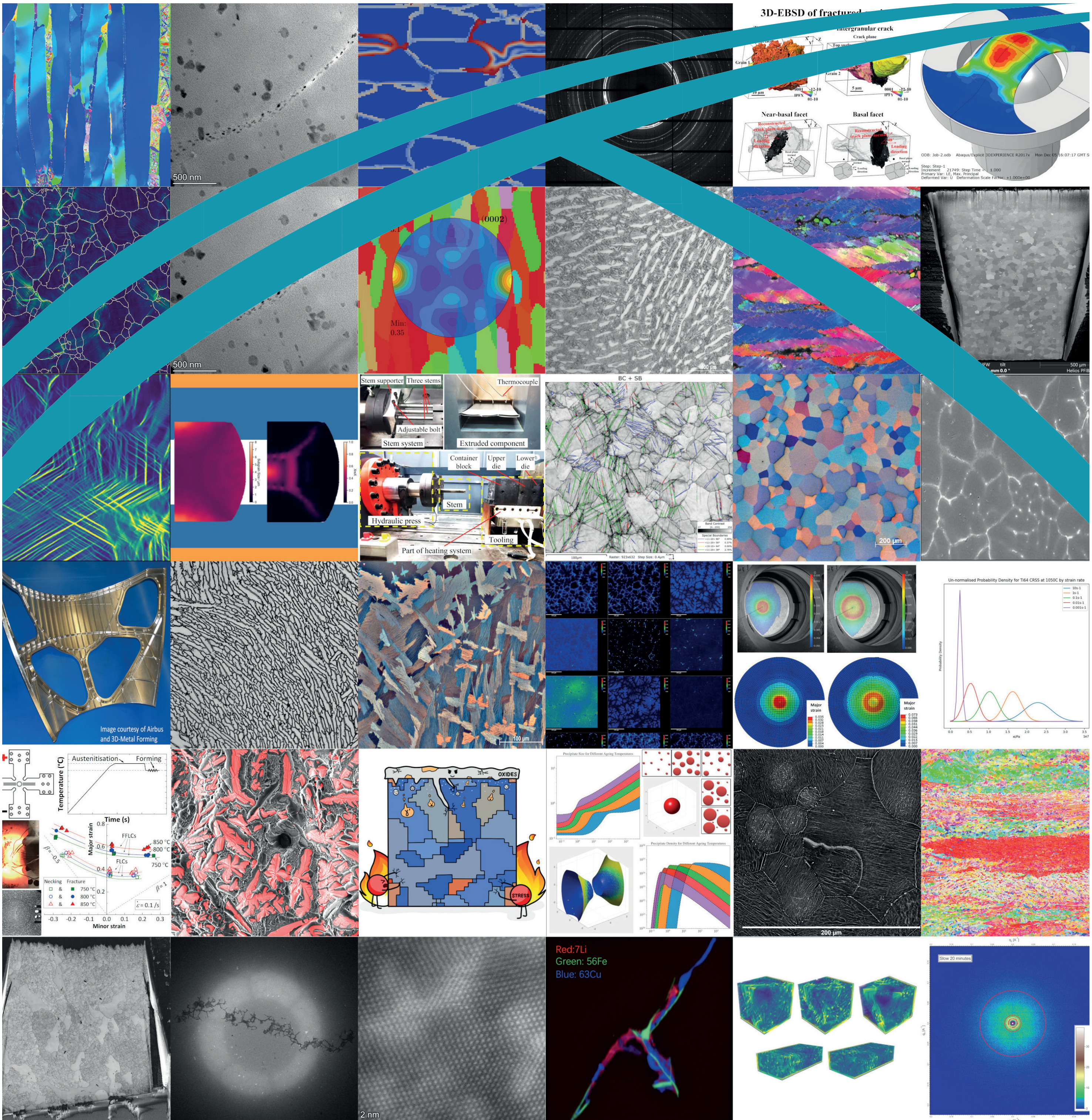
LIGHT FORM

2022 REPORT



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The University of Manchester

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LIGHT FORM

MESSAGE FROM THE DIRECTOR

LightForm is now entering its final year, and after a tumultuous period due to COVID and other changes, we are now back running at full capacity and starting to see the impact of LightForm research. In May, we received confirmation from EPSRC that the project would be allowed a one-year extension. This no-cost extension, will allow us to deliver on several projects that had been severely impacted by COVID and continue to support the PhD students whose projects have also been extended. In this year's report, we are pleased to update you on changes in personnel, highlight major scientific achievements, report on recent research impact and introduce new projects.

LightForm has seen major changes to personnel over the previous year, with co-investigator Pratheek Shanthraj moving on from The University of Manchester and being replaced by Alec Davis, a new lecturer also at Manchester, and a former associate postdoctoral researcher in LightForm. We have also seen two postdoctoral researchers move onto new academic careers in France, and another to work at Jacobs on nuclear materials research. The training and development of people is a major objective in our programme grant, and it is very gratifying to see our researchers move on and advance in their careers. The drawback, of course, is the challenge of constantly renewing our team and being able to do so without losing know-how and expertise. In LightForm, we address this challenge through an emphasis on good data management, and the reliance on reproducible and reusable data analysis tools. At this stage in the project, a number of PhD students who were trained in LightForm are also graduating, a few of which we will hopefully be able to retain as researchers until the end of the project.

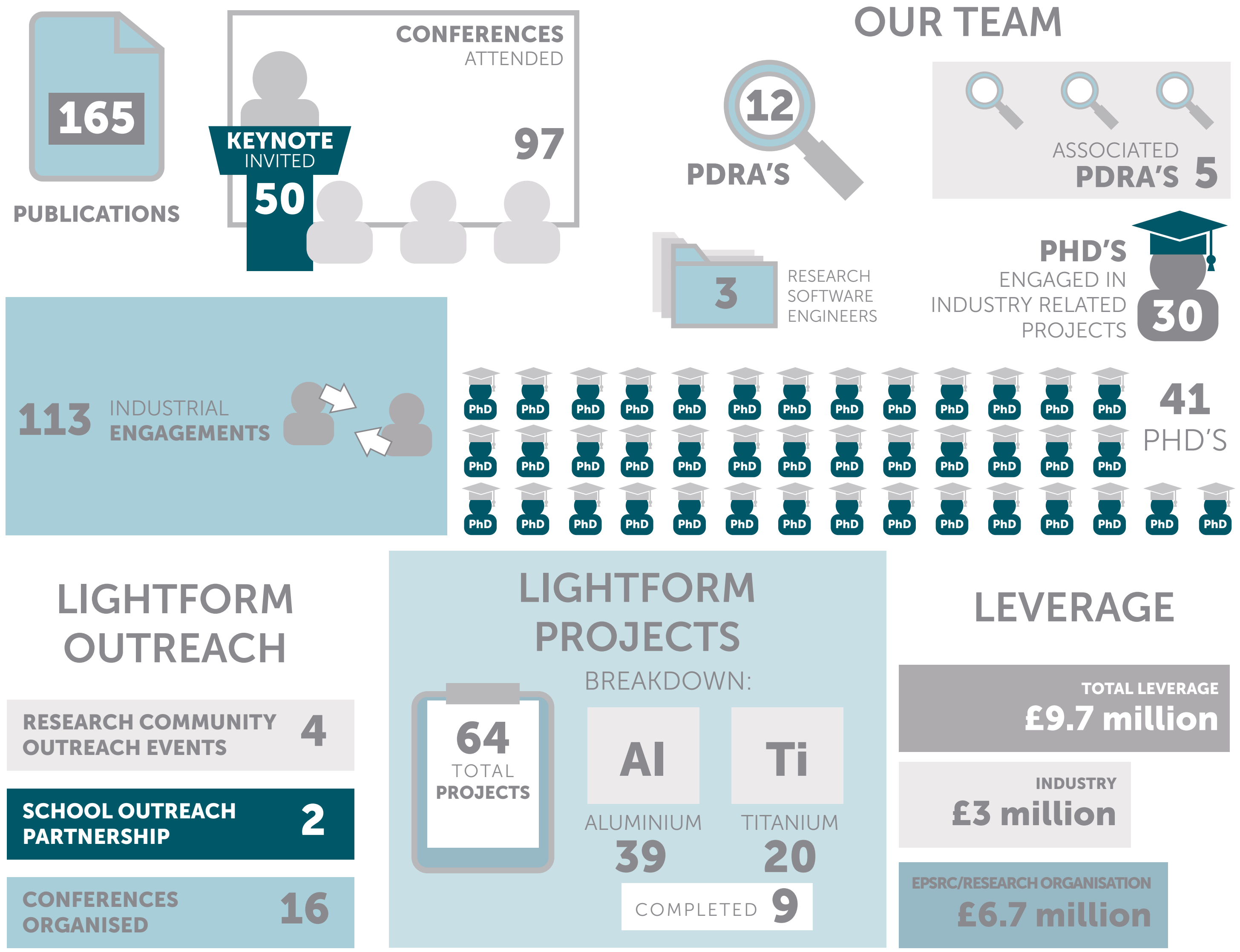
There have been a number of research highlights over the past year. We have continued to develop our work on understanding and modelling dynamic precipitation in aluminium alloys. We have now validated our model using in-situ synchrotron diffractions and have successfully implemented the KWN model as a material model in DAMASK. The single point model has also been repackaged and released to the community. This work has been reported in two peer-reviewed, high-profile journal articles.

Although the pandemic severely limited our ability to carry out synchrotron diffraction measurements, the past year has given us the opportunity to carry out key experiments. We are finally starting to benefit from the unique insights these experiments provide. Our synchrotron measurements made at DESY show a clear difference in the texture evolution behaviour during deformation above ~915°C, which agrees with previous work carried out using hot compression testing in the lab. Crucially, this work reveals that most of the changes happen during or after deformation, which is essential information for the modelling effort. We have also refined our methodology for measuring texture using synchrotron X-ray diffraction and carried out a series of in-situ straining experiments to help calibrate single crystal parameters for our crystal plasticity modelling.

