role of deformation is incorporated through enhanced solute diffusion resulting from excess vacancies and dislocations. The evolution of excess vacancies is calculated using a classical phenomenological model describing the balance between vacancy production and vacancy annihilation at sinks such as dislocations and grain boundaries. The model is calibrated and validated using a combination of small angle X-ray scattering (SAXS) and electron microscopy data generated in Theme 1 (Figure 2a). The precipitate evolution rate can then be predicted as a function of process parameters, and it is shown that the sensitivity of dynamic precipitation to temperature and strain-rate is complex and non-monotonic (Figure 2b). The deformation coupled KWN model is then embedded into an integrated crystal plasticity framework to quantify the effect of micro-scale strain heterogeneities on precipitate spatial distribution under different loading conditions and initial textures (Figure 2c)..

Future plans

In the coming year, we will aim to increase the number of industry-supported PhD students working on computational modelling by leveraging the simulation framework MatFlow. We will also aim mature the key sub-models, currently under development, on full-field dynamic precipitation in aluminium alloys and thermomechanical processing of titanium alloys.

Core research activity will focus on using the modelling framework to: 1) design complex warm forming operations for high strength aluminium alloys, through exploiting the dynamic precipitation effect, and 2) mitigating abnormal microstructure development during thermomechanical processing of titanium alloys.

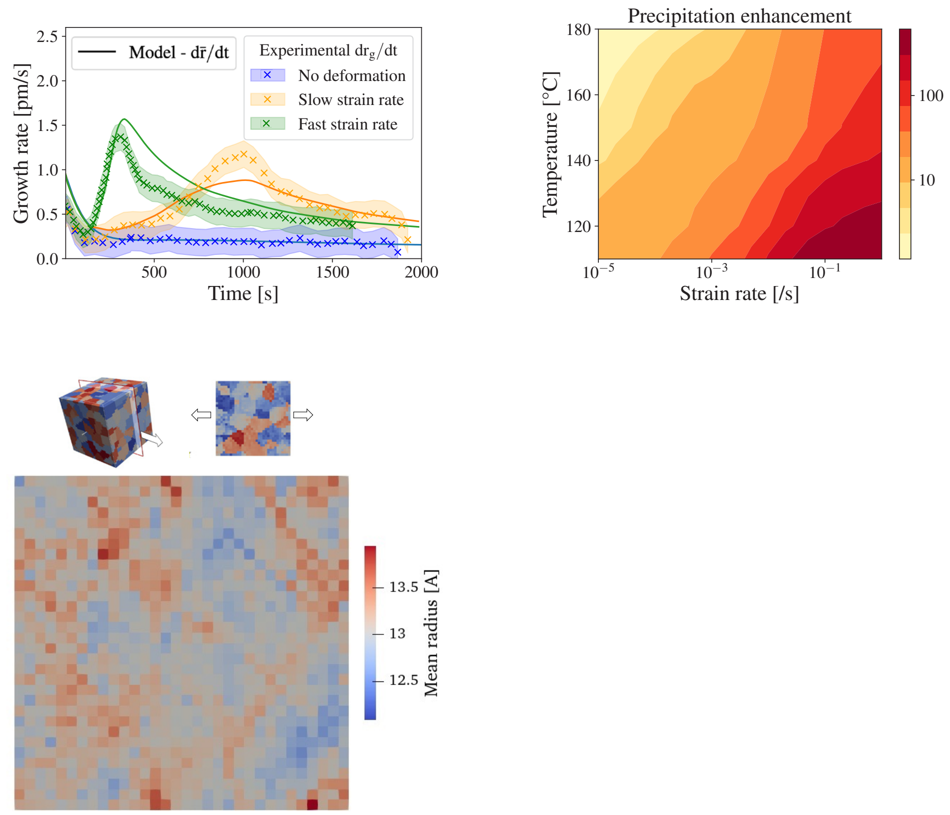

Figure 2: (a) KWN model predictions of precipitate growth rate during deformation compared to experiments (b) Precipitate growth rate dependence on temperature and strain rate (c) KWN model embedded into an integrated crystal plasticity framework showing heterogeneous precipitate distribution

CHALLENGE 3:

PROCESS INNOVATION – MANUFACTURING WITH EMBEDDED MATERIALS ENGINEERING (MEME) IMPLEMENTATION

Challenge Theme 3 aims to use the underpinning science for manufacturing with embedded materials engineering (MEME) developed in Challenge 1 and multiscale simulation methods with microstructurally informed computational models developed in Challenge 2, to simultaneously improve manufacturability and component performance - while reducing cost and time to market in advanced forming processes. Challenge 3 also aims to work closely with our industrial partners to maximise the impact of the work by 'industrialising' the modelling capability and expanding the resource for MEME applications with leveraged projects.

Over the past year, the Challenge Theme 3 activities have continued to grow across all work packages. The major research activities in Challenge Theme 3 have been:

(1) Implementing the MEME from Theme 1 to optimise the HFQ process, improving its efficiency and reducing the manufacturing cost.

(2) Using the dynamic precipitation model developed in Theme 2 to predict the yield strength and formability.

(3) Integrating this new model with unified constitutive equations in finite element modelling to facilitate the design and manufacturing processes.

(4) Optimising the grain/precipitate structures in forged Ti or rolled Al against the in-service fatigue and corrosion problem.

(5) Developing the microstructure informed modelling to predict the microstructure and materials flow simultaneously during the forming processes.

Highlights

Fast ageing & blank transfer maps for HFQ

The aim of this project, led by Imperial College in close collaboration with Manchester and Cambridge, was to investigate the viability of reducing the artificial ageing cycle and to build blank transfer maps during HFQ. It was found that at an elevated ageing temperature, the pre-deformation can reduce the current ageing time from 9h to less than 1h. The obtained blank transfer maps could also be used to identify the optimum blank transfer parameters. The sensitive temperature range for blank transfer was found to be 250 to 450 °C, and the most sensitive temperature (nose) around 350 °C. In addition, physically-based constitutive equations have been developed to incorporate the grain and precipitate evolution during the HFQ process. These equations are now ready to be embedded in a commercial FE simulation package, such as Pam-Stamp. This will enable the relevant industrial users to access the obtained scientific understanding and modelling techniques for their component's design and processes optimisation.

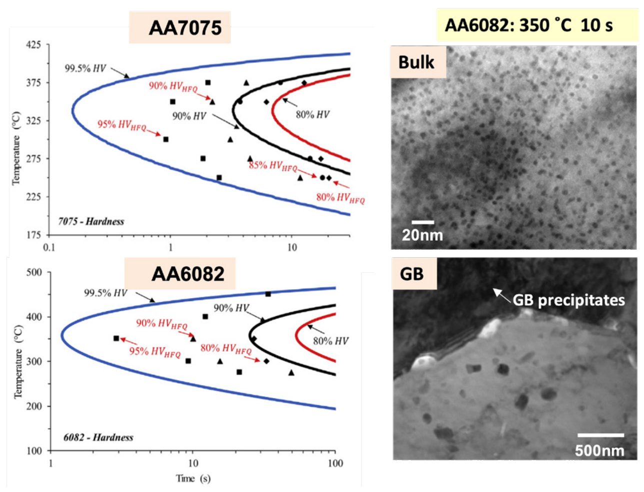

Figure 1. The blank transfer and strength maps for AA7075 and AA6082 and the TEM revealed precipitate distribution in AA6082 after being transferred at 350°C in 10 seconds.

Novel biaxial testing

A MatFlow model has been developed in Theme 2 to incorporate the dynamic precipitation in crystal plasticity modelling. This model can predict the strength and formability of an alloy for various forming conditions. However, it is non-trivial to calibrate the formability at elevated temperatures because of the difficulties in controlling the cooling rates. The friction also causes non-uniform deformation in the gauge region and the instability of painted digital image correlation (DIC) patterns for strain measurement. Hence, a novel biaxial testing rig has been designed and developed in Theme 3 to enable biaxial testing in a Gleeble machine. The thermal process can be precisely controlled, and no friction/punch is required. New cruciform specimen designs for uniform temperature/strain distribution within the gauge region has been completed. We have also developed a new DIC painting method for warm/hot forming temperatures (up to 900 °C). Because of the increasing industrial demand, the Multi-X Solution Limited spin-out was established in November 2020.

Environmentally Assisted Cracking (EAC)

The new generation Al-Zn-Mg-Cu thick-plate alloys was found to have a significant environmentally assisted cracking problem, compared to the aerospace industry benchmark alloy AA7050. Crack growth rates are 6-20 times higher than for AA7050-T7651. This cannot be revealed by industry standards (ASTM-G47) in saline solutions. A better mechanistic understanding of initiation has been observed, as no one before has been able to track backwards in time to see where the cracks started. The cracking sequence was determined from slow strain rate tests. With the help of 3D serial laser-FIB sectioning off a large block and atom probe tomography, it was found that the convoluted grain structure in older alloys helped prevent cracks entering sustained propagation. The size, morphology and Zn and Mg chemical composite of phase precipitates were also found to play a vital role for EAC. The new understanding helps OEMs to integrate it into their design code. A phase-field based model is under development to better understand the principate formation to guide the industrial alloy design.

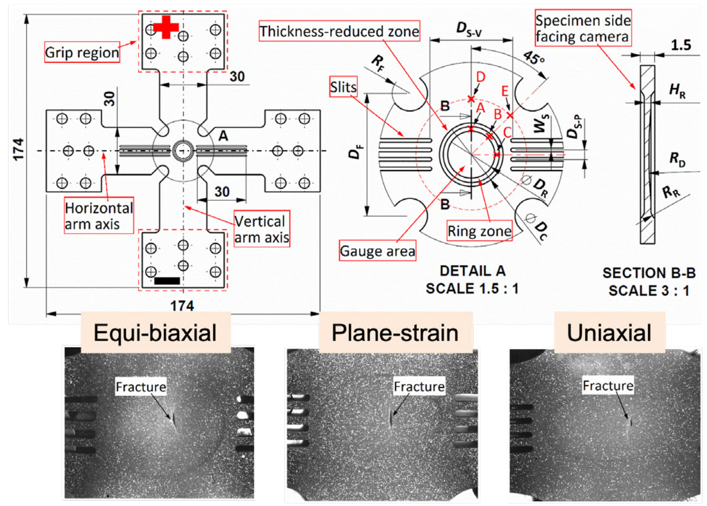

Figure 2. The new biaxial specimen designs, the observed fracture locations under various loading conditions, and the determined forming and fracture forming limit curves for boron steel.

Abnormal Grain Growth (AGG) in Ti forging

Large titanium component forgings used in aerostructures are usually heat treated to produce an optimised microstructure with high toughness. On occasion, unwanted abnormal grain structures can develop during heat treatment, affecting the properties of the material; this project aimed to understand the origins of these abnormal microstructures. Electron backscatter diffraction (EBSD) analysis found that these abnormal grains originate in regions of very strong texture that develop during hot forging. Four follow-up projects have been funded by DSTL, AFL, ICL and Airbus respectively, three of them will start in 2022. This past year, the project that started is to use the none-destructive-evaluation (NDE) method to monitor AGG during the manufacturing process. Also, the project will examine the effects of those abnormal grains on fatigue performance, using EBSD, DIC and crystal plasticity modelling. This enables the integration of manufacturing with structure integrity through microstructure-informed modelling.

