MAPP

Manufacture using Advanced Powder Processes
EPSRC Future Manufacturing Hub

Annual Report | 2024

UKRI Engineering and Physical Sciences Research Council

Location of Mapp Project Partners

University of Sheffield | University of Cambridge | Imperial College London | University of Leeds | Manchester 1824 The University of Manchester | University of Oxford | UCL

MAPP TIMELINE

Founding Partners

University of Sheffield

Imperial College London

MANCHESTER 1824
The University of Manchester

UNIVERSITY OF LEEDS

UNIVERSITY OF OXFORD

2016

In 2016, MAPP's vision was to deliver on the promise of powder-based manufacturing processes to provide low energy, low cost, and low waste high value manufacturing routes and products to secure UK manufacturing productivity and growth. To do this, MAPP will pull together a complementary and interdisciplinary team of leading UK researchers to recouple manufacturing process development with the underpinning materials science in a research programme that spans the fundamentals of powder materials, advanced in-situ process monitoring and characterisation, and new approaches to modelling and control.

2017

Industry Partner Workshop
(June 2017).

2018

MAPP First International Conference
(Jan 2018).

MAPP AAMS (Sept 2018).

Partner Joined

UCL

2019

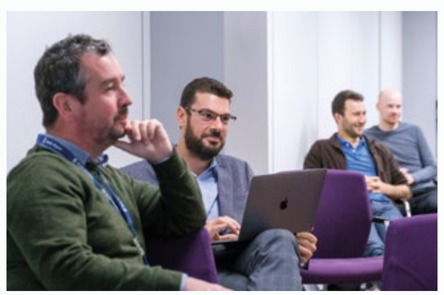
Industry Partner Briefing Day
(April 2019).

2020

Covid-19 pandemic.

MAPP Virtual Poster Day
(July 2020).

2021



First Joint CAM² Workshop
(October 2021).

Partner Joined

UNIVERSITY OF CAMBRIDGE

2022

Second Joint CAM² Workshop
(Oct 2022).

2023

MAPP Second International Conference
(June 2023).

2024

Over its duration, MAPP has delivered on its vision, creating a critical mass of intellectual effort and leading infrastructure and acting as an international focal point for research, development, innovation and training on advanced powder processes. It has drawn together industrial, academic, and innovation communities to deliver the maximum academic, technological, societal, and economic impact for the UK in the advanced powder processing field. MAPP has attracted more than £30 million aligned and leveraged income from across Industry and Academia and published around 200 international journal papers.

CONTENTS

WELCOME

Welcome to the seventh and final MAPP Annual Report.

Professor Iain Todd
MAPP Director

Throughout 2023, MAPP continued to deliver impactful research in its platform and cross-cutting themes. The EPSRC has granted MAPP a nine month no-cost extension and the hub will now complete at the end of June 2024. This final annual report presents a series of case studies that span the MAPP platform and cross-cutting themes and highlights the wide range of engagement activities that our colleagues have attended.

Over the course of last year, members of MAPP took part in a wide range of engagement activities and these are summarised later in this report (pages 42 and 43). On 28th and 29th June, MAPP held its second International Conference at the Novotel Hotel in Sheffield. The event highlighted, shared and celebrated the breadth and diversity of research we have undertaken, bringing together industrial and academic experts from across this interdisciplinary field. An article by Rachel Park reviews the conference on pages 28 and 29.

Our Quarterly Review Meeting (QRM) in March was held at The Edge in Sheffield. Research updates were presented by the MAPP ECR's and an interactive poster session was held. There was also an opportunity for those who had not yet visited to tour the facilities at the Royce Discovery Centre (RDC) and Royce Translational Centre (RTC) in Sheffield. In October the MAPP QRM was hosted by Imperial at 170 Queen's Gate, South Kensington. In addition to our theme updates, we incorporated three invited talks: Prof. Richard Todd from the University of Oxford presented "Accelerated sintering of ceramics through rapid heating: evidence, mechanisms and prospects". Angus Baker from the Royal Academy of Engineering presented "How to commercialise research through a spinout company" and Henry Saunders from the University of Sheffield presented his team's Commercialisation Journey towards becoming a spinout company.

When MAPP was launched in 2016 we set out our key performance indicators (KPI's), some of which are summarised on page 7. In most cases these have met or exceeded the initial expectations and this has been one way that demonstrates how the hub has made significant impacts across all aspects of research; from industrial collaboration and funding to Outreach events with local schools. We continue to publish MAPP research in leading international journals and have already published around 200 papers. Details of the journal papers in MAPP are given in this report with their doi link. We have also included summaries of the MAPP/aligned PhD's and project researchers that have joined MAPP since its launch (pages 54 to 57) across the partner universities.