Going forward, our plans are to continue to apply the tools we have developed to make accurate microstructure development predictions during warm forming of aluminium alloys and hot working of titanium alloys. A number of new EPSRC and industrial funded projects are already under way that exploit the research in LightForm and apply it to new problems of industrial and scientific interest. Once again, I will end by thanking all our collaborators and the advisory board members for their support and valuable input. I look forward to a successful final year working together and to seeing the culmination of all the work from the past five years.

Professor João Quinta da Fonseca

LIGHTFORM AT A GLANCE



NEWS

LightForm Attends the ICAA18 Conference

The International Conference on Aluminium Alloys 18 (ICAA18) took place in Toyama, Japan on the 4th- 8th September. The ICAA18 is the largest aluminium focused international conference in the world and had a total of 410 delegates, with over 200 oral and poster presentations. The host city of Toyama is a centre for aluminium within Japan which made it the perfect location for the ICAA18.

The focus of the conference was 'Aluminium and Its Alloys for a Zero Carbon Society', and many of the presentations and keynote speaker talks centred on sustainability and introduced novel ideas on the forefront of this topic.

Nine postdoctoral researchers (PDRAs), PhD students and lecturers from the University of Manchester gave presentations on a wide range of topics including, heat treatment, precipitation, mechanical properties, advanced processing, modelling, simulations, and corrosion. The presentations were well received and sparked interesting discussion with the rest of the international research community. For many in LightForm this was the first in-person conference since the Covid-19 pandemic; it allowed for bonding and networking with the wider research community in a way that wasn't possible in online conferences.

NEWS

LightForm Hosts Latest Advances in Modelling and Characterisation of Alloys Symposium

In November, LightForm hosted a one-day symposium on the Latest Advances in Modelling and Characterisation of Alloys at the University of Manchester's Core Technology Facility. The symposium provided LightForm's stakeholders and the wider community with an opportunity to hear about the latest developments in computational modelling and advanced characterisation, and stimulated discussion about future directions and challenges. Around 70 delegates and speakers came to Manchester from our partner institutions as well as visitors from the international light alloy community.

Topics included the development of sustainable alloys, efficient crystal plasticity modelling, digital twinning of materials and open science and reproducibility. The speakers at the symposium included Prof. Claire Davis (University of Warwick), Prof. Chad Sinclair (University of British Columbia), and Prof. Bjørn Holmedal (Norwegian University of Science and Technology), amongst many others

The event allowed experts from academia and industry to meet in person and share the latest research and developments from LightForm and beyond. Many attendees commented on how informative and successful the event was, as well as how stimulating it was to have larger in-person gatherings. We in LightForm enjoyed it thoroughly and cannot wait to have our final research showcase towards the end of 2023 to show the entirety of what our Programme Grant has achieved.

LightForm Co-Investigator Dr Pratheek Shanthraj Leaves UoM

Dr Pratheek Shanthraj has recently stepped down from his position as Lecturer in Materials Performance at the University of Manchester and co-investigator in LightForm. Pratheek led the Computational Modelling theme and has contributed significantly to the use of microstructural simulation tools among LightForm researchers. Key scientific software authored by Pratheek underpins MatFlow, the materials simulation workflow platform developed in LightForm, and has enabled the strong crystal plasticity and precipitation modelling capabilities at Manchester. While Pratheek will continue supporting computational activities within the research group as a visiting research fellow at The University of Manchester, he will move on to a research scientist role at the UK Atomic Energy Authority as Principal Scientist. Everyone at LightForm wishes him all the best for this new chapter in his career!

LightForm joins Next Wing

LightForm has been asked to partner in the new £19M Aerospace Technology Institute, Innovate funded project, 'Next-Wing'. This project, led by Airbus, aims to develop a series of enabling models which will be integrated into tools for design optimisation and subsequently demonstrated at a wing level, to shorten the aircraft product development cycle. The partners in the project are Airbus operations Ltd, Capgemini UK Plc, Daptablade Ltd, Imperial College, Queen Mary College, and Loughborough, Sheffield, Exeter and Manchester Universities. The LightForm team will work on the 'Highly loaded metallic SMART Components' work package with the Prof. Tim Dodwell from the University of Exeter (Alan Turin Institute Fellow), where they will use large industrial data sets, and high-throughput characterisation tools to develop a data-driven engineering models to quantify how large scatter in the available coupon testing data will propagate to uncertainty in the fatigue lifetime of 'sized' components. This will include microstructure-informed fatigue prediction through incorporating microstructure and texture parameter correlations into crack growth laws, within a multi-scale Bayesian framework. The approach will enable a move towards component tailored knockdown safety factors and greater accuracy in digital design optimization using coupon materials test data with less dependence on component scale testing.

LightForm Awarded Royce Institute Funding to Develop Novel Database

A data-centric approach to materials science requires access to large, high-quality datasets that are findable but also explorable, and whose connections to other datasets are identified.

With this aim and in the spirit of the open science movement, LightForm reseracher have been awarded funding under the competitive Royce Materials 4.0 Feasibility & Pilot Scheme, to develop a framework for organising large materials science databases. Having secured funding, they are now in the process of "pump-priming" a Royce database of high-quality microstructure data on hot formed Ti64.

The Ti64 data-set is made up of optical microscopy and electron backscatter diffraction (EBSD) data of samples produced in a recent, well-controlled hot-rolling study. This material is a Ti64 billet provided by TIMET, with the agreement to allow open sharing of this invaluable processing data. The rolling matrix is a rich data-set, at small temperature increments, covering the typical temperature range used in hot working of Ti alloys.

LightForm aims to demonstrate best practice in data management and sharing, which is vital in supporting future, scientifically reproducible, materials research. The data produced is being uploaded to the repository Zenodo, with full traceability to the physical samples and the original billet. We are creating an easy-to-use searchable database, using Ampletracks (a custom software for data organisation), and we are developing standardised metadata templates for optical microscopy, EBSD, and other forms of data.

Over the next 3 years, it will be complemented by a variety of other rich, related datasets all using the same billet material, which will also be indexed using this Royce Materials 4.0 database. This includes further characterisation data such as mechanical flow data, data from in-situ synchrotron studies, spatially resolved acoustic spectroscopy (SRAS) texture measurements, and data from further processing studies.

CHALLENGE 1 UPDATE

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 has produced important new science in the areas of dynamic precipitation in aluminium alloys, microstructure and texture evolution in titanium alloys, and formability of aluminium and magnesium alloys. We have also said goodbye to two of our PDRAs, Madeleine Bignon and Thomas Jailin, who have left to take up academic appointments in France, and welcomed Gideon Obasi, Conghui Lui, and Mirtunjay Kumar to the PDRA team. The number of PhD students working on projects associated with challenge 1 is 21 – an increase of 2 from the last year. In total, challenge 1 is now running 29 projects, including 9 cross-theme projects taking the fundamental science from Theme 1 and using it for model development (Theme 2) and novel applications (Theme 3).

Research Highlights

Dynamic Precipitation in Aluminium Alloys

Deformation can strongly accelerate precipitation in aluminium alloys. Understanding this effect is central to optimise warm forming of strong aluminium alloys. For example, exploiting the effect can be used to reduce aging heat treatment times, saving cost and reducing energy consumption.

In LightForm, we have used in-situ experiments to study dynamic precipitate evolution in strong aluminium – AA7075, an alloy currently being considered for automotive sheet applications. By investigating precipitate evolution during deformation (in the beamline at Diamond) through small angle X-ray scattering (SAXS) we have been able to understand the role of strain, strain rate, and temperature. This work has in turn been used to inform models of dynamic precipitate evolution. For the first time, we have developed a coupled crystal-plasticity/dynamic precipitation model, so that the effects of heterogeneous deformation at the microstructural scale on the non-uniform dynamic response can be predicted. This work is now being applied to predict dynamic precipitation behaviour in a formed component, coupling micro- and macro-scale models to predict final microstructure and hence properties across the part.

The work has led to several publications, including two in *Acta Materialia*. Further details can be found in the research spotlight “Dynamic Precipitation in Aluminium Alloys”.

Texture Development in Ti-64

Texture and microstructure are critical to the in-service performance of components produced from titanium alloys such as Ti-6Al-4V (Ti64). For example, phenomena such as cold dwell fatigue are known to be strongly linked to local texture. TiFun is a set of coordinated projects initiated by LightForm in which a consortium of six companies have contributed to fund pre-competitive research into the fundamentals of titanium alloy metallurgy. This coordinated activity seeks to address long-standing problems in the processing and use of Ti64, such as understanding the development of texture macro-zones and the role of recrystallization during hot deformation. The approach combines the use of in-situ experiments in the beamline, laboratory simulation of industrial processes, and computer modelling (linking Challenge Themes 1 and 2).

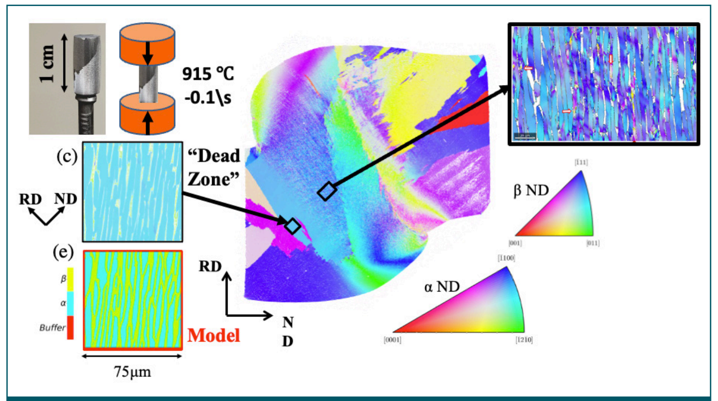


Fig. 1: Study of deformation at the local scale in Ti64 crystals with well-defined prior β orientation, compared to the results from crystal plasticity modelling.