Sideways Extrusion

Currently, extrusion and bending are commonly used for forming curved profile components. Many manufacturing difficulties exist, however, including defects control, poor flexibility, low efficiency and yield rate. A novel differential speed sideway extrusion technology has been proposed and developed to tackle these issues. To enable this new technique to be adopted by manufacturing companies, understanding/predicting the microstructure evolution and property is vital. We developed a continuous dynamic recrystallisation (CDRX) MEME model and worked on the shear and normal strain effects on CDRX to predict grain size evolution and thus the mechanical properties. This enables both geometries and microstructure to be tailored simultaneously. As a result, various curved tubes, hollow profiles and thin-wall structure components have been produced. Even Al-Mg composite components can be manufactured with excellent bonding strength. All these are impossible without understanding the stress-strain-microstructure relationships provided by the MEME modelling.

Future Plans

In the coming year, Challenge 3 will apply the fast-ageing and blank transfer maps in HFQ, where it is expected to significantly reduce the processing cycle time while ensuring its optimal properties. We will further validate the newly developed dynamic precipitation model with the latest biaxial formability testing method. This would considerably improve its accuracy in formability prediction at elevated temperatures, and hence enable us to efficiently identify the optimal forming window for a new light alloy. We will also use the new modelling capability to determine the parameters for our MEME forming modelling to predict the thinning and fracture during the practical forming processes. Through MEME, the obtained understanding in EAC and AGG will be linked with parts' corrosion and fatigue performance, and several industrially funded PhD projects will start this year to investigate this. Finally, the MEME based forming model for sideway extrusion will be further developed to accelerate the technique adoption.

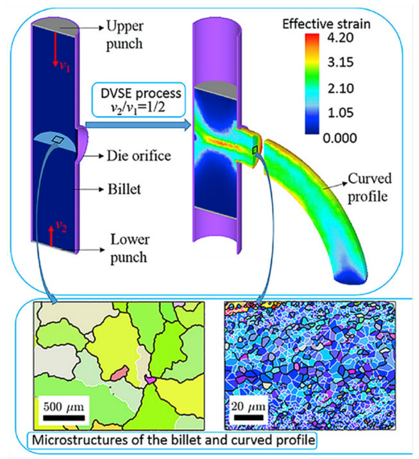

Figure 3. The materials plastic strain and microstructure distribution and evolution in a sideways extruded part.

Highlighted Publications

1. J.-H. Zheng et al. "Quantifying geometrically necessary dislocation density during hot deformation in AA6082 Al alloy." Materials Science and Engineering: A 814 (2021): 141158.

2. R. Zhang et al. "An effective method for determining necking and fracture strains of sheet metals." MethodsX 8 (2021): 101234.

3. A. Garner et al. "Multiscale analysis of grain boundary microstructure in high strength 7xxx Al alloys." Acta Materialia 202 (2021): 190-210.

4. N. E. Byres et al. "The evolution of abnormally coarse grain structures in beta-annealed Ti-6Al%-4V% rolled plates, observed by in-situ investigation." Acta Materialia 221 (2021): 117362.

5. W. Zhou et al. "A comparative study on deformation mechanisms, microstructures and mechanical properties of wide thin-ribbed sections formed by sideways and forward extrusion." International Journal of Machine Tools and Manufacture 168 (2021): 103771.

CHALLENGE UPDATES

New Insight into Environmentally Assisted Cracking (EAC) In 7xxx Alloys

Researchers:

Prof. Joseph Robson, Prof. Phil Prangnell, Dr Michele Curioni, Dr Pratheek Shanthraj Dr Chris Race, Dr Tim Burnett, H. Holroyd (visiting Prof.), Dr Al Garne, Dr Yasser Aboura, Dr Alex Cassell

Project partners: Airbus (£1.1M), Otto Fuchs (£100k), Impression Tech (£53k).

7xxx series Al-Zn-Mg-Cu alloys are widely used in aerospace and there is increasing demand to exploit their exceptional properties in formed-automotive components, to reduce the mass of crash protection systems. However, their wider-scale application and further alloy development is currently being inhibited by a lack of understanding of their high susceptibility to Environmentally Assisted Cracking (EAC).

Despite 40 years of effort, a mechanistic understanding of EAC in 7000 series Al-alloys and the relationships to their composition and thermo-mechanical history has remained elusive. In both immersed and humid air exposure the phenomenon has been widely linked to the production and chemical adsorption of (protonic) H•, by reaction with water, driven by complex chemical processes at surface initiation sites and within propagating cracks, which diffuses to regions under high stress and leads to brittle intergranular fracture along Grain Boundaries (GBs). In 7xxx alloys the surface reactions at initiation sites and within propagating cracks that generate H have been strongly linked to the microchemistry of the GBs and GB precipitates (e.g. the M phase), which are a complex function of the alloy's bulk composition, macrosegregation behaviour, and process history; with, strong relationships to quench rate, grain structure and ageing treatments.

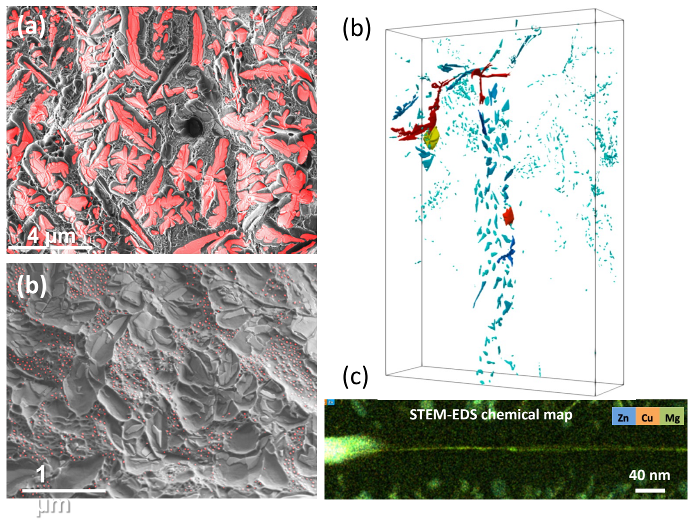

Fig. 1 Size and distribution of (a) quench induced and (b) age-induced η grain boundary precipitates, in a AA7050 thick plate revealed by a cold fracture technique; (c) 3D reconstruction of the GB precipitates using Plasma FIB slices, and (d) high resolution STEM map of GB segregation.

Work in LightForm has focused on applying advanced multi-scale characterisation techniques, 3D real-time imaging, combined with phase field modelling and accelerated testing, with in-situ monitoring, to develop new insight into this complex problem. Research has been particularly focusing on the recently-reported higher susceptibility of new-generation thick plate 7xxx series aerospace alloys to EAC when exposed to humid air.

Progress to date has provided important new insights into the subtle relationships between GB microchemistry and EAC susceptibility. This work has revealed important differences in GB segregation, precipitate distributions, and precipitate chemistries, between alloy variants and product forms, which are highly sensitive to the bulk alloy composition and quench rate in thick plates. Multi-scale analysis has shown the 3D-nature of GB precipitate populations in thick plate alloys are far more complex than originally realised and can result in range of local microsegregation effects and precipitate microchemistries depending on the bulk alloy composition and thermal history (Fig. 1). CALPHAD coupled phase field simulation, validated by experimental observations, have been developed to predict the effect of alloy composition, when combined with quench rate and aging treatment, on the local GB microstructure and micro-chemistry (Fig. 2).

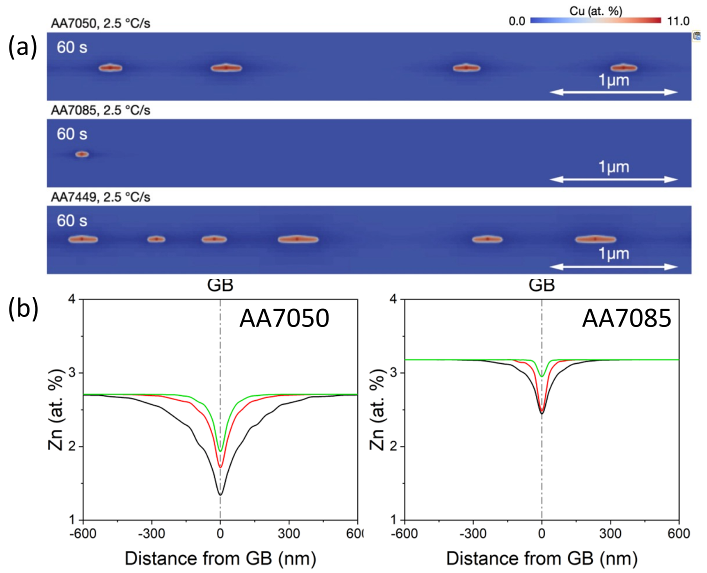

Fig. 2 CALPHAD-Phase Field predictions of the (a) Cu distribution at grain boundaries and the residual solute across the boundary for different 7xxx alloys after quenching a thick plate.

A bespoke in-situ monitoring system developed in the project to directly observe crack initiation under humid air conditions, combined with detailed fractography and high resolution microscopy using FIB-SEM/TEM techniques of carefully preserved samples, has been used to study the transition from initiation to sustained propagation in more detail than

New Insight into Environmentally Assisted Cracking (EAC) In 7xxx Alloys

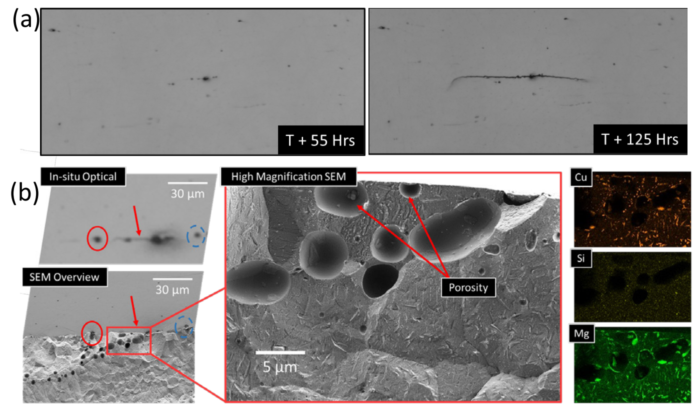

Fig. 3 Example of in-situ optical monitoring of (a) a stressed surface exposed to humid air (50% RH at 70°C) used to identify (b) a typical EAC initiation site in a new-generation 7xxx thick plate alloy.

previously possible (Fig. 3). This high fidelity research has been combined with more conventional slow strain rate and DCB propagation tests. Overall, this has confirmed there can be a greater discrimination in EAC performance between different alloys in humid air environments when there is little general corrosive attack, compared to on immersion in saline solutions (Fig. 4). It has been shown that more established alloys like AA7050 are intrinsically more resistant to cracking under humid air conditions and exhibit more residual ductility during crack propagation.

Finally, bottom up, DFT-atomistic modelling has been used to predict the segregation of H to grain boundaries in association with other solute elements (e.g. Zn, Mg) and other trapping sites, and the effect of H on GB cohesive strength and slip activity.

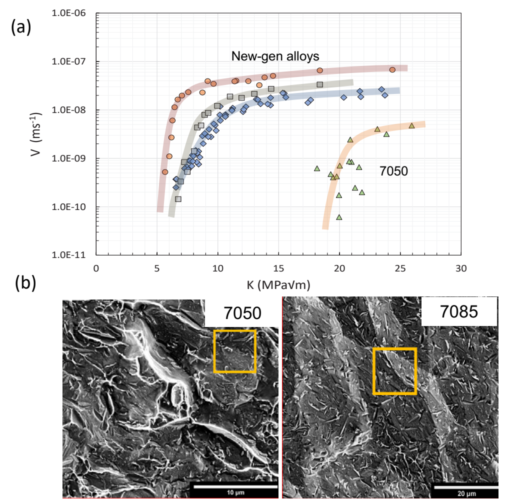

Fig. 4 Difference in (a) growth rate of long cracks in humid air determined from DCB tests between new-gen 7xxx alloys and AA7050 and (b) GB fracture process imaged near the initiation site in slow strain rate tests showing highly brittle intergranular fracture of 7085 and residual ductility for 7050.