Finally, thank you to everyone in MAPP, past and present, for what has been a very successful and wide-ranging partnership. I wish you every success in your next endeavours.

Prof. Iain Todd. MAPP Director

ACHIEVEMENTS 2017 – 2024

MAPP's collaborative and interdisciplinary research and innovation programme continues to deliver on the new and fundamental understanding of powder-based manufacturing processes.

The academic, industrial and innovation partners have continued to drive the hub's research which is needed to solve many of the challenges hindering the commercialisation of powder-based processes. A number of key outputs have been achieved over the past seven years including:

- *In situ* research on Laser Powder Bed Fusion that paves the way for using synchrotron-calibrated digital twins for process prediction and suggests new ways to improve process reliability.
- The creation of a second generation Blown-powder Additive Manufacturing Process Replicator, BAMPR-II, as a physical twin to provide deeper insights and process optimisation of key new alloys being used for repair applications in aerospace.
- Demonstration of calibrated closed-loop control in reducing the effects that geometry can have on mechanical behaviour in Directed Energy Deposition (DED).
- Research and publications on understanding the role of additive manufacturing in the development of astronomical hardware.
- The feasibility of using Field Assisted Sintering Technology (FAST) to consolidate powder of a Nb-silicide based alloy for high temperature aerospace applications.
- Techniques developed using calibrated closed-loop monitoring and control of the Directed Energy Deposition process to achieve geometry-agnostic builds with more repeatable mechanical properties.
- Recommendation that a Spreadability Index is measured as a new property for Metal Powders used in Additive Manufacturing applications.
- Useful insights into the Hot Isostatic Pressing (HIPing) process of a novel Ti-Fe binary alloy via in-situ mimic HIPing experiments under synchrotron X-ray. For the first time, the whole densification process has been recorded by X-ray imaging.
- The extension of robocasting to the fabrication of ceramic composites and glasses.
- Work that opens new opportunities for the extension of digital light processing to non-oxide ceramics.
- Characterising a library of powders at the individual and bulk level.
- Methods to coat stainless steel powders to prevent oxidation.
- Using Field Assisted Sintering Technology (FAST) to optimise and improve process control.
- Developing deep-learning algorithms to enable rapid process parameter development, monitoring components as they are manufactured to enable 'right first time' manufacturing.
- The most in-depth understanding to date of porosity and pore formation as a result of varying levels of energy input in High Speed Sintering (HSS).
- New understanding in process models through the development of a laser powder bed Additive Manufacturing (AM) replicator, a Directed Energy Deposition (DED) replicator and an in-situ synchrotron rig for investigating the FAST process.
- Use of machine learning to develop data driven approaches to predict printability in AM.

Some of our research has progressed more quickly through additional links with our aligned projects (you can find out more about these on pages 58 to 63), and we continue to successfully leverage funding to enable us to retain key skills and build a broader team.

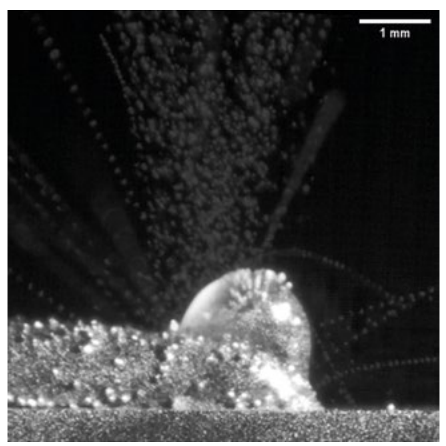
We are a hub that sets the research agenda in emerging technology areas including artificial intelligence (AI) in AM, in-situ and in-operando monitoring of advanced powder processes and processing and fundamentals relating to ceramics and multi-material.

Our leadership of the national agenda is highlighted by:

- In September 2023, Professor Iain Todd was elected into the Royal Academy of Engineers in recognition of his outstanding contribution to engineering and technology and, in December 2023, he was awarded the IOM3 Gold medal in recognition of his significant contribution to a field of interest within the materials, minerals or mining sector
- Professor Iain Todd continues to lead the Materials Made Smarter Centre (MMSC), launched in 2021.
- MAPP continues with close involvement with the Henry Royce Institute agenda in Materials 4.0.
- Our partnerships with Catapults.
- Our partnerships with UKRI Critical Mass Activities.
- MAPP Executive member Professor Visakan Kadirkamanathan appointed as the Chair of the UK Automatic Control Council.

Throughout its duration, MAPP has collaborated with over 120 industrial companies (these are listed on pages 30 to 31) in both the UK and internationally, and we have continued to engage with academia through conferences, workshops, MAPP lectures and feasibility studies. The MAPP Second International Conference was held at the Novotel Hotel in Sheffield on 28th and 29th June 2023 and an article has been written by Rachel Park on pages 28 and 29. A series of talks on five key themes of MAPP were presented by the PI's and Researchers. These were complemented with three sessions from invited speakers in Academia and Industry presenting their work in the field of advanced powder processing. A flash presentation competition was held for 19 Early Career Researchers (ECR's) to showcase their research with the winners in each category announced at the conference and listed on page 29.