Studies on selected grains with known orientation and bi-crystal specimens have been used to investigate the texture evolution at a local level during hot deformation (Fig. 1). Evidence for the importance of dynamic recrystallization has been found, implying that this must be included in any successful physics-based model for texture evolution. Great attention has been paid to understanding and modelling the heterogeneity of strain and temperature during testing so that the macroscopically applied conditions can be related to the true local deformation (Fig. 2). This enables the results from in-situ and ex-situ compression studies to be correctly interpreted, since such tests produce heterogeneous distributions of deformation and hence final texture.

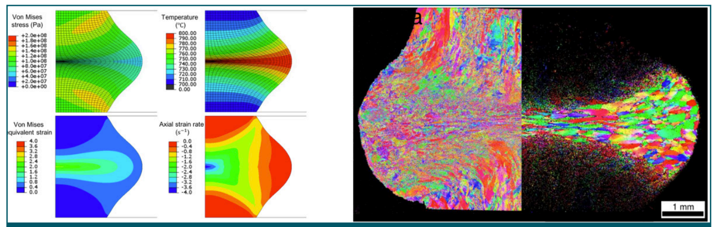


Fig. 2: Modelling and measurement of deformation heterogeneity during hot compression of titanium alloy.

The experimental work has produced large datasets for systematic variations in deformation conditions and temperature. This data is being used to help inform and test models developed in Challenge 2 but has also been made available on the LightForm Zenodo platform so that it can be exploited by other researchers for model development (https://doi.org/10.5281/zenodo.6554355).

Discontinuous Precipitation in Magnesium Alloys

The critical mass of LightForm has enabled us to attract many self-funded PhD students interested in working on topics related to light alloys. These students in turn are contributing important science to meet core LightForm objectives. For example, there are currently 7 self-funded students associated with Challenge 1. These projects are unconstrained by commercial requirements and able to focus on interesting, curiosity driven research.

An example of such a project is work underway to better understand discontinuous precipitation in magnesium—aluminium—zinc alloys (AZ series). These alloys can form a high-volume fraction of precipitation, but despite this have poor strength. One reason for this is due to discontinuous precipitation (DP). DP occurs in over 70 alloy systems but is not yet fully understood. All current knowledge of the DP structure comes from examination of thin foils or 2-dimensional sections, but this can provide misleading information regarding the true 3-dimensional (3-D) structure. Knowledge of this true structure is essential to explain how twins and dislocations can navigate DP regions.

To understand the true 3-D structure, we have taken advantage of the recent developments in plasma focussed ion beam (PFIB) technology available at Manchester. This allows for controlled serial sectioning and automatic imaging of a 3-D volume at rates orders of magnitude faster than older generation FIBs. This has enabled us to study and reconstruct the 3-D structure of a full DP colony within a grain. Fig. 3 shows an example output from this analysis, where all objects of the same colour are interconnected. This reveals that the DP morphology is a fully interconnected network (coloured purple) but that this contains large gaps and channels through which dislocations or twins may propagate. Further details are also revealed about the branching and splitting of the DP layers. These results are being used to better understand and model DP formation, and to determine how to improve the properties of alloys in which such structures form.

The data and 3-D dataset, along with instructions for viewing using the free software package Paraview have been made openly available on the LightForm Zenodo platform (https://doi.org/10.5281/zenodo.7112791)

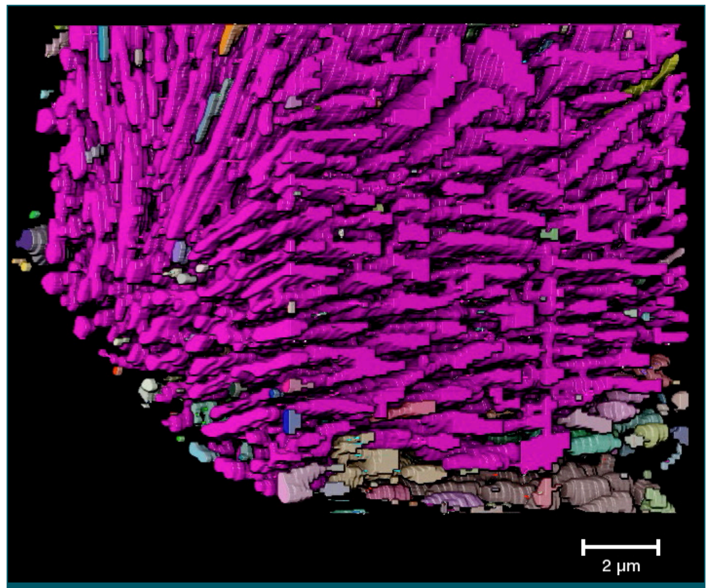


Fig. 3: Discontinuous precipitates (DP) reconstructed from a 3-D volume, forming an interconnected network (purple) in magnesium alloy AZ80.

Future Plans

In the next year, there are several key areas where we will focus our efforts. In aluminium, the dynamic precipitation model will be applied to predict the microstructural evolution in formed parts. Further studies of the combined effect of dynamic precipitation and accelerated ageing post-deformation will be conducted. The outcome of this will be recommended practices and modelling tools to predict optimized conditions to obtain high strength formed aluminium alloy sheet components with minimum cycle time and energy requirement. The work on Ti64 will be used to improve models developed in Challenge 2 by incorporating our new understanding about the role of recrystallization and local deformation effects.

CHALLENGE 2 UPDATE

Computationally efficient material and process modelling

The aim of Challenge Theme 2 is to develop an efficient computational framework for modelling material behaviour, including microstructural evolution, and embed it into forming process models. The theme's main objectives are to:

- Develop material sub-models that capture key aspects of the evolution of deformation structures
- Develop new models for sub-transus deformation of dual phase Ti alloys
- Couple microstructure evolution models with crystal plasticity codes to produce "virtual materials testing" 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 continued to focus 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 using phase field modelling to model grain growth during the thermomechanical processing of titanium alloys.

Two of the PDRAs working in computational modelling challenge theme have moved onto academic positions in France, and we have appointed one new PDRA, to help with delivering the project aims in the last year of the project. In total there are now 4 PDRAs working in the theme, and a total of 14 PhD students for whom computational modelling is major part of their project.

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.

MatFlow Rewrite

Over the past year, we have continued to develop MatFlow, a computational framework for running reproducible hybrid workflows. With the support of a research software engineer, we have been working on a major rewrite of the core MatFlow program, with the aims being to simplify installation, streamline the extension development process, and to support different computational environments. We have also moved to continuous integration, which means that any changes to the code base are tested automatically before a new release is made. This simplifies maintenance and makes it easier to add new features. As well as making it easier to maintain and extend, the new version of MatFlow will have exciting new features like the ability to run tasks on local machines when high performance computing (HPC) capability is not required, resuming interrupted workflows and a move to the cloud-friendly Zarr file format from HDF.

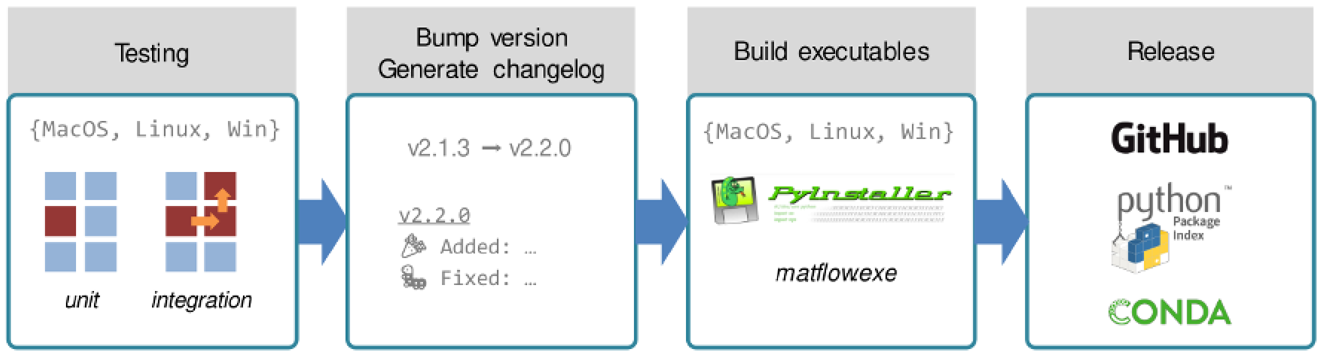


Fig. 1: MatFlow now has automated continuous integrations, which carries out testing, building, and releasing automatically.

MatFlow enabled statistical modelling

MatFlow is being used in a number of different projects in LightForm, primarily to run computational work involving crystal plasticity modelling. In one associated project the capabilities of MatFlow make it an essential tool. In the associated Doing more with Less Project (DMWL), we are developing statistical methods for predicting texture evolution during forging of Ti alloys. In a typical forging, the deformation conditions vary considerably with position, as does the texture developed. However, detailed crystal plasticity models of texture development are too computationally demanding to be run at every location in the forging. Instead, a surrogate statistical model of the texture development has been developed using Gaussian processes. The model is trained on a reduced number of full field crystal plasticity simulations, managed using MatFlow, and can then be used to make texture predictions for the entire forging in fractions of a second. The next step is to combine experimental measurements of the texture at different positions into the surrogate model, to further improve its capability and accuracy.

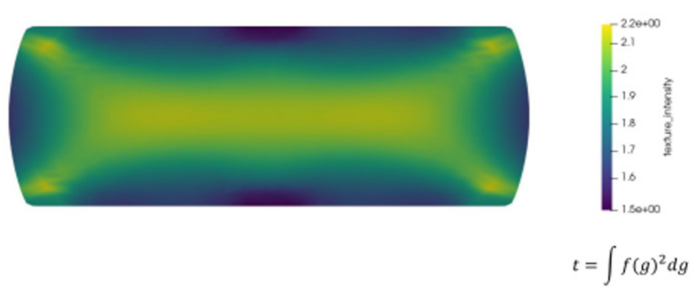


Fig. 2: Prediction of the texture strength in a beta Ti forging made using a surrogate model based on Gaussian processes trained on full field crystal plasticity simulations.