Key outputs and Impact:

Significant outputs include.

- Confirmation of the higher EAC sensitivity to humid air environments of new-generation higher zinc content 7xxx alloys.
- Clearer understanding and predictive models of the effect of bulk alloy chemistry and thermal history on the grain boundary precipitate population and microchemistry, including the microsegregation behaviour.
- Identification of the dominant initiation sites and strong evidence for the conditions leading to initiation of EAC cracks in 7xxx alloys exposed to humid air.
- Identification of the characteristic stages of EAC fracture and their relative dominance in new generation alloy variants relative to more established alloys.
- DFT- atomistic model predictions of the effect of H on GB cohesive strength and slip activity.

Summary

Improving current understanding of the effects of alloy composition and microstructure on EAC of 7xxx series Al alloys in different environments is important for the development of future high-performance wrought products, particularly in the aerospace industry. Advanced multi-scale and in-situ techniques have been applied to understand this complex problem in more depth than previously possible. This work has confirmed the recently reported higher EAC sensitivity to humid air environments of new-generation higher zinc content 7xxx alloys. The stages of crack initiation and propagation have also been directly observed and correlated to the local microstructure. Models have been developed to predict the GB precipitate populations and microchemistry as a function of composition and thermal history and to explore the effect of H on grain boundary embrittlement.

Outputs

1. C. Liu, A. Garner, H. Zhao, P.B. Prangnell, B. Gault, D. Raabe, P. Shanthraj; CALPHAD-informed phase-field modeling of grain boundary microchemistry and precipitation in Al-Zn-Mg-Cu alloys, Acta Mater. 214 (2021) 116966. doi.org/10.1016/j.actamat.2021.116966
2. A.J.W. Garner, Y. Yao, R. Euesden, Y. Al Aboura, M. Curioni, H. Zhao, B. Gault, P. Shanthraj, T.L. Burnett, Z. Barrett, C. Engel, P.B. Prangnell, Multiscale Analysis of Grain Boundary Microstructure in High Strength 7xxx Al Alloys, Acta Matter. 202 (2021) pp 190-210. https://doi.org/10.1016/j.actamat.2020.10.021.
3. E. Schwarzenböck, E. Ollivier, A. Garner, A. Cassell, T. Hack, Z. Barrett, C. Engel, T.L. Burnett, H. Holroyd, J.D. Robson, P.B. Prangnell; Environmental Cracking Performance of New Generation Thick Plate 7000-T7x series Alloys in Humid Air, Corr. Sci. 171 (2020), 108701.
4. J.D. Robson, Analytical Electron Microscopy of Grain Boundary Segregation: Application to Al-Zn-Mg-Cu (7xxx) Alloys, Mater Character, 154 (2019), 325-334.
5. A.M. Cassell, J.D. Robson, X. Zhou, T. Hashimoto, M. Besel; The direct observation of Cu segregation at broad faces of η' and η precipitates in AA7010 Al-alloy; Mater. Character. 163 (2020,) 110232. doi.org/10.1016/j.matchar.2020.110232
6. B.T. Wilson, C.P. Race, J.D. Robson Modelling Hydrogen Embrittlement using Density Functional Theory: A theoretical approach to understanding environmentally assisted cracking in 7xxx series aluminium alloys, ICAA17, Grenoble (2020).

Researchers:

Prof. Phil Prangnell, Prof. João Quinta da Fonseca, Dr Pratheek Shanthraj, Dr Alec Davies, Dr Christopher Daniel, Nick Byers

Project partners: Airbus (£100k).

Within the supply chain to the aerospace industry for semi-finished wrought titanium components, there is currently a quality issue with the intermittent development 'macro zones' or Micro Textured Regions (MRTs). These strongly-textured regions are an industry wide concern because they can lead to an unpredictable fatigue life. An important related problem for Ti-64 (Ti, 6%Al, 4%V) wrought alloys with beta-annealed fully-lamellar microstructures, used in large structural aerospace components, is the formation of Abnormally-Coarse β Grain (ACG) structures. The β-annealed microstructure condition is designed to provide low fatigue crack growth rates by promoting the deflection of fatigue cracks at single-variant α-colony boundaries, which nucleate on the β grain boundaries during cooling following β-annealing. Their fatigue performance is thus very dependent on control of the β grain structure and texture. ACGs are currently found to form in a significant percentage of Ti-64 wrought products supplied to manufacturers, which leads to the costly rejection of high-value parts. An extreme example of this phenomenon is shown in Fig. 1, which typically occurs in the centre of forged billets.

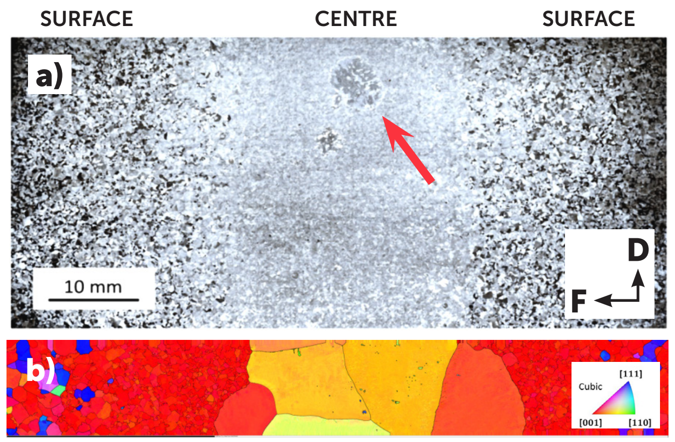

Fig. 1. Example of an 'Abnormally' Coarse Grain (ACG) structure in the centre of a β-annealed forged bar; (a) optical overview, showing a uniform 'fine' grained region containing ACGs and (b) a large area EBSD map across the centre, showing the extremely strong textured matrix in abnormal region surrounding ACGs.

LightForm has now come a long way towards understanding the origin of this problem. In collaboration with Airbus, we have investigated the reasons why this unstable coarsening behaviour is seen in some regions of wrought titanium products during β-annealing treatments. This has included developing novel in-situ heating experiments in a high-resolution SEM, with high-speed Electron Back Scatter Diffraction (EBSD) texture mapping, as well as applying a new ultra-high speed EBSD system (available through the Royce Institute) to map the texture of whole sections of large forgings. This is the first time an in-situ EBSD technique has been used to study texture evolution in titanium alloys to above the β-transus. These were challenging experiments to perform because of the high temperatures needed (1000 °C), the requirements for rapid data collection and the need to prevent oxygen contamination of the samples. Using this approach, samples were selected with different starting textures to study directly the re-growth of the β grains through the $\alpha \rightarrow \beta$ transition (examples of which can be found in the Acta Materialia article). This work has highlighted the importance of the formation of a strong prior-β cube/rotated cube texture after hot working in the α-β phase field. Although originally present in bands in rolled products and in stronger regions in forgings, the cube texture component was shown to first expand greatly during the early stages of heating, when long range mobility of the β boundaries is prevented by pinning of the α phase (Fig. 2). As the α phase dissolves, and greater boundary migration can occur, an extremely strong cube texture region emerges which contains a few surviving β grains from the α and γ deformation fibres. However, most of these grains which are now highly misorientated with respect to the cube matrix are then consumed during grain coarsening apart from a small subset that exist that fulfil a 'Goldilocks' condition, with respect to their size and misorientation range. This condition allows them to survive and then rapidly grow consuming the cube orientation subgrain matrix as the α grains pinning their boundary mobility continue to transform to β. A summary of this behaviour is provided in Fig. 2 taken from experiments performed on hot rolled titanium plates. While previous studies have shown the importance of the prior texture in setting up the conditions for ACG regions to develop, the reasons for this unstable grain coarsening behaviour were not understood. Because they relied on the interpretation of post-mortem samples, it was not possible to 'see' the material response through the critical step, where the β phase re-grows during heating through the β–transus.

A longer-term goal of LightForm is to understand and model the texture development that occurs during α–β processing of wrought titanium products, so that process simulation can be more widely used across the supply chain. Simulation can be used to design thermal and deformation paths that avoid the development of such strong texture regions in Ti products, that lead to such problems occurring in the first place. The advanced in-situ heating and high speed EBSD mapping technique developed is also now being more widely exploited to directly study the role of grain structure and texture on the $\beta \rightarrow \alpha$ transformation in titanium alloys [3].

Key outputs and Impact:

- The development of a powerful new SEM-based technique for studying in-situ coupled phase transformation and texture-grain structure evolution processes in α–β titanium alloys.
- Fundamental understanding of the stages and mechanisms that control the development of ACG structures in commercial aerospace products.
- Feedback to manufacturers (e.g. Airbus) and supply chain companies on (e.g. Voestalpine-Böhler, ATI, TiMET) on how to avoid the development of ACG structures in high value β-annealed titanium products. This is currently at a qualitative level, but will be developed to a predictive simulation capability in TIFUN.

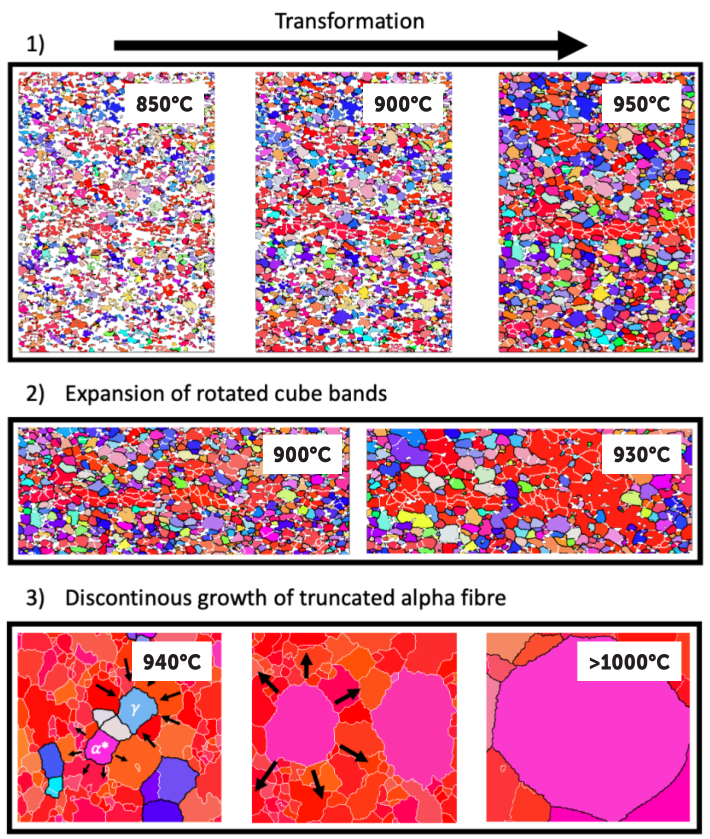

Fig. 2: Example figures taken from the in-situ annealing experiments, representing the three stages of the annealing process that are necessary for the formation of ACGs.

1) The $\alpha \rightarrow \beta$ phase transformation that reforms the high temperature deformed state, 2) expansion of rotated cube texture bands and 3) the subsequent discontinuous growth of β orientations that fulfil the 'Goldilocks' conditions that allow them to survive within the cube texture component when it initially expands.

Summary

Abnormally coarse grain structures are a major quality control issue in β-annealed, wrought, Ti-64 products in the aerospace sector. A new powerful SEM-based technique for studying in-situ coupled phase transformation and texture-grain structure evolution processes in α–β titanium alloys has been developed and applied to investigating the origin of this complex problem. This research has revealed the underlying mechanisms giving rise to the growth of very coarse, 'rogue' grains within a highly textured matrix, frequently seen in the central sections of forgings and rolled plates and confirmed the connection to the evolution of a strong prior texture. This project has highlighted the importance of the longer-term research ongoing within TiFUN that aims to simulate the texture development in α–β titanium alloys during hot working, by explicitly incorporating the coupled effects of deformation and dynamic-phase transformation when hot working complex two-phase materials.