Our researchers have continued to support our online, in-person and hybrid events as well as deliver on our research programme. This year we saw another large annual increase in MAPP and MAPP-aligned PhD students completing their theses. A number of MAPP researchers have also moved on to more senior academic posts and positions within industry (more detail can be found on pages 54 to 57).



DED in progress
A runner up photograph in the MAPP 2023 Image Competition was taken by Harry Chapman, University College London. This image was captured using a FASTCAM Nova S12, a Cavilux Illumination Laser, and a 480 nm light filter. This is an average pixel value plot over the course of 0.01 seconds, with contrast normalised and equalised. The image depicts a weld bead with powder being injected into it in the Directed Energy Deposition (DED) process and some powder rebounding off the weld track.

A number of MAPP researchers have moved to new positions in 2023, including:

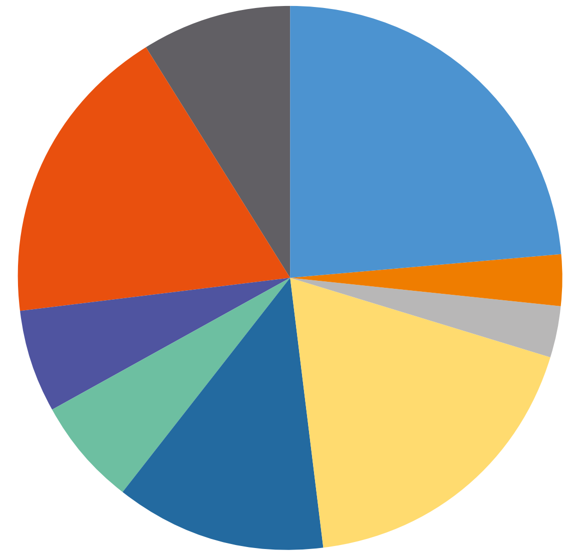
- MAPP Post-Doctoral Research Associate (PDRA) at Sheffield, Dr Felicity Freeman, is now a Lecturer in the Department of Mechanical, Aerospace and Civil and Structural Engineering at the University of Sheffield.
- MAPP PDRA at Sheffield University, Dr Simon Graham, has taken up a new role as a Senior Materials Engineer at BAE Systems – Air.
- MAPP-aligned PDRA at Sheffield, Dr Bo Luo, has taken up a new role at Vulcan.

Seventeen PhD researchers successfully received their doctorates in 2023/2024, these included:

- MAPP PhD's at Sheffield; Dr Alex Goodall and Dr Cameron Barrie
- MAPP-aligned PhD's at Sheffield; Dr Adam Gothorp, Dr Elaine Livera, Dr George Maddison, Dr Halil Emre Caglar, Dr James Pepper, Dr Kubra Genc, Dr Mohamed Atwya, Dr Mohammed Alsaddah, Dr Muhammed Aftab and Dr Sarath Veetil.
- MAPP-aligned PhD at Imperial College London; Dr Max Chester Jude Emmanuel.
- MAPP-aligned PhD at Manchester; Dr Jiaqi Xu
- MAPP-aligned PhD's at UCL; Dr Alisha Bhatt, Dr Caterina Iantaffi and Dr Xianqiang Fan

Our colleagues have taken part in a wide range of leading conferences and public engagement events both online and in person. You can read more about some of these activities on pages 42 and 43.

COMPONENTS OF MAPP'S FUNDING PORTFOLIO



- **Core EPSRC grant** £10,724,131
- **EU** £1,411,473
- **Facilities** £1,380,000
- **EPSRC** £8,261,223
- **IUK (inc ATI)** £5,653,700
- **RAEng** £2,887,000
- **Other** £2,762,143
- **Industry*** £8,155,330
- **Universities**** £3,912,500

SOME OF MAPP'S KEY PERFORMANCE INDICATORS

195 International Journal publications

£30.510M Aligned and leveraged income (from Industry and Academia)

11.376 Average Impact Factor^

310 Conference presentations including 103 keynote/invited talks

>125 Industrial collaborators across MAPP

52 Schools and over 1500 pupils engaged in Outreach events

>1250 Delegates at MAPP events (Industry and non-MAPP Academic)

46 MAPP and MAPP Aligned PhD's Completed (2018 to 2023)

^ The average journal Impact Factor is based on value from Academic Accelerator in 2023