Using MatFlow to model microstructure evolution in Ti

The past year has also seen major developments in our ability to model the microstructure evolution in Ti alloys. One key issue in predicting texture during the processing of Ti alloys in the dual phase regime, is that at high temperatures texture evolves due to deformation but also through recrystallization and phase transformation. To model these processes, we are developing phase field models of grain growth and phase transformation, using software packages like CIPHER. In this work, MatFlow is again used to great effect, making it possible to quickly develop and integrate pre-processing pipelines, such as that shown in Figure 3, where we include the effect of texture in grain growth simulations via known empirical laws. Using MatFlow, we can also easily link to other software packages. For example, outputs from DAMASK crystal plasticity simulations can be used as inputs in CIPHER to simulate recrystallization.

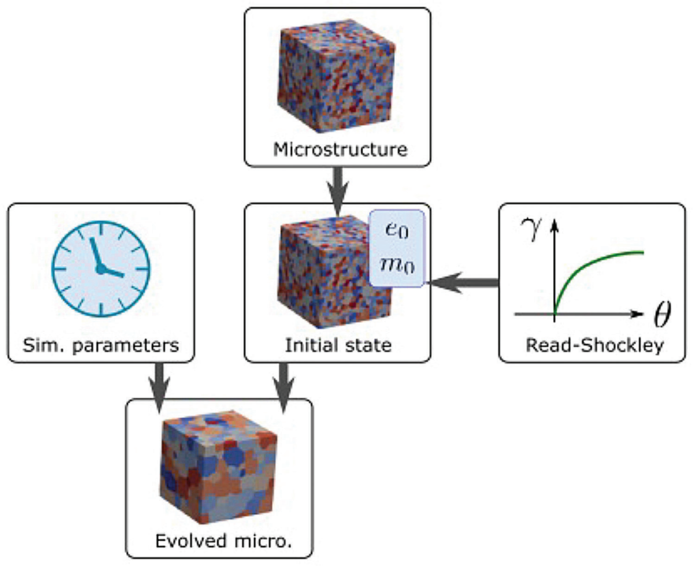


Fig. 3: MatFlow workflow for simulating grain growth in Ti alloys using phase field modelling.

Future Plans

In the last year of the project, we are looking forward to releasing the new version of MatFlow to the wider community and to have it running outside Manchester, by both our partner institutions and industrial partners. We will also release a case study demonstrating our capability to model microstructure evolution during warm forming of high strength aluminium alloys, and will release our modelling tools as standalone applications, MatFlow extensions and as an ABAQUS UMAT. Finally, we will start applying our Ti alloy microstructure development models to predict texture changes during forging and rolling in LightForm and in other new projects that will exploit the tools developed in LightForm.

CHALLENGE 3 UPDATE

Process innovation – manufacturing with embedded materials engineering implementation

Challenge Theme 3 aims to use the underpinning science for manufacturing with embedded materials engineering (MEME) developed in Challenge Theme 1 and multiscale simulation methods with microstructurally informed computational models developed in Challenge Theme 2, to simultaneously improve manufacturability and component performance - while reducing cost and time to market in advanced forming processes. Also, Challenge Theme 3 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.

The key specific research objectives in Challenge Theme 3 are:

1. Implementing MEME methodologies in practical forming operations
2. Developing novel forming technologies
3. Dynamic controlling of the microstructure and property
4. Applying LightForm philosophy to critical issues in-service performance.

As LightForm is approaching its sixth year, towards the end of this programme grant, most research activities from Themes 1 and 2 have been converging to this implementation theme to maximise their impact on the UK industry and economy. This report aims to summarise and highlight some examples of Theme 3 projects to demonstrate how LightForm has been utilising the obtained science and modelling capabilities from Themes 1 and 2 to improve the industrial forming processes (e.g. HFQ), generate novel forming technologies, and solve critical in-service performance issues.

Highlights

1. Warm Forming Aluminium Project

This is the core part of the LightForm programme, involving the majority of core PDRAs, with the ultimate aim of developing a versatile forming model which can predict the macroscopic material flow, flow stress, forming limits, post-forming strength and mechanical properties of aluminium, through the accurate modelling of the microstructure dynamic precipitate evolution during forming and heat treatment. Note that the precipitate hardening is the primary hardening mechanism in high-strength and high-performance aluminium alloys and, thus, is the main focus of microstructure. This warm forming project links Theme 1, discovering new science on dynamic microstructure evolution, Theme 2, developing forming process modelling, and Theme 3, implementing it for practical industrial use. Also, this Warm Forming project has enabled The University of Manchester (Themes 1 and 2), Cambridge (Theme 2) and Imperial College (Theme 3) to work closely and collaboratively throughout this programme.

A robust forming process finite element model, including constitutive laws, dynamic yield surface and friction, has been developed at Cambridge and applied to simulate the materials (AA7075 and Sufalex alloys) flow in not only the industrial standard Nakazima forming test but also the cross-die test, which involves more complex stress-state evolution during forming. These simulated results were experimentally validated at Manchester by mapping the strain distribution and evolution during both Nakazima and cross-die tests using a high-resolution 3D digital image correlation (DIC) technique. These high-fidelity experimental results enabled direct point-to-point validation and calibration between the developed forming model and experimental results.

More importantly, this model included the underlying dynamic precipitate evolution of aluminium alloys during the forming, developed and validated by Manchester, such that the flow stress, strain, precipitate size and volume fraction during the forming can now be accurately predicted. The relationships between precipitate size and volume fraction and forming fracture were explored and established through uniaxial and in-plane strain testing, in which the samples with characteristic precipitate size and volume fraction were prepared, characterised and correlated with their fracture behaviour, such that the developed warm forming model can accurately capture the mechanistic nature of the forming fracture of aluminium alloys.

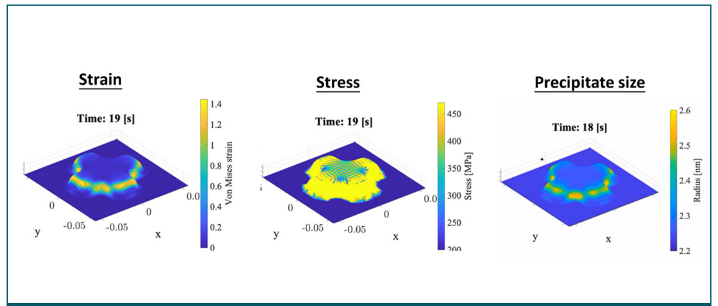


Fig. 1: The warming forming process finite element (FE) model simulated strain stress and precipitate size distribution of a cross-die formed sample.

The commonly used Nakazima and cross-die forming testing methods have limited accuracy for obtaining warm/hot forming limits due to the difficulty in controlling the friction and fracture location (maintaining constant strain rate), limited heating/cooling rate, etc. To address these issues, through LightForm, Imperial developed a novel biaxial testing technique, Multi-X, using Gleeble by transferring the uniaxial to biaxial testing; thus, more accurate forming limits data can be generated and a more complex dynamic forming process by controlling the heating and cooling rate can be in-lab simulated.

Therefore, to ensure the high reliability of the Warm Forming model, Gleeble biaxial tests have been planned and conducted at Imperial to validate the developed forming model. In addition, to allow the industry to benefit from this new technology, a spin-out company, Multi-X Limited, was founded to transfer this technique to industry effectively. Last year, a new DIC strain mapping method, called XPLOE, uses polarised filers to enable high-temperature (to 520°C for Al), large-deformation (90% strain to fracture) strain measurement successfully developed and transferred to Mulit-X Limited.

2. Intelligent Optimisation of HFQ.

Understanding dynamic precipitation evolution through the Warm Forming project enabled the hot forming in-die quenching (HFQ) technique to be further optimised through the collaboration between Imperial and Manchester. Three aspects, including the optimal blank transfer window, the optimal pre-ageing and the optimal corrosion performance, have been undertaken in LightForm. The optimal forming/ageing windows for optimal mechanical strength and corrosion resistance were identified. Also, the pre-ageing process allows the HFQ technique to reduce the ageing time from 9 hours to less than 1 hour, significantly improving the efficiency and productivity of the HFQ technique.

All these identified optimal windows and processes through LightForm have been transferred to Impression Technology Limited to enhance its technical competitiveness and enable it to grab new business opportunities, such as using HFQ to form electric vehicles' battery trays with complex-shaped cooling channels, identifying HFW as the most cost-effective manufacturing method to produce some of the aeroplane structural parts and using HFQ to form 100% recycled aluminium alloys for a circular economy.

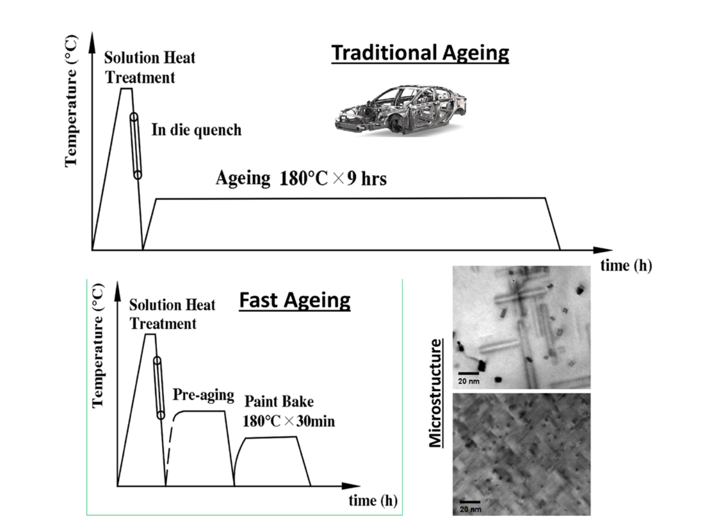


Fig. 2: Fast ageing compared with the traditional ageing process.