Outputs

1. N.E. Byres, J. Quinta da Fonseca, C.S. Daniel, J. Donoghue, A.E. Davis, P. Shanthraj, B. Dod, P.B. Prangnell, The evolution of abnormally coarse grain structures in beta-annealed Ti-6Al%-4V% rolled plates, observed by in-situ investigation, Acta Mater. 221 (2021) 117362; doi.org/10.1016/j.actamat.2021.117362
2. N.E. Byres, J. Quinta da Fonseca, B. Dod, P.B. Prangnell, Analysis of the Development of Abnormal Grains Structures During Beta Annealing of Ti-64 Wrought Products, Titanium 2019, Nantes, France, June 2019.
3. A. E. Davis, J. Donoghue, J. R. Kennedy, N. Byres, P. B. Prangnell, In-Situ Direct Real-Time Observation of Single Variant α Colony Formation in Ti-6Al-4V, Acta Mater. 220 (2021) 117315. doi.org/10.1016/j.actamat.2021.117315
4. N.E. Byres, P. Shanthraj, B. Dod, J. Donoghue, A. Davis, J. Quinta da Fonseca, P.B. Prangnell. The Evolution of Abnormal Grains Structures during Beta Annealing of Ti-64 Wrought Products: Purveyors of Processing Science and ICME Symposium, TMS 2020, San Diego, USA (Invited).
5. N.E. Byres, J. Quinta da Fonseca, B. Dod, P.B. Prangnell, The origins of abnormal grain structures in Beta annealed Ti-64 aerospace components, LightMAT 2019, Manchester, UK, Nov 2019.

SPOTLIGHT ON MATFLOW

Researchers:
Dr Adam Plowman, Dr Pratheek Shanthraj,
Prof João Quinta da Fonseca

Introduction

MatFlow is an open-source Python code that is being developed by LightForm for managing and executing computational workflows in materials science. In essence, MatFlow provides a framework for connecting arbitrary simulation and data processing tasks (using both proprietary and open-source software) to form cohesive and reproducible pipelines that can be run on high-performance computing (HPC) facilities, shared, and re-used. The integrated nature of MatFlow enables new researchers to quickly reproduce and then further develop existing analysis and enables our industry partners to generate computational predictions more rapidly. MatFlow will ultimately support the ongoing digital transformation in materials design and manufacturing.

The workflow lifecycle in MatFlow begins with the user writing a simple YAML text file, in which they list the tasks that should be combined to achieve their scientific objective. The set of available tasks from which a user may construct and parametrise their workflow now includes over 50 task definitions, which enable integration with a wide range of materials science packages, including the crystal-plasticity (CP) framework DAMASK, the texture-analysis MatLab package MTEX, the finite-element code Abaqus, and the materials science data analytics tool Dream3D. After a workflow has completed, MatFlow generates a single file (using an open-source format) that encapsulates all workflow data and processing steps. In turn, this file can be automatically archived to cloud storage, enabling further local analysis of the results (via Dropbox), or generation of a citation for referencing the workflow from within a publication (via Zenodo).

MatFlow aims to enable fast, efficient, and collaborative research. Over the previous year, we have continued to develop the core MatFlow code, and enabled integration with additional software. In this time, we have also taken initial steps towards (and planned for) improving the robustness and portability of MatFlow, which will enable MatFlow to become a valuable tool for a much wider userbase throughout the UK's materials science research institutes and industry organisations.

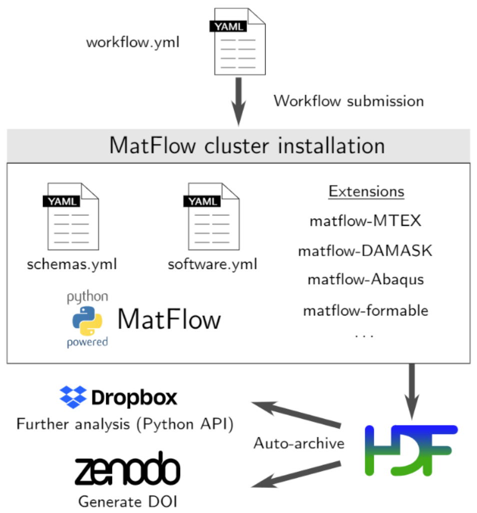

Figure 1: The MatFlow workflow lifecycle

New functionality

- The ability to import workflow data from existing workflows. The user specifies the path to an existing workflow and which parameters they would like to import. This enables reuse of, for example, computationally expensive simulation outputs. With MatFlow, the workflow that runs such simulations can be uploaded to a public data repository such as Zenodo, at which point other researchers may perform their own novel analysis using the simulation results. This feature therefore improves both researcher efficiency, and the ease with which scientific collaborations can be founded.
- Improved Zenodo integration: when designing a MatFlow workflow, metadata can now be specified that integrates with the metadata application programming interface (API) of the scientific data repository Zenodo. This enables proper attribution of the workflow authors.
- Improved support for more general workflow topologies. Tasks are defined according to their input and output parameters, which, in a virtual testing or formability analysis workflow might include the representative volume element (RVE), the type of loading that is to be simulated, the single-crystal critical resolved shear stresses (CRSSs) that are used in the CP model, and the response of the RVE to the loading. In MatFlow, some tasks can be used to modify a parameter, such that this parameter is both an input to, and output of, that task. An example of such a parameter is the single-crystal (CRSSs) in a workflow that performs an iterative fit of these to experimental data. With updates to MatFlow this past year, many more workflow scenarios that utilise these parameter-modifying tasks are now accessible to MatFlow (e.g., see the "multi-pass" rolling workflow section).
- Improved archiving capabilities. Archiving of workflows can now be performed on-demand (i.e., sometime after workflow completion), which is in addition to existing support for automatically archiving on workflow completion.
- Improvements to the Python API of MatFlow. A common working pattern when using MatFlow is to perform a CP simulation using DAMASK on an HPC resource, and then load the workflow into a Jupyter notebook using the Python API. At this point, the researcher can easily generate figures from the simulation results, such as a plot of the volume-averaged Von Mises stress-strain curve. Often, the researcher will be interested in comparing the effect of some variable. For example, different inputs textures (perhaps originating from real EBSD texture data) may result in different stress-strain curves. Recent improvements to MatFlow have greatly simplified the alignment of metadata across tasks, which means it is now much easier to associate the output of a "downstream" task, such as a simulated stress-strain curve, with the input of an "upstream" task, such as the name of the EBSD file from which RVE orientations were sampled. This becomes an important feature when working with workflows with many "elements" (e.g. many input textures, which we want to compare).

Formability analysis with MatFlow

We have developed comprehensive "hybrid" workflows for making formability predictions using virtual materials testing in combination with a small set of basic experimental data (Figure 1). These workflows use EBSD data to encode representative texture into RVEs containing 2000 spatially-resolved grains. We have developed workflows that then perform iterative fitting of the modelled CRSS values, with respect to experimental tensile testing data. A large set of multiaxial loading simulations are performed to then parametrise an anisotropic yield criterion. We include support for fitting the simulated data to multiple yield functions, including: Barlat's six-parameter Yld91 criterion, Barlat's 18-parameter 2004 criterion, and Hill's criterion. The fitted yield criterion is then input into a finite-element Abaqus simulation that employs Marciniak-Kuczynski analysis to identify forming limit curves, using a particular necking criterion. Repeating this formability analysis with a new material is straightforward. Additionally, performing extra or alternate analysis, such as fitting the set of CP simulations to a different yield criterion, is also easy using MatFlow's parameter-import functionality.

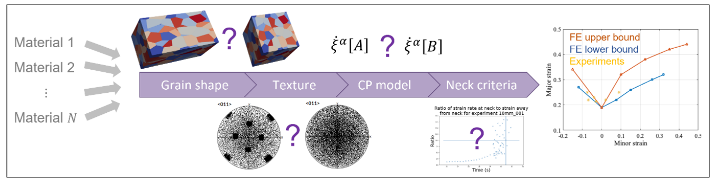

Figure 2: Formability predictions with virtual materials testing significantly reduces the experimental expense, and allows for sensitivity studies to discover the influence of each parameter. Each question mark represents a point at which the workflow can easily be forked.

Iterative "multi-pass" simulations with MatFlow

In full-field crystal-plasticity simulations, the rolling process can be approximated by plane-strain compression mixed boundary conditions, which specify mutually exclusive components for both stress- and strain-like tensors. Under such a loading regime, it can be numerically difficult to achieve high strains. To avoid this problem, we developed a workflow using MatFlow's iteration capabilities, that simulates plane-strain compression to a certain achievable strain, and the re-defines the RVE using the rotated crystal orientations but a uniformly deformed RVE. This process is repeated multiple times to achieve an overall large strain whilst avoiding numerical convergence problems.

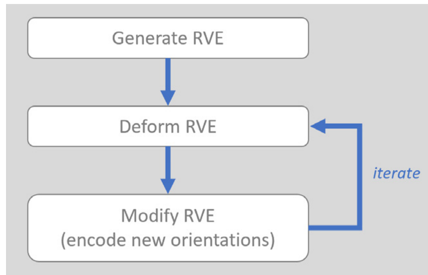

Figure 3: MatFlow enables assigning arbitrary iteration to a given parameter, in this case the RVE. The RVE for the next iteration depends on the orientations of the deformed RVE (and the non-deformed RVE) in the current iteration.

In addition to providing some initial texture-evolution predictions for large-strain rolling of dual-phases titanium, the results from this "multi-pass" method can now be compared to our subsequently developed approach that uses non-mixed boundary conditions (via specifying an approximate target velocity gradient tensor) to simulate large strain with just one pass.

Modelling dual-phase microstructures with MatFlow
The recently developed MatFlow integration with Dream3D enables researchers to generate RVEs whose phase distributions follow sophisticated and realistic statistical models, and which can then be simulated using a full-field crystal-plasticity code, such as DAMASK. Dream3D enables these synthetic microstructures to be parametrised according to, for instance, phase volume fraction, particle size and shape distributions, and particle morphological and crystallographic orientation distributions. All these options are exposed to the associated MatFlow task, enabling straightforward simulation of realistic RVEs in materials such as aluminium, where precipitate phases are observed to follow specific statistics. We have used MatFlow to study the effect on formability of these particle statistics in recycled 6xxx series aluminium alloys.

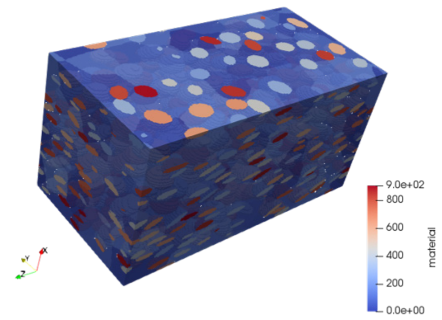

Figure 4: MatFlow's integration with Dream3D provides a simple method to generate realistic precipitate-containing RVEs.

Plan

In the next year, we will focus on ensuring MatFlow adopts software best-practices so that it remains a sustainable software package in the long-term. This will include some code refactoring and the development of an automated documentation system that will integrate with the various software extensions through which MatFlow connects to arbitrary software. A second aim will be to develop support for other HPC schedulers, including SLURM (currently only the SGE scheduler is supported). We then aim to install MatFlow at other universities and industry partner organisations.
Furthermore, we will also develop new workflows, such as a workflow that can perform statistical analysis on parameter sensitivity, which will be used to determine optimal system sizes for crystal plasticity simulations (i.e. system sizes that computationally cheapest, whilst maintaining a given level of accuracy). Finally, we will apply and further develop our existing workflows to new problems and materials, such as understanding warm-formability of aluminium alloys.