* Industry funding includes direct and indirect (in-kind) contributions

** University funding includes the total support from offer letters

MAPP PROJECT
ORGANISATION CHART

Industrial Advisory Board

MAPP Director
Prof. Iain Todd

Scientific Advisory Board

MAPP Operations Team

Powders and Process by Design

P2.1
Metal AM

P2.2
Solid State Processing

P2.3
Future ManufacturingPlatforms

P2.1a
Laser Powder Bed Fusion
Co-Leads
Prof. Andrew Bayly, University of Leeds and Prof. Iain Todd, University of Sheffield

P2.2a
FAST/SPS/HIP
Co-Leads
Prof. John Francis, University of Manchester and Prof. Martin Jackson, University of Sheffield

P2.3a
Diode Area Melting
Lead
Dr Kamran Mumtaz, University of Sheffield

P2.1b
Directed Energy Deposition
Lead
Prof. Iain Todd, University of Sheffield

P2.2b Fundamentals of Solid State Processing
Co-Leads
Dr Enzo Liotti, University of Oxford and Prof. Martin Jackson, University of Sheffield

P2.3b
High Speed Sintering and Polymer AM
Lead
Dr Candice Majewski, University of Sheffield

P2.3c
Ceramics
Lead
Prof. Eduardo Saiz, Imperial College London

X1 *In-situ* Process Monitoring
Lead Prof. Peter Lee, University College London

Co-Investigators

- Prof. John Francis, University of Manchester
- Dr Finn Giuliani, Imperial College London
- Prof. Patrick Grant, University of Oxford
- Dr Chu Lun Alex Leung, University College London
- Prof. Iain Todd, University of Sheffield

X2 Advanced Characterisation
Lead Prof. Philip Withers, University of Manchester

Co-Investigators

- Prof. Andrew Bayly, University of Leeds
- Prof. John Francis, University of Manchester
- Dr Finn Giuliani, Imperial College London
- Dr Candice Majewski, University of Sheffield
- Prof. Mark Rainforth, University of Sheffield

X3 Modelling, Optimisation and Control
Co-Leads Prof. Visakan Kadirkamanathan and Prof. George Panoutsos, University of Sheffield

Co-Investigators

- Prof. Andrew Bayly, University of Leeds
- Assoc. Prof. Ali Hassanpour, University of Leeds
- Prof. Philip Prangnell, University of Manchester
- Prof. Phillip Stanley-Marbell, University of Cambridge

Co-Investigators in Powders and Process by Design

- Dr Finn Giuliani, Imperial College London
- Prof. Patrick Grant, University of Oxford
- Dr Kristian Groom, University of Sheffield
- Assoc. Prof. Ali Hassanpour, University of Leeds
- Prof. Philip Prangnell, University of Manchester
- Dr Jon Willmott, University of Sheffield

University Partners

University of Sheffield · University of Cambridge · Imperial College London · University of Leeds · Manchester 1824 The University of Manchester · University of Oxford · UCL

RESEARCH PROGRAMME

SUMMARY

P2.1 ADDITIVE MANUFACTURING

(Sheffield)

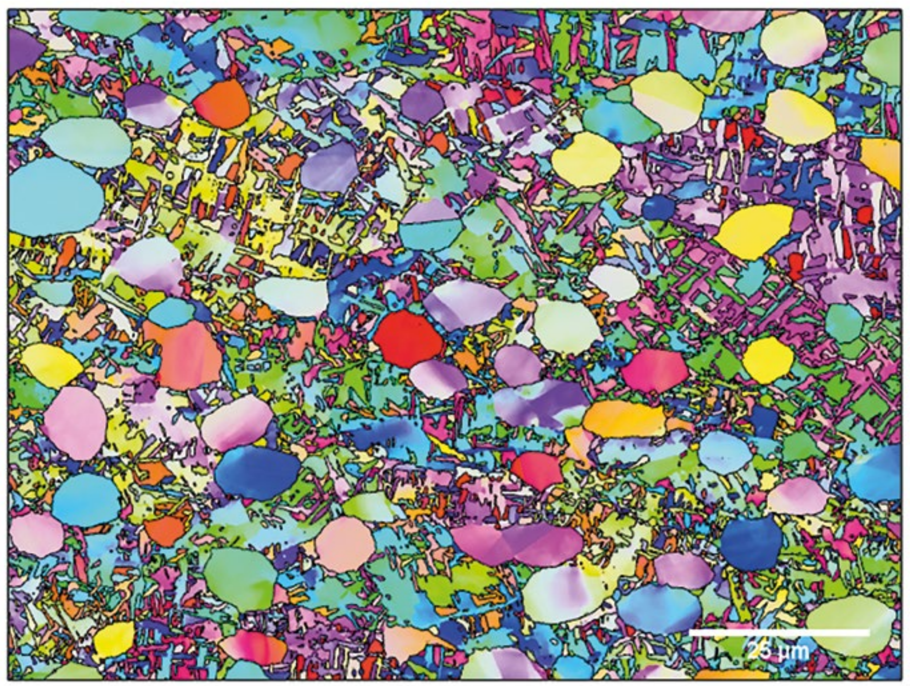
Investigator; Prof. Iain Todd

Researchers: Dr Sam Tammas-Williams, Dr Ben Thomas, Dr Rob Snell, Dr Christopher Smith, Dr Jo Sharp, Dr Minh Phan, Dr Phillip Mahoney, Dr Elaine Livera, Dr Everth Hernandez-Nava, Dr Oliver Hatt, Dr Felicity Freeman