3. MATFlow Modelling Translation

In parallel to the Warm Forming project, MATFlow is the other powerful modelling tool developed in LightForm, with a focus to characterise and simulate the volume representative microstructure (dislocations, grain size, orientations (texture) and precipitates) distribution and evolution through materials' forming-heat treatment process, such that the materials' dynamic yield surface, forming limits (strain localisation), and performance, e.g. fatigue and corrosion resistance can be understood and predicted.

Two successful industrial applications of MATFLow are highlighted: an in-depth understanding of the origin of abnormal grain growth in forming titanium parts and texture effects on the bendability of extruded aluminium components. These two projects were funded directly by LightForm's industrial partners: DSTL, Air Force Research Laboratory and Novelis, who were attracted through reading the early work publications of LightForm. The abnormal grain growth mechanism in titanium beta heat treatment was captured in these two projects using MATFlow. A phase field recrystallisation model is developed to simulate grain growth and optimise the corresponding manufacturing process. MATFlow tackled the bendability problem by understanding the texture effects on strain localisation through detailed electron back scatter (EBSD) characterisation and crystal plasticity finite element (CPFE) modelling.

Furthermore, since MATFlow is capable of capturing and predicting the texture and precipitate effects on the yield strength of the materials, it provides the dynamic yield surface data to the Warm Forming model, which essentially provides 'BIG DATA' across the length-scales to ensure the reliability of the Warm Forming model covers a wide range microstructure spectrum.

4. Novel Forming Processes

Based on the critical knowledge and scientific understanding of the relationship between the microscopic and macroscopic behaviour of the material, many novel forming processes have been invented through LightForm, for example, the in-direct HFQ technique and titanium Fast Stamping technology.

In-direct HFQ technique was developed to lower the technical and design barrier to adopting the hot stamping technique since most of the stamping processes used by the automotive industry have been cold stamping, and the design and equipment are all oriented around cold stamping. Thus, from a business perspective, it is uneasy about asking automotive original equipment manufacturer (OEMs) to adopt HFQ directly, though HFQ offers many technical advantages for forming high-strength aluminium sheets. Therefore, the in-direct HFQ, combining cold forming and hot forming, was invented to allow the OEMs to use their existing cold forming equipment and design expertise to form high-strength complex-shaped aluminium alloys. This technique is based on understanding the precipitate effects on the formability of aluminium alloy. A patent was filed and successfully granted this year. This new forming technique has been transferred to Impression Technology Limited for use.

Also, through understanding the alpha-phase precipitation process of titanium alloys and its corresponding strain rate hardening effects, a novel heat stamping technology was invented through LightForm, which allows complex-shaped titanium panel parts to be manufactured in a few seconds rather than hours. Most titanium sheets are formed through the slow superplastic forming technique, typically requiring several hours. This innovative heat stamping method achieved a considerable drawing ratio of 1:8, which means most of the conventional superplastic-formed titanium parts can be replaced with the heat stamping method, resulting in significant energy and cost savings. This technology has been successfully proven in the lab, and now the principal investigator of this technology is preparing to increase the technical readiness level of this technology through an Innovation UK grant with Senior Aerospace.

5. Environmental Performance

The final highlight of Theme 3 is the application of LightForm philosophy to critical issues of in-service performance through understanding dynamic precipitation evolution. This is demonstrated through solving the unexpected Environmental Assisted Cracking (EAC) issue in 7xxx aluminium alloys.
The unexpected environmental assisted cracking issue was discovered in the first year of LightForm, through working with our industrial partner Airbus, that the crack growth rate of later developed 7xxx alloys was 6-20 times higher than AA7050 when they were stressed in a hot (~70°C) relatively high humidity environment. However, these 7xxx alloys have similar mechanical properties. The existing industrial standard does not cover this significant difference in crack propagation rate in 7xxx alloys. Airbus invested £1.1 M to investigate the reasons for this unexpected EAC behaviour in 7xxx alloys.

Adopting LightForm's philosophy, linking materials' microstructure to their properties, in the past two years, significant progress was made in identifying the causes of the EAC problem through Manchester's state-of-the-art testing, characterisation and modelling techniques. For example, the in-situ EAC testing rig was developed in the lab to replicate the industrial EAC failure. This in-situ method allowed the EAC crack nucleation site to be unambiguously determined by tracing the crack path. Then, various advanced characterisation techniques, such as the laser tri-beam FIB and EBSD, were used to reconstruct the 3D grain structure at the crack tip. Together with other chemical characterisation tools, it was found that from a chemical composition perspective, the difference of copper and zinc content in the η phase of 7050 and other 7xxx alloys could be one of the main reasons for the observed EAC issue. Also from a grain structure perspective, as observed from the 3D grain structure map, 7050 exhibits considerably more torturous grain boundary morphology than other alloys, providing higher resistance to crack propagation and deviation of the driving stress for cracking.

The EAC model is being developed to account for these critical microstructural factors to accurately predict the EAC rate and provide the optimal microstructure to guide the manufacturing processes. This project affects the whole Airbus alloy selection and design philosophy (£60 bln pa business) and the reconsideration of the existing manufacturing process, i.e. high-speed machining of large integral components from thick plates.

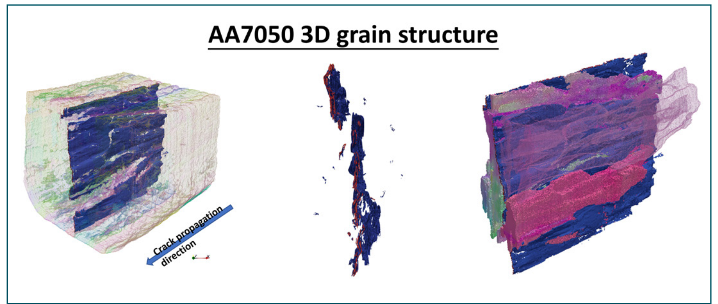


Fig. 3: The 3D grain structure of the crack tip of AA7050 was characterised using EBSD and laser tri-beam FIB.

Summary

The research activities in Theme 3 have demonstrated the significant impact generated through the LightForm programme. Not only does the gained new dynamic microstructure evolution scientific understanding help various industrial partners to solve their current urgent critical manufacturing or performance problems, such as abnormal grain growth in titanium, texture effects on the bendability of extruded aluminium profiles, grain boundary morphology of the EAC problem in 7xxx aluminium alloys, but also does LightForm optimise industrial forming processes to enhance their global technical competitiveness, such as the HFQ process optimisation for Impression Technology Limited. Moreover, LightForm enabled several disruptive forming technologies (e.g. in-direct HFQ, Heat Stamp) or forming-related technologies (e.g. Multi-X) to be invented to generate a broad, long-term impact on the UK industry and economy.

A Novel Heat Stamping Process for Forming Titanium Alloy Components

Researchers Famin Tian, Dr Nan Li, Professor Jianguo Lin
Project Partners N/A. Partner for next step scale-up: Senior Aerospace Thermal Engineering

Introduction

To achieve a sustainable low-carbon future, high performance lightweight materials play a key role in the transport industry. Titanium (Ti)-alloys are the only high temperature light-alloys and are candidates to reduce weight of vehicles by their superior strength-to-weight ratios. However, the application of Ti in transport has been limited mainly to the aero sector, and existing manufacturing methods remain prohibitively inefficient and expensive for medium/high quantity production.

To overcome the shortcomings of cold forming (CF), low formability and excessive springback, and isothermal hot forming (IF)/superplastic forming (SPF), and low productivity and poor energy-efficiency, we have proposed a hybrid forming process of heat treatment and fast stamping, known as Heat Stamping (HS), to produce complex-shaped Ti-alloy panels with significantly reduced energy-consumption, cycle-time, and cost. The novel HS process is to heat treat Ti-alloy sheets at a relatively high temperature (near SPF temperatures), with the subsequent step of quenching to a lower temperature (near IF temperatures), and to stamp the sheets at a high speed, using cold dies. The material is deformed within a very short period of time (less than 1 second) and quenched in closed-pressurised-dies to eliminate distortion and enable the required microstructures to be obtained.

The aim of the project is to develop and prove the concept of the new HS process through fundamental material characterisation, manufacturing system development, and laboratory forming trials, assisted by material and process modelling.

Research activities

Our research under LightForm has focused on addressing scientific challenges arising from the complicated interactions between metallurgical and thermo-mechanical responses under non-isothermal and high-strain-rate HS conditions, extremely sensitive non-equilibrium microstructures, and very narrow forming windows of the two-phase Ti-alloy Ti-6Al-4V, as well as tackling the technical difficulties of thermal control, tool design, and process integration for implementing the HS process.

To reduce the flow softening of Ti-6Al-4V under hot deformation at a high strain rate (i.e., 10^{-1}~10/s to simulate stamping conditions), we systematically investigated its mechanisms through thermo-mechanical testing and microstructural analysis (Fig. 1). An essential activity underpinning the study was to accurately capture the material stress-strain responses during hot deformation, which was realised by an advanced strain measurement system, enabled by a bespoke gripping fixture and an in-house image processing script. We found that the desired thermo-mechanical properties of Ti-6Al-4V could be achieved under specially designed HS conditions, by balancing its various flow softening/hardening mechanisms, utilising the material strain hardening and strain rate hardening, and restraining the softening associated with adiabatic heat caused phase transformation.