Outputs

MatFlow software: A. J. Plowman, P. Crowther, J. Quinta da Fonseca, and M. Atkinson. LightForm-Group/MatFlow: V0.2.25. Zenodo, 2021. https://doi.org/10.5281/zenodo.5793969.

Formable software: A. J. Plowman, and M. Atkinson. LightForm-Group/Formable: V0.1.19. Zenodo, 2021. https://doi.

Publication (in preparation): A novel integrated framework for reproducible formability predictions using virtual materials testing, A. J. Plowman, P. Jedrasiak, T. Jailin, P. Crowther, S. Mishra, P. Shanthraj, J. Quinta da Fonseca

LIGHTFORM STRUCTURE

Professor João Quinta da Fonseca
Principal Investigator

University of Cambridge

Dr Hugh Shercliff
Co-Investigator

Manchester 1824 – The University of Manchester

Professor Phil Prangnell
Co-Investigator

Professor Joseph Robson
Co-Investigator

Dr Michele Curioni
Co-Investigator

Professor Xiaorong Zhou
Co-Investigator

Prof. Sarah Haigh
Co-Investigator

Dr Christopher Race
Co-Investigator

Dr Pratheerk Shanthraj
Co-Investigator

Imperial College London

Professor Jianguo Lin
Co-Investigator

Dr Nan Li
Co-Investigator

Dr Jun Jiang
Co-Investigator

Operations Team Members

Professor João Quinta da Fonseca	Professor Phil Prangnell	Professor Joseph Robson
Dr Michele Curioni	Professor Xiaorong Zhou	Dr Doyin Mansell, Project Manager

Challenge Theme Leaders

THEME 1 Professor Joseph Robson	**THEME 2** Dr Pratheek Shanthraj	**THEME 3** Dr Jun Jiang

Management Team Members

Professor João Quinta da Fonseca	Dr Michele Curioni	Dr Sarah Haigh
Professor Xiaorong Zhou	Dr Nan Li	Dr Jun Jiang
Professor Jianguo Lin	Dr Christopher Race	Dr Pratheek Shanthraj
Dr Hugh Shercliff	Professor Joseph Robson	Dr Doyin Mansell
Professor Phil Prangnell		

LightForm International Advisory Board – Steering Committee Members

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Dr Matthew Murphy	Luxfer	Professor Chad Sinclair	University of British Columbia

Engineering and Physical Sciences Research Council

Naomi South, Senior Portfolio Manager

LIGHTFORM PEOPLE

Principal Investigator
Prof. João Quinta da Fonseca

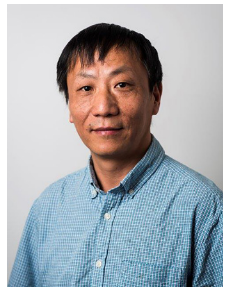
THE UNIVERSITY OF MANCHESTER
Co-Investigators

Prof. Phil Prangnell

Prof. Joseph Robson

Dr Michele Curioni

Prof. Xiaorong Zhou



Prof. Sarah Haigh

Dr Christopher Race

Dr Pratheek Shanthraj

Project and Communications Manager
Dr Doyin Mansell

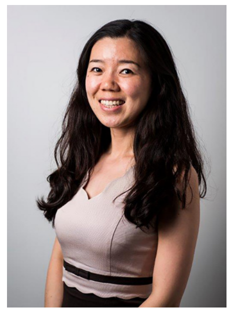
CAMBRIDGE UNIVERSITY
Co-Investigator

Dr Hugh Shercliff

IMPERIAL COLLEGE LONDON
Co-Investigators

Prof. Jianguo Lin

Dr Nan Li



Dr Jun Jiang

RESEARCH TEAM

THE UNIVERSITY OF MANCHESTER

Dr Christopher Stuart Daniel

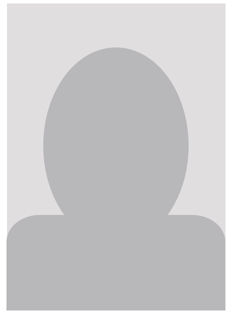
Dr Adam Plowman

Dr Peter Crowther

Dr Thomas Jailin

Dr Madeleine Bignon

Dr Yida Xiong

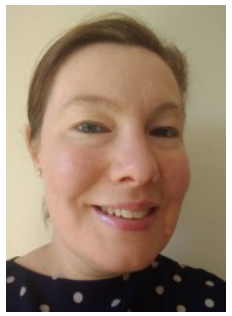


CAMBRIDGE UNIVERSITY

Dr Patryk Jedrasiak

IMPERIAL COLLEGE LONDON

Dr Victoria Yardley



LIGHTFORM PROJECTS

ALUMINIUM

1 Novel pre-age deform and re-age processing route for tailoring properties in aluminium alloys

2 Novel aluminium alloys for defence applications

3 EAC of new generation 7xxx Al-aerospace alloys: 4D imaging of initiation processes

4 Slip localisation in forming high strength Al / Warm forming of 7xxx alloys

5 SCC in AA7050 alouminium alloy

6 Crystal plasticity and microstructure evolution for rolled aluminium sheet

7 The effect of accelerated ageing of hybrid-hot formed aluminum automotive panels on corrosion resistance

8 Chemo-mechanical modelling of hydrogen diffusion and fracture in wrought 7xxx series Al alloys

9 Atomistic simulation of hydrogen embrittlement mechanisms in 7xxx series aluminium alloys

10 Tailored properties in Al automotive body sheet with taper-rolled geometry

11 Age forming of AA2139 with prior deformation

12 Through process modelling for sustainable aluminium

13 Formability and performance of circular 75R Al alloys

14 Warm forming simulation

15 Assessment of formability of light alloys under hot stamping conditions

16 Microstructural effects on the formability of recycled 6xxx alloys

17 Generating forming limit curves at hot sheet forming conditions - formability assessment for metallic sheet materials under hot stamping conditions

18 EAC initiation in wrought aerospace plate

19 Integrated computational-experimental study of microstructurally short crack propagation in AA7xxx alloys

20 Microstructure evolution in sideway extrusion of aluminium alloys

21 Creep age forming of aircraft panels

22 Microstructural effects on environmentally assisted cracking in model 7xxx alloys

23 Understanding crack initiation on aluminium alloys

24 Understanding and modelling the interaction between deformation and precipitation in aluminium alloys

25 Mapping lithium in aluminium alloys using nanoSIMS and microprobe analysis

TITANIUM

26 Microstructure evolution during forging high performance Ti aerospace alloys

27 The texture of hot formed Ti alloys

28 The effect of microstructure on the ductility of Ti alloys

29 Understanding micro-texture heterogeneity effects on the micromechanical behaviour of Ti aerospace forgings

30 Control of abnormal grain structures in titanium forgings

31 Developing a microstructural fingerprint of Ti alloys - metallurgy in the information age

32 Modelling the microstructure evolution during hot working of Ti alloys

33 Novel hot stamping of Ti alloy panel components - development of novel hot stamping process of titanium alloy

34 Influence of process variables upon microstructure and texture of dual phase zirconium alloys

35 Lightform micromechanics of deformation (In situ)

OTHER PROJECTS

36 Deformation behaviour of magnesium alloys studied using digital image correlation

37 Dynamic strengthening of magnesium alloys

38 Low cost rolling of Mg-alloy sheets - a novel and cost effective method to manufacture magnesium alloy sheets

39 Lightform computational modelling of formability

40 Reproducibility and data management

41 Modelling environmentally assisted cracking in Ni-based superalloys

42 Development of microstructural simulation tools for fusion materials

43 OAAM programme plans to develop directed energy deposition additive manufacturing technologies that can build multi-metre scale components with in-process deformation

44 Microstructure informed forming modelling -Ti, Al, Modelling

[1] R. Zhang, Z. Shi, Z. Shao, T. A. Dean, J. Lin, A novel spatio-temporal method for determining necking and fracture strains of sheet metals, International Journal of Mechanical Sciences. 189 (2021) 105977. https://doi.org/10.1016/j.ijmecsci.2020.105977.

[2] X. Zhang, Y. Lv, T. Hashimoto, J.-O. Nilsson, X. Zhou, Intergranular corrosion of AA6082 Al–Mg–Si alloy extrusion: The influence of trace Cu and grain boundary misorientation, Journal of Alloys and Compounds. 853 (2021) 157228. https://doi.org/10.1016/j.jallcom.2020.157228.

[3] P. Hidalgo-Manrique, S. Cao, H. R. Shercliff, R. D. Hunt, J. D. Robson, Microstructure and properties of aluminium alloy 6082 formed by the Hot Form Quench process, Materials Science and Engineering: A. 804 (2021) 140751. https://doi.org/10.1016/j.msea.2021.140751.

[4] S. C. Altıparmak, V. A. Yardley, Z. Shi, J. Lin, Challenges in additive manufacturing of high-strength aluminium alloys and current developments in hybrid additive manufacturing, International Journal of Lightweight Materials and Manufacture. 4 (2021) 246-261. https://doi.org/10.1016/j.ijlmm.2020.12.004.

[5] J.-H. Zheng, C. Pruncu, K. Zhang, K. Zheng, J. Jiang, Quantifying geometrically necessary dislocation density during hot deformation in AA6082 Al alloy, Materials Science and Engineering: A. 814 (2021) 141158. https://doi.org/10.1016/j.msea.2021.141158.

[6] A. Davis, J. Donoghue, J. Kennedy, N. Byres, P. Prangnell, In-situ observation of single variant α colony formation in Ti-6Al-4V, Acta Materialia. 220 (2021) 117315. https://doi.org/10.1016/j.actamat.2021.117315.

[7] C. Liu, A. Garner, H. Zhao, P. B. Prangnell, B. Gault, D. Raabe, P. Shanthraj, CALPHAD-informed phase-field modeling of grain boundary microchemistry and precipitation in Al-Zn-Mg-Cu alloys, Acta Materialia. 214 (2021) 116966. https://doi.org/10.1016/j.actamat.2021.116966.

[8] T. Dorin, S. Babaniaris, L. Jiang, A. Cassel, C. Race, A. Eggeman, D. Kelly, S. Haigh, J. Robson, Stability and stoichiometry of L12 Al3(Sc,Zr) dispersoids in Al-(Si)-Sc-Zr alloys, Acta Materialia. 216 (2021) 117117. https://doi.org/10.1016/j.actamat.2021.117117.

[9] A. Davis, J. Kennedy, D. Lunt, J. Guo, D. Strong, J. Robson, Preageing of magnesium alloys, Materials Science and Engineering: A. 809 (2021) 141002. https://doi.org/10.1016/j.msea.2021.141002.

[10] K. Zhang, Z. Shao, C. S. Daniel, M. Turski, C. Pruncu, L. Lang, J. Robson, J. Jiang, A comparative study of plastic deformation mechanisms in room-temperature and cryogenically deformed magnesium alloy AZ31, Materials Science and Engineering: A. 807 (2021) 140821. https://doi.org/10.1016/j.msea.2021.140821.

[11] B. J. Usman, M. Curioni, Influence of temperature on the corrosion testing of anodized aerospace alloys, Corrosion Science. 192 (2021) 109772. https://doi.org/10.1016/j.corsci.2021.109772.

[12] A. Garner, R. Euesden, Y. Yao, Y. Aboura, H. Zhao, J. Donoghue, M. Curioni, B. Gault, P. Shanthraj, Z. Barrett, C. Engel, T. L. Burnett, P. B. Prangnell, Multiscale analysis of grain boundary microstructure in high strength 7xxx Al alloys, Acta Materialia. 202 (2021) 190-210. https://doi.org/10.1016/j.actamat.2020.10.021.