Over the course of MAPP, work at Sheffield in theme P2.1 has explored an extensive array of novel, cutting edge research in the field of Additive Manufacturing including:

- Process Definition and Control in Laser Powder Bed Fusion (LPBF).
- Process Definition and Control in Directed Energy Deposition (DED).
- *In-situ* thermal imaging combined and correlated with microscopy and X-Ray Computed Tomography (XCT).
- Deep learning control for LPBF.
- Understanding scalability and design of experiment (DoE) methodologies for DED.
- Closed loop process control in DED.
- Powder flow rate in DED systems.
- Digitisation of Powder Manufacturing (a Henry Royce Institute - Materials 4.0 feasibility project).
- Predictive process diagram for LPBF parameter selection to achieve high-density and low-cracking built parts
- SmartSlicer - Predictive LPBF strategy optimisation software.
- Research to maximise the potential of AM for use in telescopes, optics and astronomical devices.

More information on these research topics is given in MAPP reports 2018 to 2023, copies of which are available from the MAPP website (link to MAPP Website at end of this section). Two case studies on aspects of the research in P2.1 are included on pages 13 to 15 of this report.



FAST-*roll* Ti-64 EBSD
An entry in the MAPP 2023 Image Competition was taken by Dr Sam Lister, University of Sheffield. EBSD crystallographic orientation map of Ti-64 produced from powder using Field Assisted Sintering Technology and hot-rolled at the Royce Discovery Centre, Sheffield. Scale bar = 25 microns.

P2.2 SOLID STATE PROCESSING

Solid-state processing of metal powders (Sheffield)

Investigator; Prof. Martin Jackson

Researchers; Dr Nick Weston, Dr Ben Thomas, Dr James Pepper, Dr Simon Graham, Dr Oliver Levano Blanch

Research into solid-state processing of metal powders at Sheffield has developed considerably over the course of MAPP, with successful outputs and case studies, many of which are described in the MAPP 2023 report. Research centred on the use of Field Assisted Sintering Technology (FAST) at Sheffield is summarised in the article on pages 16 and 17 of this report.

Solid-state joining of dissimilar metal powders (Manchester)

Investigator; Prof. John Francis

Researchers; Dr Rahul Unnikrishnan, Dr Sandeep Irukuvarghula

The Manchester-led MAPP team have investigated the use of solid-state processes involving powders to create welds between type 316L austenitic stainless steel and SA508 Grade 3 pressure vessel steel, a common dissimilar weld that is found in the primary loop of a pressurised water reactor. Solid state processes, such as hot isostatic pressing (HIP), field assisted sintering (FAST), and powder interlayer bonding (PIB), have been explored. A case study on the work carried out at Manchester has been included on page 18 of this report.

New applications for powder-based manufacturing and Field Assisted Sintering Technology (Oxford)

Investigator; Dr Enzo Liotti

Researchers; Dr Yun Deng, Dr Wen Cui

Research at Oxford focused on exploring innovative applications of (FAST) to address unresolved manufacturing challenges related to joining dissimilar metals and creating multi-material components. The research focused on developing a FAST-based process to sinter millimeter-scale tungsten coatings on bulk steel substrates for plasma-facing structural components in nuclear fusion reactors. Several methods to lower the sintering temperature and shorten the sintering time were investigated. Sculptured patterns designed on the substrate and the use of functionally graded material approaches were used to fabricate thick tungsten coatings (4mm) on martensitic steel and Eurofer 97 steel substrates. Other branches of research explored the 3D printing of sacrificial moulds to design non-symmetrical geometries, and functionally graded approaches for multi-materials manufacturing. A case study on the work carried out at Oxford is on the MAPP website (link to MAPP website at the end of this section).

P2.3 FUTURE MANUFACTURING PLATFORMS

P2.3a Diode Area Melting (DAM) (Sheffield)

Investigators; Dr Kamran Mumtaz, Dr Kristian Groom

Researchers; Dr Zhuoqun Zhang, Dr Zicheng Zhu, Dr Anqi Liang, Dr Ashfaq Khan, Dr Ryan Brown

MAPP supported research on the Diode Area Melting (DAM) process has sought to overcome the challenge of limited productivity and thermal control within current Laser Powder Bed Fusion (LPBF) additive manufacturing approaches. A DAM system has been developed with over a thousand 450 nm laser arrays (32 x 32 lasers) that enable simultaneous parallel scanning across a build area coupled with improved thermal control through the strategic use of the laser arrays (activation patterns) in pre- and post-heating the powder/melt-pool. Recent work has shown further efficiency gains with the use of low power blue laser sources. A case study on the work carried out in P2.3a is written on pages 19 and 20 of this report.