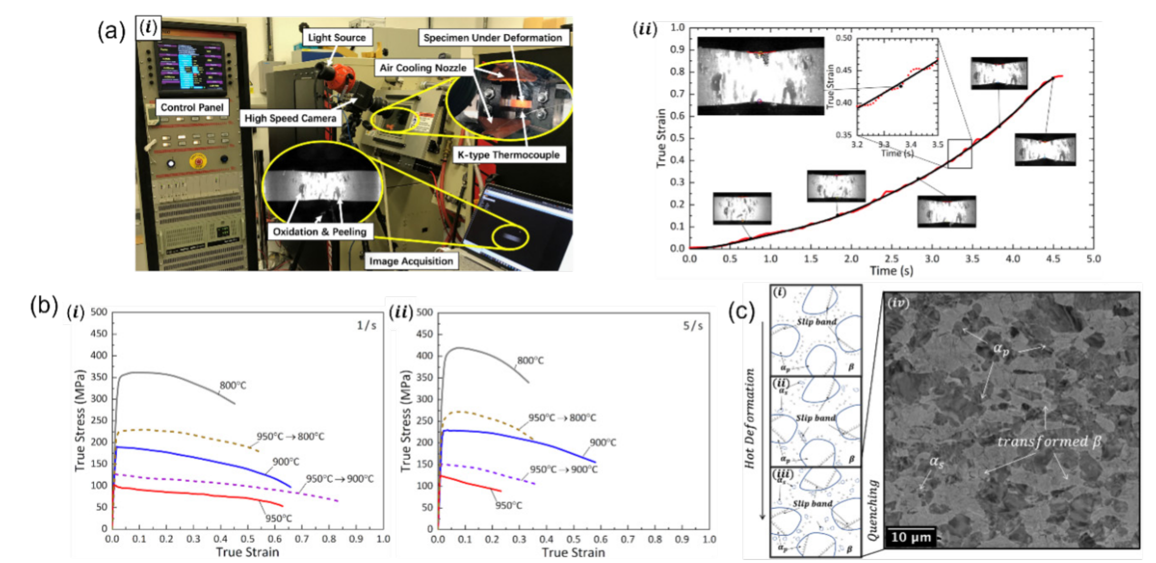


Fig. 1: Fundamental studies on the HS process: (a) uniaxial tensile testing (i) set-up on Gleeble with high-speed image acquisition and (ii) in-house image processing script for accurate strain measurement on a Ti-6Al-4V specimen with surface oxide layers peeling off; (b) flow stress curves of Ti4Al6V under different conditions; (c) schematic illustrations of (i, ii, iii), the microstructural evolution mechanisms under HS conditions and (iv) the resulting post forming microstructure.

To investigate the feasibility of implementing the novel HS process, we have developed a lab-scale in-situ HS manufacturing system (Fig. 2(a)), capable of accurately implementing the temperature profile determined from the fundamental studies. The system was composed of a rig integrating a tool set, an uniform airflow distribution subsystem, and an airflow control subsystem, which are all bespoke. In HS forming trials, a heat-treated circular blank was quickly transported from a furnace to the forming tool for controlled uniform fast quenching, and subsequently fast stamped (200 mm/s) and quenched. A deep-drawn cup (Fig. 2(b)), with a draw ratio of 1:8, was successfully produced with net shape, which proved the concept of heat stamping complex-shaped Ti-6Al-4V components.

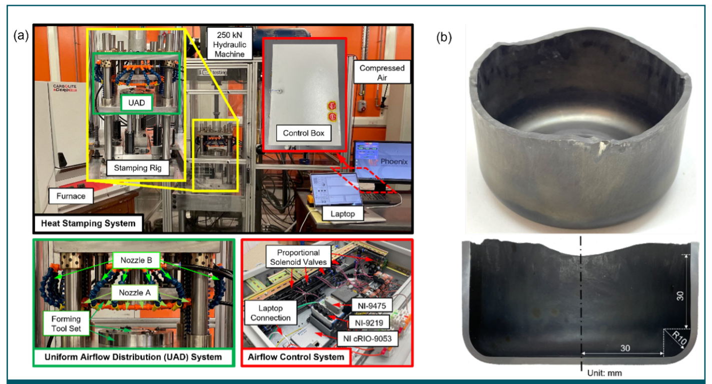


Fig. 2: A Proof-of-concept study of the HS process: (a) an in-situ HS system set on a high-rate hydraulic machine, and its bespoke fast quenching subsystems for uniform airflow distribution and airflow control; (b) an as-stamped, cylindrical-cup-shaped component (draw ratio 1.8), and its cross-section view.

Key Outputs and Impact

- A better understanding of the hot deformation mechanisms of Ti-6Al-4V at a high-rate range (i.e., ε is between 10^{-1}~10/s) and determination of the optimal HS forming window.
- Proof of concept of the novel HS process, realised by a lab-scale in-situ HS manufacturing system.
- Preliminary cost analysis enabled by the proof-of-concept study with the estimation of 88% manufacturing and tool cost reduction in certain applications.

Future Work

In the next year, we will focus on upscaling the novel Heat Stamping process for industrial implementation and applications by collaborating with potential industrial partners. We will identify industrial scale demonstrator components with aerospace manufacturer Senior Aerospace Thermal Engineering and their clients as aerospace OEM end users. We will address new challenges in large-scale productions and new research questions (e.g., stress relaxation).

Publications/Outputs

F. Tian and N. Li, Investigation of the feasibility of a novel heat stamping process for producing complex-shaped Ti-6Al-4V panel components, Procedia Manuf., vol. 47, no. 2019, pp. 1374–1380, 2020.

F. Tian, J.Lin, N. Li, Experimental study and constitutive modelling of the thermo-mechanical properties and microstructural evolution of Ti-6Al-4V under new Heat Stamping process conditions, drafted for publishing.

F. Tian and N. Li, Investigation of effects of texture and macrozone on the flow behaviours of Ti-6Al-4V under hot stamping conditions, drafted for publishing.

F. Tian and N. Li, Novel heat treating and fast stamping process for complex-shaped Ti-6Al-4V components with an in-situ manufacturing system, drafted for publishing.

Synchrotron diffraction studies of hot Ti alloy deformation

Researchers Prof. João Fonseca, Dr Christopher Daniel, Guy Bowker, Xiaohan Zeng
Project Partners Diamond Light Source and the TIFUN consortium:
Airbus, Rolls-Royce, Otto Fuchs, Safran, Aubert & Duvall and TIMET

Introduction

During hot forming, the microstructure of dual phase alloys like Ti6Al4V changes through a variety of different mechanisms including deformation, recrystallization and phase transformation. Although these mechanisms are reasonably well understood in isolation, their relative importance is difficult to determine, which thwarts our efforts to develop computational models of microstructure evolution. Conventionally, the deformed state is studied by post-mortem characterisation and interpreted in terms of the physical mechanisms. However, during hot forming, recrystallization and phase transformation happen quickly, which obscures many of the details. More importantly, post-mortem characterisation does not allow the sequence of mechanisms or their relative importance to be determined.

One of the key aims in LightForm is to improve our understanding and ability to predict the texture development during hot forming of Ti6Al4V. Although the alloy contains comparable amounts of alpha and beta phase during hot working, the beta volume fraction is very low at room temperature, making it challenging to study using electron back scatter diffraction (EBSD), for example.

Using synchrotron X-ray diffraction (SXRD), we can overcome many of these challenges. SXRD measurements are fast and therefore make it possible to study behaviour in-situ, revealing when the sequence of mechanisms is responsible for the final microstructure. They are also a better probe for beta, since information from both phases can be separated and the measurements are less affected by deformation in the material. Synchrotron diffraction can be used to measure texture, but also to measure load sharing between phases, which can be used to calibrate crystal plasticity models and reveal the onset of deformation in both phases.

Although access to synchrotron diffraction facilities was limited by COVID-19, over the past year we have been able to complete a number of key experiments at both DESY and Diamond Light Source in the UK.

A new method for measuring texture

The first set of experiments involved measuring the texture in previously rolled Ti64. Texture measurements are now usually done by EBSD. However, in deformed dual-phase Ti alloy microstructures, this method becomes more difficult, particularly for the minority beta phase that exists as very small heavily deformed grains. This means that EBSD texture measurements made on samples deformed to large strains and at higher temperatures (and higher beta volume fractions) have high levels of uncertainty. We used SXRD diffraction to measure the distributions of texture as a function of position in hot rolled material to large reductions.

In a first experiment, we used material for which EBSD also works well, so we could ensure the data analysis methods for the synchrotron data were sound. The methodology for measuring texture using 2D detector data usually involves a refinement of the structure and then fitting the ODF to the pole figures, using software like MAUD. However, we found that for this material this methodology produces erroneous textures, and instead proposed a new method, based on the Fourier series fitting of the diffraction rings. Using this method, we showed that 3 different sample orientations could be used to accurately measure the alpha and beta textures, and that qualitative measurements could be made with 2 measurement directions. Analysis revealed that when only using data from a single direction, significant texture components can be missed out, which is important for the analysis of in-situ data where only one sample direction is usually available.