[13] R. Thomas, D. Lunt, M. Atkinson, J. Q. d. Fonseca, M. Preuss, F. Barton, J. O'Hanlon, P. Frankel, The Effect of Loading Direction on Slip and Twinning in an Irradiated Zirconium Alloy, Zirconium in the Nuclear Industry: 19th International Symposium. (2021) https://doi.org/10.1520/STP162220190027.

[14] A. Orozco-Caballero, T. Jackson, J. Q. da Fonseca, High-resolution digital image correlation study of the strain localization during loading of a shot-peened RR1000 nickel-based superalloy, Acta Materialia. 220 (2021) 117306. https://doi.org/10.1016/j.actamat.2021.117306.

[15] W. Zhou, Z. Shi, Y. Li, Q. Rong, Y. Zeng, J. Lin, Elastic-plastic buckling analysis of stiffened panel subjected to global bending in forming process, Aerospace Science and Technology. 115 (2021) 106781. https://doi.org/10.1016/j.ast.2021.106781.

[16] J.-H. Zheng, J. Lin, J. M. Allwood, T. Dean, A universal mass-based index defining energy efficiency of different modes of passenger transport, International Journal of Lightweight Materials and Manufacture. 4 (2021) 423-433. https://doi.org/10.1016/j.ijlmm.2021.06.004.

[17] R. Zhang, Z. Shi, Z. Shao, V. A. Yardley, J. Lin, An effective method for determining necking and fracture strains of sheet metals, MethodsX. 8 (2021) 101234. https://doi.org/10.1016/j.mex.2021.101234.

[18] W. Zhou, J. Yu, X. Lu, J. Lin, T. A. Dean, A comparative study on deformation mechanisms, microstructures and mechanical properties of wide thin-ribbed sections formed by sideways and forward extrusion, International Journal of Machine Tools and Manufacture. 168 (2021) 103771. https://doi.org/10.1016/j.ijmachtools.2021.103771.

[19] N. E. Byres, J. Q. da Fonseca, C. S. Daniel, J. Donoghue, A. E. Davis, P. Shanthraj, B. Dod, P. B. Prangnell, The evolution of abnormally coarse grain structures in beta-annealed Ti-6Al%-4V% rolled plates, observed by in-situ investigation, Acta Materialia. 221 (2021) 117362. https://doi.org/10.1016/j.actamat.2021.117362.

[20] W. Mirihanage, J. Robson, S. Mishra, P. Hidalgo-Manrique, J. Q. da Fonseca, C. Daniel, P. Prangnell, S. Michalik, O. Magdysyuk, T. Connolley, M. Drakopoulos, Direct observation of the dynamic evolution of precipitates in aluminium alloy 7021 at high strain rates via high energy synchrotron X-rays, Acta Materialia. 205 (2021) 116532. https://doi.org/10.1016/j.actamat.2020.116532.

[21] C. S. Daniel, A. Garner, P. D. Honniball, L. Bradley, M. Preuss, P. B. Prangnell, J. Quinta da Fonseca, Co-deformation and dynamic annealing effects on the texture development during alpha–beta processing of a model Zr-Nb alloy, Acta Materialia. 205 (2021) 116538. https://doi.org/10.1016/j.actamat.2020.116538.

[22] C. S. Daniel, P. Jedrasiak, C. J. Peyton, J. Q. D. Fonseca, H. R. Shercliff, L. Bradley, P. D. Honniball, Quantifying Processing Map Uncertainties by Modeling the Hot-Compression Behavior of a Zr-2.5Nb Alloy, Zirconium in the Nuclear Industry: 19th International Symposium. (2021) 93-122. https://doi.org/10.1520/STP162220190031.

[23] D. Lunt, R. Thomas, M. D. Atkinson, A. Smith, R. Sandala, J. Q. da Fonseca, M. Preuss, Understanding the role of local texture variation on slip activity in a two-phase titanium alloy, Acta Materialia. 216 (2021) 117111. https://doi.org/10.1016/j.actamat.2021.117111.

[24] J.-H. Zheng, R. Pan, J. Lin, C. M. Davies, FE Simulation of the residual stress reduction in industrial-sized T-section component during a newly proposed manufacturing process, Procedia Manufacturing. 50 (2020) 492-497. https://doi.org/10.1016/j.promfg.2020.08.089.

[25] G. Garcés, A. Orozco-Caballero, J. Quinta da Fonseca, P. Pérez, J. Medina, A. Stark, N. Schell, P. Adeva, Initial plasticity stages in Mg alloys containing Long-Period Stacking Ordered phases using High Resolution Digital Image Correlation (HRDIC) and in-situ synchrotron radiation, Materials Science and Engineering: A. 772 (2020) 138716. https://doi.org/10.1016/j.msea.2019.138716.

[26] L. Wang, X. Yang, J. D. Robson, R. E. Sanders, Q. Liu, Microstructural Evolution of Cold-Rolled AA7075 Sheet during Solution Treatment, Materials. 13 (2020) 2734. https://doi.org/10.3390/ma13122734.

[27] F. Tian, N. Li, Investigation of the Feasibility of a Novel Heat Stamping Process for Producing Complex-shaped Ti-6Al-4V Panel Components, Procedia Manufacturing. 47 (2020) 1374-1380. https://doi.org/10.1016/j.promfg.2020.04.267.

[28] R. Zhang, Z. Shao, Z. Shi, J. Lin, A study on ratio and linearity of strain path in in-plane biaxial tensile test for formability evaluation, Procedia Manufacturing. 50 (2020) 584-588. https://doi.org/10.1016/j.promfg.2020.08.105.

[29] M.-T. Pérez-Prado, J. Bohlen, S. Yi, D. Letzig, T. Al-Samman, J. Robson, M. Barnett, W. Poole, C. Mendis, S. Agnew, N. Stanford, Emerging Hot Topics and Research Questions in Wrought Magnesium Alloy Development, JOM. 72 (2020) 2561-2567. https://doi.org/10.1007/s11837-020-04051-5.

[30] R. Zhang, Z. Shao, Z. Shi, T. A. Dean, J. Lin, Effect of cruciform specimen design on strain paths and fracture location in equi-biaxial tension, Journal of Materials Processing Technology. (2020) 116932. https://doi.org/10.1016/j.jmatprotec.2020.116932.

[31] T. Yasmeen, B. Zhao, J.-H. Zheng, F. Tian, J. Lin, J. Jiang, The study of flow behavior and governing mechanisms of a titanium alloy during superplastic forming, Materials Science and Engineering: A. 788 (2020) 139482. https://doi.org/10.1016/j.msea.2020.139482.

[32] Z. Shao, J. Lee, J. Wang, J. Lin, J. Jiang, A study of various heating effects on the microstructure and mechanical properties of AA6082 using EBSD and CPFE, Journal of Alloys and Compounds. 818 (2020) 152921. https://doi.org/10.1016/j.jallcom.2019.152921.

[33] Q. Luan, H. Xing, J. Zhang, J. Jiang, Experimental and crystal plasticity study on deformation bands in single crystal and multi-crystal pure aluminium, Acta Materialia. 183 (2020) 78-92. https://doi.org/10.1016/j.actamat.2019.11.006.

[34] T. Simm, Y. Das, A. Forsey, S. Gungor, M. Fitzpatrick, D. Prakash, R. Moat, S. Birosca, J. Quinta da Fonseca, K. Perkins, The -plot, a multicomponent 1-D pole figure plot, to quantify the heterogeneity of plastic deformation, Materials Characterization. 160 (2020) 110114. https://doi.org/10.1016/j.matchar.2019.110114.

[35] N. E. Byres, J. Q. d. Fonseca, B. Dod, J. Donoghue, A. Davis, P. B. Prangnell, Analysis of the Development of Abnormal Grains Structures During Beta Annealing of Ti-64 Wrought Products, MATEC Web of Conferences. 321 (2020) 12043. https://doi.org/10.1051/matecconf/202032112043.

[36] G. Singh, J. Quinta da Fonseca, M. Preuss, Microstructure evolution and deformation texture during rolling of TIMETAL® 407, Materialia. 9 (2020) 100596. https://doi.org/10.1016/j.mtla.2020.100596.

[37] D. Lunt, R. Thomas, M. Roy, J. Duff, M. Atkinson, P. Frankel, M. Preuss, J. Quinta da Fonseca, Comparison of sub-grain scale digital image correlation calculated using commercial and open-source software packages, Materials Characterization. 163 (2020) 110271. https://doi.org/10.1016/j.matchar.2020.110271.

[38] C. Dichtl, Z. Zhang, H. Gardner, P. Bagot, A. Radecka, D. Dye, M. Thomas, R. Sandala, J. Q. da Fonseca, M. Preuss, Element segregation and $\alpha 2$ formation in primary α of a near-α Ti-alloy, Materials Characterization. 164 (2020) 110327. https://doi.org/10.1016/j.matchar.2020.110327.

[39] J. Donoghue, A. Davis, C. Daniel, A. Garner, F. Martina, J. Quinta da Fonseca, P. Prangnell, On the observation of annealing twins during simulating β-grain refinement in Ti–6Al–4V high deposition rate AM with in-process deformation, Acta Materialia. 186 (2020) 229-241. https://doi.org/10.1016/j.actamat.2020.01.009.

[40] C. S. Daniel, C.-T. Nguyen, M. D. Atkinson, J. Q. d. Fonseca, Direct Evidence for Dynamic Phase Transformation during High Temperature Deformation in Ti-64, MATEC Web of Conferences. 321 (2020) 12037. https://doi.org/10.1051/matecconf/202032112037.

[41] C. Liu, R. Thomas, J. Q. d. Fonseca, M. Preuss, Early slip activity and fatigue crack initiation of a near alpha titanium alloy, MATEC Web of Conferences. 321 (2020) 11040. https://doi.org/10.1051/matecconf/202032111040.

[42] B. J. Usman, F. Scenini, M. Curioni, Corrosion Testing of Anodized Aerospace Alloys: Comparison Between Immersion and Salt Spray Testing using Electrochemical Impedance Spectroscopy, Journal of The Electrochemical Society. 167 (2020) 041505. https://doi.org/10.1149/1945-7111/ab74e3.

[43] C. Dichtl, D. Lunt, R. Thomas, M. Atkinson, M. Thomas, D. Rugg, R. Sandala, J. Q. d. Fonseca, M. Preuss, Understanding strain localisation behaviour in a near-α Ti-alloy during initial loading below the yield stress, MATEC Web of Conferences. 321 (2020) 11039. https://doi.org/10.1051/matecconf/202032111039.

[44] D. Lunt, A. Ho, A. Davis, F. Martina, J. Hönnige, J. Q. d. Fonseca, P. Prangnell, Microscopic strain localisation in WAAM Ti-6Al-4V during uniaxial tensile loading, MATEC Web of Conferences. 321 (2020) 03008. https://doi.org/10.1051/matecconf/202032103008.

[45] J. R. Hönnige, A. E. Davis, A. Ho, J. R. Kennedy, L. Neto, P. Prangnell, S. Williams, The Effectiveness of Grain Refinement by Machine Hammer Peening in High Deposition Rate Wire-Arc AM Ti-6Al-4V, Metallurgical and Materials Transactions A. 51 (2020) 3692-3703. https://doi.org/10.1007/s11661-020-05781-6.

[46] X. Wu, S. K. Makineni, C. H. Liebscher, G. Dehm, J. Rezaei Mianroodi, P. Shanthraj, B. Svendsen, D. Bürger, G. Eggeler, D. Raabe, B. Gault, Unveiling the Re effect in Ni-based single crystal superalloys, Nature Communications. 11 (2020) 389. https://doi.org/10.1038/s41467-019-14062-9.