P2.3b High Speed Sintering and Polymer AM (Sheffield)

Investigator; Dr Candice Majewski

Researchers; Dr Alec Shackleford, Dr Ryan Brown

Since the start of the MAPP programme, research into Powdered-polymer Additive Manufacturing (AM) processes, including Selective Laser Sintering and High Speed Sintering, has led to developments in several key areas: Modelling work with MAPP cross-cutting theme X3 has used machine learning techniques to optimise process settings, developing a thermal model of the High Speed Sintering process to understand the effects of material characteristics on their processability. Experimental work with MAPP cross-cutting theme X2 has used advanced scanning techniques to understand the effects of processing parameters on the development of porosity within AM parts and the first ever use of Positron Annihilation Lifetime Spectroscopy to identify nano-scale structural changes at the surface of powdered-polymer AM parts. Other highlights of the MAPP research in P2.3b include; the effects of ultraviolet ageing on the aesthetic and mechanical properties of parts, successful demonstration of the inclusion of anti-bacterial properties into AM parts, and an understanding of tribological properties and ways in which they can be controlled. More information on this research is given in MAPP reports available from the MAPP website (link to MAPP Website at end of this section).

P2.3c Ceramics (Imperial College London (ICL))

Investigators; Prof. Luc Vandeperre, Prof. Eduardo Saiz, Dr Finn Giuliani,

Researchers; Dr Siyan Wang, Dr Iuliia Tirichenko née Elizarova, Dr Erik Poloni, Dr Rohit Malik, Dr Oriol Gavalda Diaz

Throughout MAPP, a wide range of research has been conducted in P2.3c at ICL, including:

- The robocasting of technical ceramics and composites.
- Selective Laser Sintering (SLS) of ceramics and glasses.
- Digital light processing of alumina-based oxide ceramic matrix composites.
- Embedded printing and co-extrusion of composites.
- The use of a novel sintering additive, reduced Graphine Oxide (rGO) to increase the efficiency of laser-based processes.
- *In-situ*, advanced-microscopy assisted mechanical testing of ceramics to understand failure mechanisms of functional materials.
- Collaboration with UCL on advanced in-situ characterisation of additively manufactured ceramics.
- Collaboration with Manchester on X-ray Tomography (XCT) of microchannel arrays and spirals in alumina.

Many of the successful outputs from P2.3c are described in the MAPP 2023 report. Comprehensive case studies on the ceramics research are included on pages 21 and 22 of this report and on the MAPP website (link to MAPP Website at end of this section).

X1 IN-SITU PROCESS MONITORING

(University College London (UCL))

Investigators; Prof. Peter D. Lee, Dr C.L. Alex Leung

Researchers; Dr Kai Zhang, Dr Fan Xianqiang, Dr Anatassia Milleret, Dr Wei Li, Dr C. L. Alex Leung, Dr Yuze Huang, Dr Da Guo, Dr Samy Hocine, Dr Sam Clark, Dr Yunhui Chen, Dr Ratul Biswas, Dr Shishira Bhagavath

The research focus in X1 has developed unique physical twins of powder processing and component performance that can be probed on synchrotron beamlines to calibrate process digital twins. These physical twins have provided new insights into how to improve the processes and, through machine learning, developed low-cost monitoring and control systems. The physical twins have been applied to new materials, ranging from moon rock (Regolith) to reduced graphene oxide (rGO) printability additives, and to new processes such as magnetic field flow control. Two main streams have been explored for synchrotron process calibration, Laser Powder Bed Fusion (LPBF) and blown-powder Directed Energy Deposition Additive Manufacturing (DED-AM). Articles summarising the research at UCL have been included in previous MAPP annual reports. Several detailed case studies from UCL have been written and these are included on pages 23 and 24 of this report and on the MAPP website (link to MAPP Website at end of this section).