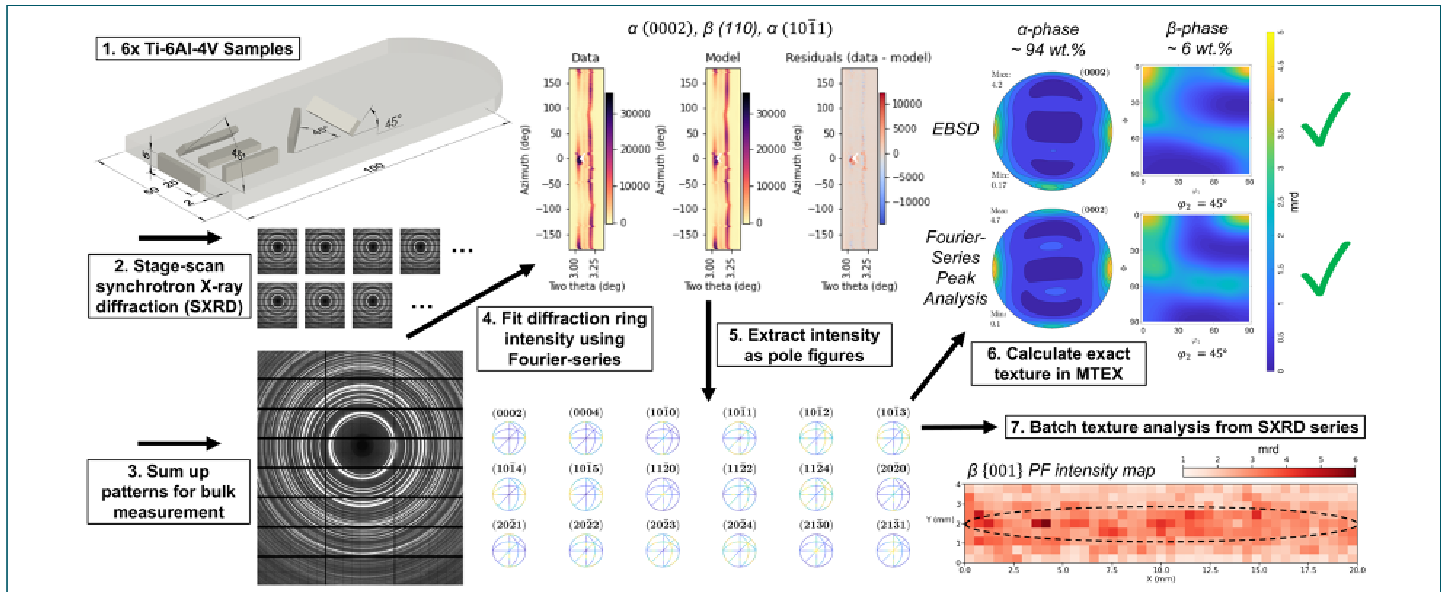


Fig. 1: Using synchrotron diffraction to measure bulk texture and microtexture in hot rolled Ti64.

The method was then used to measure the texture in samples where the beta texture was difficult to determine by EBSD. These experiments showed that the results from the beta reconstruction provided good estimates of the main components of the beta texture, although the intensities can be quite different.

By scanning the beam, we were also able to map the texture variation across the thickness of the samples, which showed very strong microtexture regions distributed throughout the microstructure as shown in Figure 1.

The first of two journal articles presenting this work is available, see output [1]. In addition, all the data and tools developed as part of this work are being shared openly on the LightForm Zenodo community.

Calibration of single crystal plasticity parameters

To develop models capable of predicting the texture evolution during hot working, it is essential to determine the flow parameters of both phases and determine how they change with strain rate and temperature. Synchrotron X-ray diffraction can be used to measure the elastic strain in both phases during deformation, and this methodology has been widely used to calibrate crystal plasticity parameters in room temperature deformation. In LightForm, we have extended this methodology to high temperature deformation. These measurements are particularly challenging, since the sample must be heated and deformed at representative strain rates of 0.1 to 1^{s-1}. In collaboration with our collaborators at I12, the JEEP beamline at Diamond Light Source, we mounted an electro-thermo mechanical testing (ETMT machine) on the synchrotron beamline, and used latest generation detectors to capture diffraction data at 100 Hz, shown in Figure 2 below. This data can then be analysed to separate the elastic response of the different phases, which in turn can be used to calibrate a crystal plasticity model. In addition to elastic strains, diffraction provides phase volume fraction, texture information and also makes it possible to detect the onset of recrystallization.

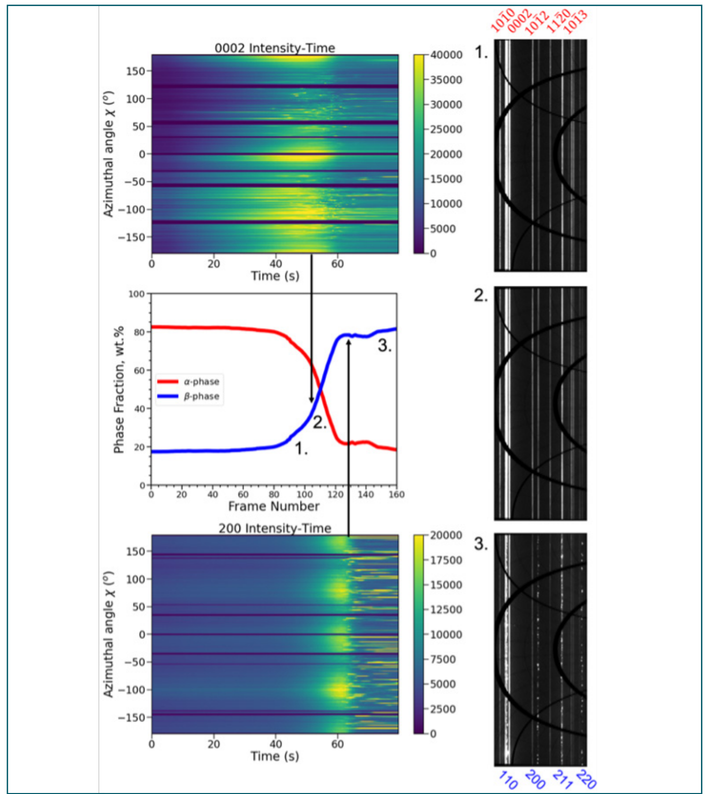


Fig. 2: Diffraction intensity profiles for both phases during heating of a hot-rolled Ti64 plate. As well as showing clear changes due to texture, recrystallization is obvious from the formation of diffraction spots on heating.

In-situ texture evolution

To study texture changes in-situ during deformation, the material needed to be tested in compression so that large strains can be reached. To carry out these experiments, we worked with scientists at the PETRA-III beamline at DESY in Germany. The beamline is equipped with a deformation dilatometer, which can deform the samples at representative strain rates to strains higher than 0.5. These experiments revealed that the texture evolution during uniaxial compression changed markedly when the temperature increased from 915°C to 950°C. This change, which is consistent with ex-situ results, happens during deformation which indicates that all changes in texture can be attributed to processes happening during deformation, after which the texture remains stable, only weakening slightly upon cooling. The biggest difference was found in the beta texture, which remains week during lower temperature deformation but strengthens appreciably at higher temperature. This is invaluable information for understanding how to model this texture change, and to develop our predictive capability for texture prediction.

Key Outputs and Impact

- Accurate measurement of beta texture in highly deformed alpha-beta rolled Ti64
- High temperature data of elastic strain partitioning for calibration of crystal plasticity models
- Evidence of recrystallization in alpha and beta phases during heating and deformation
- In-situ texture measurements reveals transition in behaviour at high beta volume fractions

Future Work

In the following year, we will continue to work to disseminate this work widely, at international conferences and through journal publications. We are carrying out EBSD measurements to support some of the incomplete texture measurement results from the DESY experiments and using our calibrated crystal plasticity models to make improved texture predictions.

Publications/Outputs

[1] Daniel, Christopher Stuart and Zeng, Xiaohan and Michalik, Stefan and Hunt, Simon A. and Quinta da Fonseca, João, A New Method for Accurate Determination of A and B Texture in Ti-6al-4v from Synchrotron Diffraction Intensities. Preprint http://dx.doi.org/10.2139/ssrn.4328082

[2] Daniel, Christopher Stuart, Zeng, Xiaohan, Hunt, Simon, Quinta da Fonseca, João, Synchrotron X-ray Diffraction Analysis - Measuring Bulk Crystallographic Texture from Differently-Orientated Ti-6Al-4V Samples, (2022). https://doi.org/10.5281/zenodo.7311323.

Dynamic Precipitation in Aluminium Alloys

Researchers Prof. Joseph Robson, Prof. João Fonseca, Dr Pratheek Shanthraj, Dr Madeleine Bignon (PDRA 100%), Ziyu Ma (PhD student 100%)
Project Partners Project partners: Constellium (£55k).

Introduction

Precipitation is exploited to achieve good mechanical properties in aluminium alloys. The nucleation and growth of strengthening precipitates usually occur during a static heat treatment that does not involve any deformation. On the other hand, it is well-known that deformation significantly accelerates precipitation. Therefore, ageing during deformation appears as a promising route to reduce the heat treatment duration. Furthermore, it may allow the development of novel precipitate distributions that gives desirable property combinations not possible to achieve by heat treatment alone. Finally, in a real warm formed part there will be variations in the local strain and temperature history. This will lead to differences in dynamic precipitate evolution that are either be undesirable or may be usefully exploited to improve formability or boost final properties.

This work has used a combination of novel in-situ dynamic precipitation experiments and coupled microstructure/crystal plasticity modelling to understand, quantify, and predict dynamic precipitate evolution in age hardenable aluminium alloys. The work has been applied to a test-case of AA7075, a high strength aluminium alloy of interest for lightweight automotive sheet applications, but the fundamental understanding and theory developed has applications to all age hardenable aluminium alloys.

Experimental Study

Dynamic precipitation has been studied in-situ using a thermo-mechanical tester (ETMT) installed on the I12 beamline at the UK Diamond Lightsource synchrotron X-ray facility (Fig. 1(a)). This high-flux beamline enables much thicker specimens than usually possible for small angle X-ray scattering (SAXS), up to 1.5mm in thickness. This, in turn, enables uniform strains in excess of 10% to be achieved at a range of strain rates. Combined with rapid SAXS pattern acquisition we have been able to track dynamic precipitate evolution at strain rates up to $2 \times 10^{-3} s^{-1}$.

The results have confirmed the strong accelerating effect of deformation on precipitate evolution (e.g. Fig 2(b)). These results are consistent with a model for deformation enhancement based on excess vacancies introduced by jogs being dragged by moving dislocations (Fig. 2(c)). These experiments provide the most comprehensive dataset to date on dynamic effects in aluminium alloys as a function of temperature and strain rate.

In addition, in these experiments, tracking of the precipitate evolution was maintained even after deformation was complete. This enables the decay of the deformation enhancement effect to be studied. This demonstrates that most of the direct effect of deformation on accelerated precipitation kinetics is lost quite rapidly at warm forming temperatures (within a few minutes, Fig 1(d)). These experiments are also consistent with the annihilation of excess vacancies and provide a measure of the effective activation energy for the vacancy diffusion process. This is an essential input parameter to the models under development.