[47] P. Shanthraj, C. Liu, A. Akbarian, B. Svendsen, D. Raabe, Multi-component chemo-mechanics based on transport relations for the chemical potential, Computer Methods in Applied Mechanics and Engineering. 365 (2020) 113029. https://doi.org/10.1016/j.cma.2020.113029.

[48] M. Diehl, D. Wang, C. Liu, J. R. Mianroodi, F. Han, D. Ma, P. J. J. Kok, F. Roters, P. Shanthraj, Solving Material Mechanics and Multiphysics Problems of Metals with Complex Microstructures Using DAMASK—The Düsseldorf Advanced Material Simulation Kit, Advanced Engineering Materials. 22 (2020) 1901044. https://doi.org/10.1002/adem.201901044.

[49] Q. Luan, J. Lee, J.-H. Zheng, C. Hopper, J. Jiang, Combining microstructural characterization with crystal plasticity and phase-field modelling for the study of static recrystallization in pure aluminium, Computational Materials Science. 173 (2020) 109419. https://doi.org/10.1016/j.commatsci.2019.109419.

[50] A. Cassell, J. Robson, X. Zhou, T. Hashimoto, M. Besel, The direct observation of copper segregation at the broad faces of η' and η precipitates in AA7010 aluminium alloy, Materials Characterization. 163 (2020) 110232. https://doi.org/10.1016/j.matchar.2020.110232.

[51] A. C. Balaskas, M. Curioni, G. E. Thompson, Corrosion protection mechanism of 2-mercaptobenzothiazole and its potential synergistic effect with cerium ions for treatment of AA 2024-T3, Journal of Electroanalytical Chemistry. 863 (2020) 114081. https://doi.org/10.1016/j.jelechem.2020.114081.

[52] J. Lv, J.-H. Zheng, V. A. Yardley, Z. Shi, J. Lin, A Review of Microstructural Evolution and Modelling of Aluminium Alloys under Hot Forming Conditions, Metals. 10 (2020) 1516. https://doi.org/10.3390/met10111516.

[53] Z. Jin, C. Cai, T. Hashimoto, Y. Yuan, D. Kang, J. Hunter, X. Zhou, Alkaline etching and desmutting of aluminium alloy: The behaviour of Mg2Si particles, Journal of Alloys and Compounds. 842 (2020) 155834. **https://doi.org/10.1016/j.jallcom.2020.155834**.

[54] B. Liu, X.-r. Zhou, X.-x. Zhang, Filiform corrosion behaviour on machined AA7150 aluminium alloy, Transactions of Nonferrous Metals Society of China. 30 (2020) 2056-2066. https://doi.org/10.1016/S1003-6326(20)65360-2.

[55] K. Zhang, J.-H. Zheng, Y. Huang, C. Pruncu, J. Jiang, Evolution of twinning and shear bands in magnesium alloys during rolling at room and cryogenic temperature, Materials & Design. 193 (2020) 108793. https://doi.org/10.1016/j.matdes.2020.108793.

[56] K. Zhang, Z. Shao, J. Jiang, Effects of twin-twin interactions and deformation bands on the nucleation of recrystallization in AZ31 magnesium alloy, Materials & Design. 194 (2020) 108936. https://doi.org/10.1016/j.matdes.2020.108936.

[57] P. Crowther, C. S. Daniel, xrdfit: A Python package for fitting synchrotron X-ray diffraction spectra, Journal of Open Source Software. 5 (2020) 2381. https://doi.org/10.21105/joss.02381.

[58] W. Zhou, J. Yu, J. Lin, T. A. Dean, Effects of die land length and geometry on curvature and effective strain of profiles produced by a novel sideways extrusion process, Journal of Materials Processing Technology. 282 (2020) 116682. https://doi.org/10.1016/j.jmatprotec.2020.116682.

[59] Y. Li, B. Gu, S. Jiang, Y. Liu, Z. Shi, J. Lin, A CDRX-based material model for hot deformation of aluminium alloys, International Journal of Plasticity. 134 (2020) 102844. https://doi.org/10.1016/j.ijplas.2020.102844.

[60] E. Schwarzenböck, E. Ollivier, A. Garner, A. Cassell, T. Hack, Z. Barrett, C. Engel, T. L. Burnett, N. J. H. Holroyd, J. D. Robson, P. B. Prangnell, Environmental cracking performance of new generation thick plate 7000-T7x series alloys in humid air, Corrosion Science. 171 (2020) 108701. https://doi.org/10.1016/j.corsci.2020.108701.

[61] A. Heidarzadeh, S. Mironov, R. Kaibyshev, G. Çam, A. Simar, A. Gerlich, F. Khodabakhshi, A. Mostafaei, D. P. Field, J. D. Robson, A. Deschamps, P. J. Withers, Friction stir welding/processing of metals and alloys: A comprehensive review on microstructural evolution, Progress in Materials Science. (2020) 100752. https://doi.org/10.1016/j.pmatsci.2020.100752.

[62] A. E. Davis, J. R. Hönnige, F. Martina, P. B. Prangnell, Quantification of strain fields and grain refinement in Ti-6Al-4V inter-pass rolled wire-arc AM by EBSD misorientation analysis, Materials Characterization. 170 (2020) 110673. https://doi.org/10.1016/j.matchar.2020.110673.

[63] A. E. Davis, A. Caballero, P. B. Prangnell, Confirmation of rapid-heating β recrystallization in wire-arc additively manufactured Ti-6Al-4V, Materialia. 13 (2020) 100857. https://doi.org/10.1016/j.mtla.2020.100857.

[64] M. Danişman, M. Kocabaş, M. Curioni, N. Cansever, Investigation of porous anodic film formation on aa1050 by electrochemical impedance spectroscopy, Surface Review and Letters. 27 (2020) 1950186. https://doi.org/10.1142/S0218625X19501865.

[65] B. J. Usman, F. Scenini, M. Curioni, The effect of exposure conditions on performance evaluation of post-treated anodic oxides on an aerospace aluminium alloy: Comparison between salt spray and immersion testing, Surface and Coatings Technology. 399 (2020) 126157. https://doi.org/10.1016/j.surfcoat.2020.126157.

[66] M. Curioni, M. Lyu, A. Cioncolini, F. Scenini, Investigating the effect of pH on corroding magnesium by dynamic pH sweep coupled with electrochemical measurements., CORROSION. (2020) https://doi.org/10.5006/3593.

[67] J. D. Robson, O. Engler, C. Sigli, A. Deschamps, W. J. Poole, Advances in Microstructural Understanding of Wrought Aluminum Alloys, Metallurgical and Materials Transactions A. 51 (2020) 4377-4389. https://doi.org/10.1007/s11661-020-05908-9.

[68] J. D. Robson, Deformation Enhanced Diffusion in Aluminium Alloys, Metallurgical and Materials Transactions A. 51 (2020) 5401-5413. https://doi.org/10.1007/s11661-020-05960-5.

[69] D. Lunt, A. Ho, A. Davis, A. Harte, F. Martina, J. Quinta da Fonseca, P. Prangnell, The effect of loading direction on strain localisation in wire arc additively manufactured Ti–6Al–4V, Materials Science and Engineering: A. 788 (2020) 139608. https://doi.org/10.1016/j.msea.2020.139608.

[70] A. Harte, M. Atkinson, M. Preuss, J. Quinta da Fonseca, A statistical study of the relationship between plastic strain and lattice misorientation on the surface of a deformed Ni-based superalloy, Acta Materialia. 195 (2020) 555-570. https://doi.org/10.1016/j.actamat.2020.05.029.

[71] B. J. Usman, F. Scenini, M. Curioni, Exploring the use of an AC-DC-AC technique for the accelerated evaluation of anticorrosion performance of anodic films on aluminium alloys, Progress in Organic Coatings. 144 (2020) 105648. https://doi.org/10.1016/j.porgcoat.2020.105648.

[72] 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. 51 (2019) 1135-1143. https://doi.org/10.1002/sia.6562.

[73] A. Cassell, J. Robson, C. Race, A. Eggeman, T. Hashimoto, M. Besel, Dispersoid composition in zirconium containing Al-Zn-Mg-Cu (AA7010) aluminium alloy, Acta Materialia. 169 (2019) 135-146. https://doi.org/10.1016/j.actamat.2019.02.047.

[74] C. Zhang, J. D. Robson, S. J. Haigh, P. B. Prangnell, Interfacial Segregation of Alloying Elements During Dissimilar Ultrasonic Welding of AA6111 Aluminum and Ti6Al4V Titanium, Metallurgical and Materials Transactions A. 50 (2019) 5143-5152. https://doi.org/10.1007/s11661-019-05395-7.

[75] V. C. Gudla, A. Garner, M. Storm, P. Gajjar, J. Carr, B. C. Palmer, J. J. Lewandowski, P. J. Withers, N. J. H. Holroyd, T. L. Burnett, Initiation and short crack growth behaviour of environmentally induced cracks in AA5083 H131 investigated across time and length scales, Corrosion Reviews. 37 (2019) 469-481. https://doi.org/10.1515/corrrev-2019-0044.

[76] T. Dorin, M. Ramajayam, S. Babaniaris, L. Jiang, T. Langan, Precipitation sequence in Al–Mg–Si–Sc–Zr alloys during isochronal aging, Materialia. 8 (2019) 100437. https://doi.org/10.1016/j.mtla.2019.100437.

[77] C. Liu, P. Shanthraj, J. Robson, M. Diehl, S. Dong, J. Dong, W. Ding, D. Raabe, On the interaction of precipitates and tensile twins in magnesium alloys, Acta Materialia. 178 (2019) 146-162. https://doi.org/10.1016/j.actamat.2019.07.046.

[78] R. Pan, J. Zheng, Z. Zhang, J. Lin, Cold rolling influence on residual stresses evolution in heat-treated AA7xxx T-section panels, Materials and Manufacturing Processes. 34 (2019) 431-446. https://doi.org/10.1080/10426914.2018.1512121.

[79] A. Fitzner, J. Palmer, B. Gardner, M. Thomas, M. Preuss, J. Q. da Fonseca, On the work hardening of titanium: new insights from nanoindentation, Journal of Materials Science. 54 (2019) 7961-7974. https://doi.org/10.1007/s10853-019-03431-w.

[80] P. Hidalgo-Manrique, J. D. Robson, Interaction Between Precipitate Basal Plates and Tensile Twins in Magnesium Alloys, Metallurgical and Materials Transactions A. 50 (2019) 3855-3867. https://doi.org/10.1007/s11661-019-05301-1.

[81] J. D. Robson, M. R. Barnett, The Effect of Precipitates on Twinning in Magnesium Alloys, Advanced Engineering Materials. 21 (2019) 1800460. https://doi.org/10.1002/adem.201800460.

[82] J. R. Mianroodi, P. Shanthraj, P. Kontis, J. Cormier, B. Gault, B. Svendsen, D. Raabe, Atomistic phase field chemomechanical modeling of dislocation-solute-precipitate interaction in Ni–Al–Co, Acta Materialia. 175 (2019) 250-261. https://doi.org/10.1016/j.actamat.2019.06.008.

[83] A. Ho, H. Zhao, J. W. Fellowes, F. Martina, A. E. Davis, P. B. Prangnell, On the origin of microstructural banding in Ti-6Al4V wire-arc based high deposition rate additive manufacturing, Acta Materialia. 166 (2019) 306-323. https://doi.org/10.1016/j.actamat.2018.12.038.

[84] P. Jedrasiak, H. Shercliff, Modelling of heat generation in linear friction welding using a small strain finite element method, Materials & Design. 177 (2019) 107833. https://doi.org/10.1016/j.matdes.2019.107833.