X2 ADVANCED CHARACTERISATION

Powder spreadability, Powder Descriptors (P1.1) and Heterogeneous Powders (P1.3) (Leeds)

Investigators; Prof. Andrew Bayly, Prof. Ali Hassanpour, Dr Andrew Mullis

Researchers; Dr Tushar Srivastava, Dr Mozhdeh Mehrabi, Dr Ye He, Dr Jabbar Gardy, Dr Timothy Bigg

A project at Leeds has studied the complex dynamics involved in droplet-particle (D-P) collisions that contribute to the agglomeration process during the manufacture of metal powders. A universal model has been created that will enable scientists to predict agglomeration regimes while manufacturing powders through atomisation. The results are expected to have significant impact in chemical, food, pharmaceutical, as well as AM industries. The University of Leeds has also gained a thorough insight into the principles of powder spreading in additive manufacturing (AM) and its relationship with the bulk flow behaviour and characteristics of single particles through: A direct assessment

MAPP CASE STUDIES

of powder spreading using an in-house spreading rig. Utilisation of flowability measurement techniques to assess the powder flowability across a diverse range of powders intended those for EBM, DED, and LPBF processes. Using X-ray micro-tomography to investigate the packing behaviour of metal powders during in-situ ball indentation processes at the NXCT facility. A case study on the work carried out at Leeds in X2 is written on page 25 of this report.

X-ray Computed Tomography (Manchester)

Investigators; Prof. Philip Withers, Prof. John Francis

Researchers; Dr Xun Zhang, Dr Zihan Song, Dr Sam McDonald, Dr Shen Cao

A range of projects across different platform projects in the MAPP partnership have used X-ray Computed Tomography (XCT) with Manchester to gain valuable insights into both additive manufacturing processes and additively manufactured parts. The MAPP team at Manchester has developed an automated workflow to analyse powders for AM using X-ray micro-CT (μCT). Working with P2.2, the Hot Isostatic Pressing (HIP) process, from powders to fully dense composite, has been recorded by X-ray imaging for the first time. In collaboration P2.3b, in-situ tension testing has been performed with XCT on a polyamide AM sample to investigate the effects of porosity on its mechanical behaviour. Joint projects with Imperial College (P2.3c) focused on understanding the fracture characteristics of an additively manufactured, steel reinforced, ceramic (Al2O3) matrix composites and the development of pores and cracks within an alumina gel-cast during drying. A case study on the work carried out in a collaboration between Manchester and Leeds is written on pages 25 and 26 of this report.

MAPP director, Prof Iain Todd, networking at the MAPP 2nd International Conference with Dr Minh-Son Phan from Imperial College London. Minh won a MAPP feasibility study in 2018; Assessing the Printability of Alloys for Fusion-based Additive Manufacturing by Coupling Thermodynamics Phase Diagrams and Machine Learning.

X3 MODELLING, OPTIMISATION AND CONTROL

Sheffield

Investigators; Prof. George Panoutsos, Prof Visakan Kadirkamanathan

Researchers; Dr Adrian Rubio Solis, Dr Scott V. Notley, Dr Bo Luo, Dr Ping Li, Dr Emad M. Grais, Dr Daliya Aflyatunova

The MAPP research in X3 took a hybrid modelling approach. Originally pioneered in a previous research hub, IMMPETUS, this was reborn in MAPP, enabled by the emergence of new in-situ characterisation and monitoring technologies. The research has helped address; how to create physics-compliant machine learning (ML) structures and surrogate models, the data needed to achieve a predetermined ML outcome, how to optimise and understand performance at scale and how to apply robust ML-assisted advanced control. The work has highlighted continuing challenges and opportunities for future research and perspectives for the future of multi-scale integration. A case study on the work carried out in X3 is written on pages 26 and 27 of this report.

Cambridge

Investigator; Prof. Phillip Stanley-Marbell

Researchers; Dr Vasileios Tsoutsouras, Dr Hamid Toshani, Dr Chatura Samarakoon, Dr Janith Petangoda

Research at Cambridge on a miniature sense-and-compute platform with integrated sensing capability evolved from a MAPP-funded feasibility study to become one of the main research platforms in the Materials Made Smarter Centre (MMSC). The platform has incorporated the ability for wireless data readouts, enabling the ability to remotely monitor, report and analyse data such as the humidity within powder to be used for AM. Cambridge subsequently became a partner in MAPP where research into the physics of signals measured during the additive manufacture (AM) process has been conducted to improve the stability of the AM control and of the quality of the components manufactured. An article describing the work conducted in Cambridge was included in the MAPP 2023 report available from the MAPP website (link to MAPP Website at end of this section).

https://mapp.ac.uk

P2.1 CASE STUDY - ASTRONOMICAL INSTRUMENTS

Investigator: Prof Iain Todd (Sheffield)

Researcher: Dr. Rob Snell (Sheffield)

MAPP is at the cutting edge of research to maximise the potential of additive manufacturing (AM) for use in telescopes, optics and astronomical devices.

AM is a fabrication process that builds an object layer-upon layer, rather than removing material from a solid block, and promotes the use of structures that would not be possible via other manufacturing methods. The technique offers increased geometric freedom and the potential for lightweight designs that would be impossible using conventional machining methods.