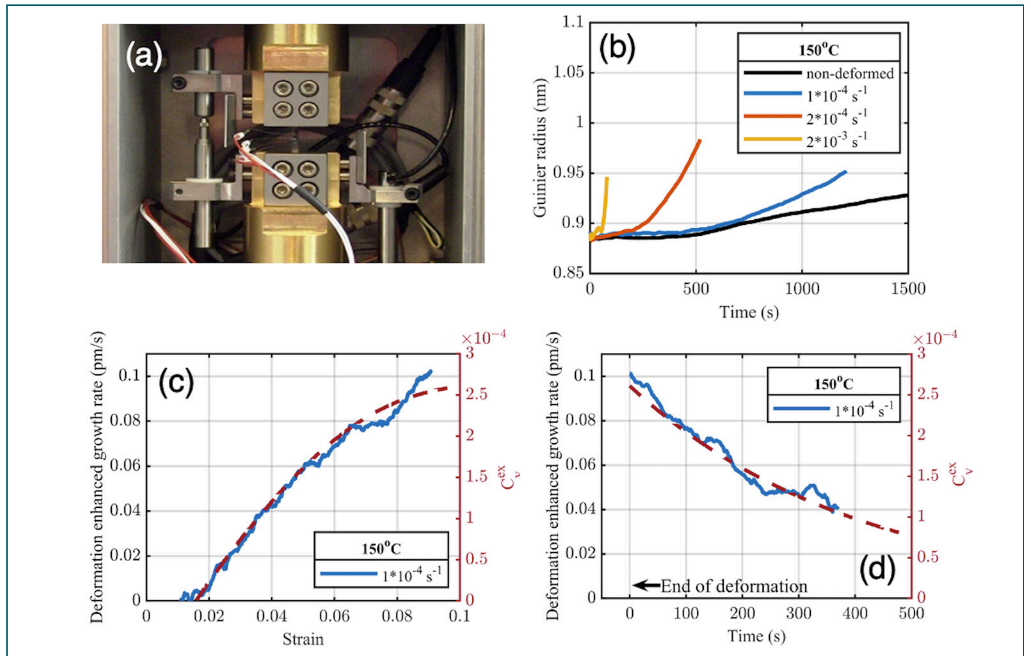


Fig. 1: (a) Dynamic precipitation experimental set up in the beam-line. (b) Measured evolution of precipitate size for different strain rates (150oC). (c) Measured increase in precipitate growth rate with strain (solid) and expected from excess vacancy effect (dashed) for an example condition. (d) Measured decay in deformation enhanced growth rate after deformation stops.

Modelling and Simulation

To predict and exploit dynamic effects, especially in a real complex formed part, requires the development and application of suitable models. We have developed physics-based models for dynamic precipitation based on the Kampmann and Wagner Numerical (KWN) method. This model allows precipitate evolution to be predicted for a given initial microstructure, strain, strain-rate, and temperature history.

The KWN model has now been incorporated into a crystal plasticity framework (DAMASK) with two-way coupling. The crystal plasticity model enables the true local strain and strain-rate to be predicted on the microstructural scale. Thus, the effect of the local heterogeneity in deformation, which is influenced by factors such as texture and grain shape, can be explored. In turn, this heterogeneity in deformation leads to a heterogeneity in local precipitate evolution. An example of such a simulation is shown in Figure 2.

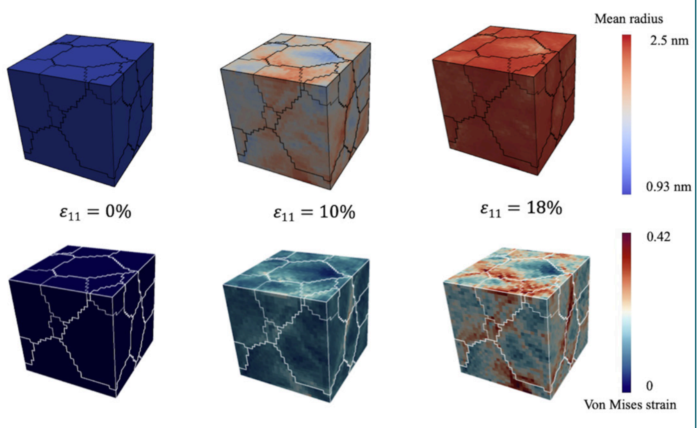


Fig. 2: Predicted heterogeneous evolution of precipitate mean radius with strain (top), which is itself a result of heterogeneity in the distribution of deformation (bottom), using the coupled KWN-DAMASK model developed in LightForm.

With such a model, the effect of microstructure and texture on dynamic precipitate evolution can be studied. For example, we can compare the variation of precipitate evolution within a grain to that predicted between grains (Fig. 3). This demonstrates that in-grain variation can be greater than grain-to-grain differences. The model also reveals details of the complex feedback mechanisms that operate in dynamically deformed material – for example, there is a compensation effect whereby the precipitate distribution becomes more and then less heterogeneous with straining as regions where localization starts harden more, leading to a spreading of deformation and enhanced precipitation kinetics to other regions.

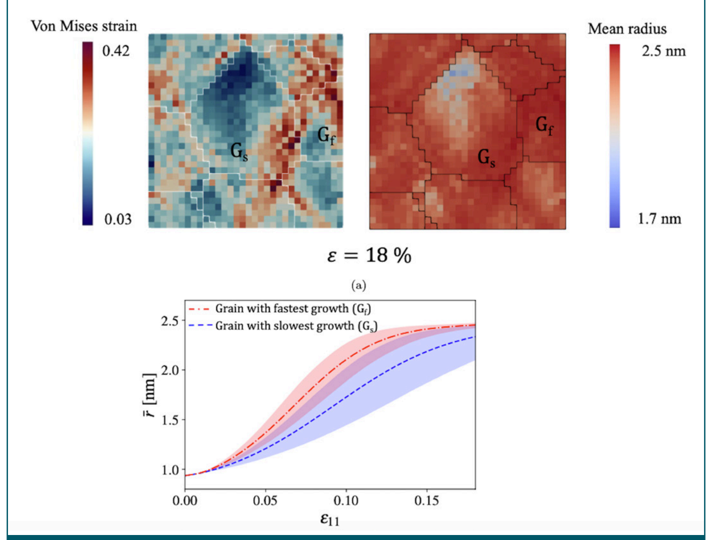


Fig. 3: Heterogeneous distribution of strain and mean precipitate radius, focussing on one grain and its neighbourhood (top). Graph showing the evolution of mean precipitate radius comparing grains with the fastest and slowest growth – the bands show the variation within each grain. The variation within a grain can be larger than the maximum grain-to-grain difference (bottom)

Key Outputs and Impact

- Confirmation and quantification of the strong effect that deformation has on accelerating precipitation in aluminium alloys.
- Evidence to support the excess vacancy theory in explaining the dynamic enhancement of precipitation.
- The first coupled crystal plasticity-dynamic precipitation model that allows prediction of the effect of microstructural heterogeneity and texture on dynamic precipitation.

Future Work

In the next year, we will use the data from the in-situ experimentation to refine our models. The model will then be applied to predict dynamic precipitation in a formed part, coupling the local crystal plasticity model to a component scale finite element simulation. The effect of post-deformation ageing on the evolution of dynamically formed precipitates will also be explored in more detail.

Publications/Outputs

[1] M. Bignon, P. Shanthraj, J. D. Robson, Modelling dynamic precipitation in pre-aged aluminium alloys under warm forming conditions, Acta Materialia, 234, 2022, 118036, https://doi.org/10.1016/j.actamat.2022.118036.

[2] W.U. Mirihanage, J.D. Robson, S. Mishra, P. Hidalgo-Manrique, J. Quinta da Fonseca, C.S. Daniel, P.B. Prangnell, S. Michalik, O.V. 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.

[3] J.D. Robson, Deformation Enhanced Diffusion in Aluminium Alloys.Metall Mater Trans A 51, 5401–5413, 2020. https://doi-org.manchester.idm.oclc.org/10.1007/s11661-020-05960-5.

[4] KWN deformation model https://github.com/LightForm-group/KWN-deformation

[5] Modelling dynamic precipitation datasets https://zenodo.org/record/6090249#.Y5GtfC-l3IE

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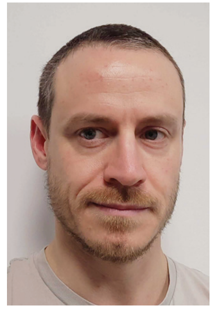

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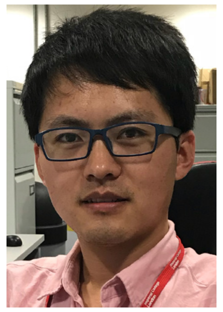

LIGHTFORM PROJECTS

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

26 Biaxial testing and modelling for Al- Warm forming conditions

27 Microstructure and damage evolution of deformed recycled Al alloys

Titanium

28 Microstructure evolution during forging high performance Ti aerospace alloys

29 The texture of hot formed Ti alloys

30 The effect of microstructure on the ductility of Ti alloys

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

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

33 Modelling the microstructure evolution during hot working of Ti alloys

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

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

36 LightForm micromechanics of deformation (In situ)

37 Digital Twin of abnormally coarse grain structures in critical titanium forgings for military aircraft applications

38 Advanced characterisation of deformation micromechanics and failure initiation in Ti alloys

39 Microstructure and texture development during hot forming of titanium alloys

40 Modelling microstructure evolution during forming

41 High throughput texture measurement in titanium alloys

Other Projects

42 Deformation behaviour of magnesium alloys studied using digital image correlation

43 Dynamic strengthening of magnesium alloys

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

45 LightForm computational modelling of formability

46 Reproducibility and data management

47 Modelling environmentally assisted cracking in Ni-based superalloys

48 Development of microstructural simulation tools for fusion materials

49 Microstructure informed forming modelling -Ti, Al, modelling

50 Microstructure modelling

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