[85] M. Kenyon, J. Robson, J. Fellowes, Z. Liang, Effect of Dispersoids on the Microstructure Evolution in Al <i>−</i> Mg <i>−</i> Si Alloys, Advanced Engineering Materials. 21 (2019) 1800494. https://doi.org/10.1002/adem.201800494.

[86] A. Davis, C. Breheny, J. Fellowes, U. Nwankpa, F. Martina, J. Ding, T. Machry, P. Prangnell, Mechanical performance and microstructural characterisation of titanium alloy-alloy composites built by wire-arc additive manufacture, Materials Science and Engineering: A. 765 (2019) 138289. https://doi.org/10.1016/j.msea.2019.138289.

[87] A. Davis, J. Robson, M. Turski, Reducing yield asymmetry and anisotropy in wrought magnesium alloys – A comparative study, Materials Science and Engineering: A. 744 (2019) 525-537. https://doi.org/10.1016/j.msea.2018.12.060.

[88] J. Robson, Analytical electron microscopy of grain boundary segregation: Application to Al-Zn-Mg-Cu (7xxx) alloys, Materials Characterization. 154 (2019) 325-334. https://doi.org/10.1016/j.matchar.2019.06.016.

[89] X. Xu, D. Lunt, R. Thomas, R. P. Babu, A. Harte, M. Atkinson, J. Q. da Fonseca, M. Preuss, Identification of active slip mode in a hexagonal material by correlative scanning electron microscopy, Acta Materialia. 175 (2019) 376-393. https://doi.org/10.1016/j.actamat.2019.06.024.

[90] W. Zhou, J. Yu, J. Lin, T. A. Dean, Manufacturing a curved profile with fine grains and high strength by differential velocity sideways extrusion, International Journal of Machine Tools and Manufacture. 140 (2019) 77-88. https://doi.org/10.1016/j.ijmachtools.2019.03.002.

[91] J.-H. Zheng, Y. Dong, K. Zheng, H. Dong, J. Lin, J. Jiang, T. A. Dean, Experimental investigation of novel fast–ageing treatments for AA6082 in supersaturated solid solution state, Journal of Alloys and Compounds. 810 (2019) 151934. https://doi.org/10.1016/j.jallcom.2019.151934.

[92] K. Zheng, Y. Dong, J.-H. Zheng, A. Foster, J. Lin, H. Dong, T. A. Dean, The effect of hot form quench (HFQ®) conditions on precipitation and mechanical properties of aluminium alloys, Materials Science and Engineering: A. 761 (2019) 138017. https://doi.org/10.1016/j.msea.2019.06.027.

[93] J.-H. Zheng, R. Pan, R. C. Wimpory, J. Lin, C. Li, C. M. Davies, A novel manufacturing process and validated predictive model for high-strength and low-residual stresses in extra-large 7xxx panels, Materials & Design. 173 (2019) 107767. https://doi.org/10.1016/j.matdes.2019.107767.

[94] T.-F. Chung, Y.-L. Yang, M. Shiojiri, C.-N. Hsiao, W.-C. Li, C.-S. Tsao, Z. Shi, J. Lin, J.-R. Yang, An atomic scale structural investigation of nanometre-sized η precipitates in the 7050 aluminium alloy, Acta Materialia. 174 (2019) 351-368. https://doi.org/10.1016/j.actamat.2019.05.041.

[95] K. Zheng, L. Zhu, J. Lin, T. A. Dean, N. Li, An experimental investigation of the drawability of AA6082 sheet under different elevated temperature forming processes, Journal of Materials Processing Technology. 273 (2019) 116225. https://doi.org/10.1016/j.jmatprotec.2019.05.006.

[96] Y. Li, Q. Rong, Z. Shi, X. Sun, L. Meng, J. Lin, An accelerated springback compensation method for creep age forming, The International Journal of Advanced Manufacturing Technology. 102 (2019) 121-134. https://doi.org/10.1007/s00170-018-3175-3.

[97] K. Zhang, J.-H. Zheng, Z. Shao, C. Pruncu, M. Turski, C. Guerini, J. Jiang, Experimental investigation of the viscoplastic behaviours and microstructure evolutions of AZ31B and Elektron 717 Mg-alloys, Materials & Design. 184 (2019) 108160. https://doi.org/10.1016/j.matdes.2019.108160.

[98] M. Kocabaş, C. Örnek, M. Curioni, N. Cansever, Nickel fluoride as a surface activation agent for electroless nickel coating of anodized AA1050 aluminum alloy, Surface and Coatings Technology. 364 (2019) 231-238. https://doi.org/10.1016/j.surfcoat.2019.03.003.

[99] R. Zhang, Z. Shao, J. Lin, A type of cruciform specimen applied to evaluate forming limits for boron steel under hot stamping conditions, IOP Conference Series: Materials Science and Engineering. 651 (2019) 012087. https://doi.org/10.1088/1757-899X/651/1/012087.

[100] 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. 54 (2019) 1-9. https://doi.org/10.1080/1478422X.2018.1521591.

[101] J. Torrescano-Alvarez, M. Curioni, H. Habazaki, T. Hashimoto, P. Skeldon, X. Zhou, Incorporation of alloying elements into porous anodic films on aluminium alloys: The role of cell diameter, Electrochimica Acta. 296 (2019) 783-789. https://doi.org/10.1016/j.electacta.2018.11.041.

[102] X. Zhang, X. Zhou, J.-O. Nilsson, Corrosion behaviour of AA6082 Al-Mg-Si alloy extrusion: The influence of quench cooling rate, Corrosion Science. 150 (2019) 100-109. https://doi.org/10.1016/j.corsci.2019.01.030.

[103] H. Zhao, A. Ho, A. Davis, A. Antonysamy, P. Prangnell, Automated image mapping and quantification of microstructure heterogeneity in additive manufactured Ti6Al4V, Materials Characterization. 147 (2019) 131-145. https://doi.org/10.1016/j.matchar.2018.10.027.

[104] C. S. Daniel, P. D. Honniball, L. Bradley, M. Preuss, J. Quinta da Fonseca, A detailed study of texture changes during alpha−beta processing of a zirconium alloy, Journal of Alloys and Compounds. 804 (2019) 65-83. https://doi.org/10.1016/j.jallcom.2019.06.338.

[105] Y. Li, Z. Shi, Q. Rong, W. Zhou, J. Lin, Effect of pin arrangement on formed shape with sparse multi-point flexible tool for creep age forming, International Journal of Machine Tools and Manufacture. 140 (2019) 48-61. https://doi.org/10.1016/j.ijmachtools.2019.03.001.

[106] Q. Rong, Y. Li, Z. Shi, L. Meng, X. Sun, X. Sun, J. Lin, Experimental investigations of stress-relaxation ageing behaviour of AA6082, Materials Science and Engineering: A. 750 (2019) 108-116. https://doi.org/10.1016/j.msea.2019.02.043.

[107] 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. https://doi.org/10.1007/s11661-017-4352-y.

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[108] 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. https://doi.org/10.1007/s11661-017-4341-1.

[109] Y. Wang, P. B. Prangnell, Evaluation of Zn-rich coatings for IMC reaction control in aluminum-magnesium dissimilar welds, Materials Characterization. 139 (2018) 100-110. https://doi.org/10.1016/j.matchar.2018.02.035.

[110] 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. https://doi.org/10.1016/j.msea.2018.05.046.

[111] J. dos Santos, P. Staron, T. Fischer, J. Robson, A. Kostka, P. Colegrove, H. Wang, J. Hilgert, L. Bergmann, 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. https://doi.org/10.1016/j.actamat.2018.01.020.

[112] 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. https://doi.org/10.1016/j.scriptamat.2017.10.012.

[113] 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. https://doi.org/10.1016/j.ijmecsci.2018.02.028.

[114] T. Sun, A. Tremsin, M. Roy, M. Hofmann, P. Prangnell, P. Withers, Investigation of residual stress distribution and texture evolution in AA7050 stationary shoulder friction stir welded joints, Materials Science and Engineering: A. 712 (2018) 531-538. https://doi.org/10.1016/j.msea.2017.12.019.

[115] 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. https://doi.org/10.1007/s11661-017-4404-3.

[116] 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. https://doi.org/10.1016/j.surfcoat.2018.02.096.

[117] 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. https://doi.org/10.1016/j.electacta.2018.01.121.

[118] F. Yu, L. Camilli, T. Wang, D. M. Mackenzie, M. Curioni, R. Akid, P. Bøggild, Complete long-term corrosion protection with chemical vapor deposited graphene, Carbon. 132 (2018) 78-84. https://doi.org/10.1016/j.carbon.2018.02.035.

[119] X. Zhang, X. Zhou, J.-O. Nilsson, Z. Dong, C. Cai, Corrosion behaviour of AA6082 Al-Mg-Si alloy extrusion: Recrystallized and non-recrystallized structures, Corrosion Science. 144 (2018) 163-171. https://doi.org/10.1016/j.corsci.2018.08.047.

[120] R. Zhang, Z. Shao, J. Lin, A review on modelling techniques for formability prediction of sheet metal forming, International Journal of Lightweight Materials and Manufacture. 1 (2018) 115-125. https://doi.org/10.1016/j.ijlmm.2018.06.003.

[121] J. 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. https://doi.org/10.1016/j.electacta.2018.03.121.

[122] 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. https://doi.org/10.1016/j.ijplas.2018.02.008.

[123] 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. https://doi.org/10.1016/j.ijmecsci.2018.03.003.

[124] 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. https://doi.org/10.1016/j.actamat.2018.02.045.

[125] A. Davis, J. Robson, M. Turski, The effect of multiple precipitate types and texture on yield asymmetry in Mg-Sn-Zn(-Al-Na-Ca) alloys, Acta Materialia. 158 (2018) 1-12. https://doi.org/10.1016/j.actamat.2018.07.044.

[126] 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. https://doi.org/10.1016/j.ijlmm.2018.03.004.

[127] 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. https://doi.org/10.1016/j.ijmachtools.2017.12.001.

[128] 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. https://doi.org/10.3390/met8040231.

[129] 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. https://doi.org/10.1016/j.msea.2017.10.066.

[130] 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. https://doi.org/10.1016/j.ijmachtools.2018.05.003.

[131] 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. https://doi.org/10.1016/j.electacta.2018.04.116.

[132] 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. https://doi.org/10.1016/j.promfg.2018.07.211.

[133] G. Timár, M. Barnett, J. Q. da Fonseca, Discontinuous yielding in wrought magnesium, Computational Materials Science. 132 (2017) 81-91. https://doi.org/10.1016/j.commatsci.2017.02.010.

[134] 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) https://doi.org/10.1515/corrrev-2016-0059.

[135] 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. https://doi.org/10.1016/j.msea.2016.12.115.

[136] 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. https://doi.org/10.1016/j.actamat.2017.02.068.

[137] 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. https://doi.org/10.1016/j.matchar.2017.09.040.

[138] 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) 7308. https://doi.org/10.1038/s41598-017-06504-5.

[139] 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. https://doi.org/10.1016/j.actamat.2017.05.040.

[140] 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. https://doi.org/10.1016/j.msea.2016.10.099.

[141] B. Rodgers, R. 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. https://doi.org/10.4028/www.scientific.net/MSF.877.205.

Front Cover Image:

High resolution electron backscatter diffraction (EBSD) orientation map of a lamellar Ti-6Al-4V microstructure contained within a single prior-β grain after hot compression. The map shows thin ligaments of β phase between the larger α laths. Larger β-phase regions have dynamically recrystallised and exhibit stepped orientation changes, within which fine α laths have precipitated. Image is 87 μm across.

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