Traditionally to achieve the best quality surface in mirrors requires a lot of weight, using components manufactured and machined from solid blocks of materials. Keeping the weight as low as possible is especially important for mirrors used in astronomical devices like telescopes and this can be made possible by creating a light weight substructure or base to the mirror using lattice-like builds.

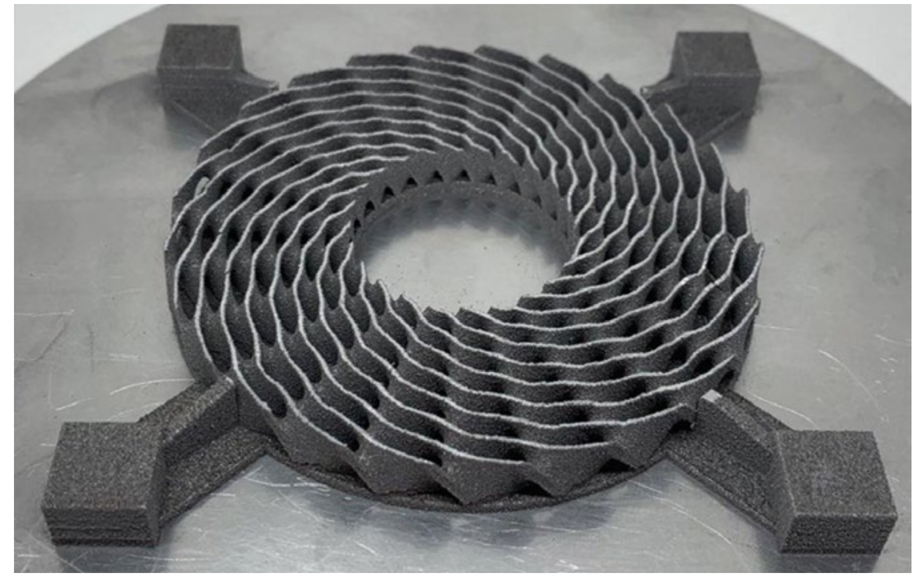
The need for lightweight components is obvious for space-based instruments, but it is equally relevant for ground-based telescopes. Telescopes are required to precisely track celestial objects, moving structures the size of buses with precision. It is therefore necessary that every component involved is as light as possible. All agencies involved with telescopes have the strictest of weight limits imposed and significant impetus to reduce weight.

Sheffield-based MAPP researchers have made use of AM's weight-saving and complex design capabilities for mirrors and other optical devices through a number of MAPP-aligned research projects:

OPTICON project (February 2018 – June 2021)

OPTICON (Optical Infrared Coordination Network for Astronomy) was an Integrated Infrastructure Initiative for improving the coordination of the European astronomical community in the fields of infrared, optics and solar physics. It was a large European project funded by Horizon 2020 with multiple partners, including several observatories and the Netherlands Organisation for Applied Scientific Research (TNO), who also work in AM.

As the project diversified Sheffield had some involvement with; modelling lightweight mirrors (IAC, Spain), Deformable Optics (LAM, France) and Flexors (UK-ATC, UK). The focus in Sheffield gravitated towards a project with the UK Astronomy Technology Centre (UK-ATC) and the Rutherford Appleton Laboratory – Space (RAL-Space) called CubeSat.



TPMS wall structure to go inside a CubeSat mirror. Image courtesy Dr Rob Snell.

CubeSat project (February 2018 to Present)

MAPP researchers in Sheffield worked with colleagues at the UK-ATC and the RAL - Space on a project to better understand and control the presence of defects in additively manufactured parts and the influence they have on the resulting optical properties of light weight CubeSat mirrors manufactured from aluminium and titanium alloys.

The Aconity 3D – Aconity Mini and Aconity Lab additive manufacturing platforms at The Henry Royce Institute, University of Sheffield have been extensively used in MAPP's research in this area. The Aconity MINI uses a laser beam to selectively melt an area of metal powder based on a 3D model of a component, then repeating it layer by layer until the final geometry is obtained. The Aconity Lab is a modifiable lab system which can either be equipped with process monitoring tools, a vacuum option or high-temperature preheating of up to 1200°C.

Several batches of high-silicon aluminium (AlSi10Mg) samples were created to investigate the relationships of laser parameters, laser paths and build orientations with defects including porosity, lack of fusion, keyholes and gas entrapped bubbles. The results showed that eliminating defects relies on a complex interaction of the process parameters and material properties, with the residual heating from the laser proving to be a significant factor. In addition, the use of a Hot Isostatic Press (HIP) was investigated and some full prototypes of the light weight CubeSat mirrors were produced. Mirrors additively manufactured from titanium alloys had very good optical properties which were far superior to the aluminium mirrors. In addition, some process modelling using the finite element software was used to understand and optimise the component lattices.

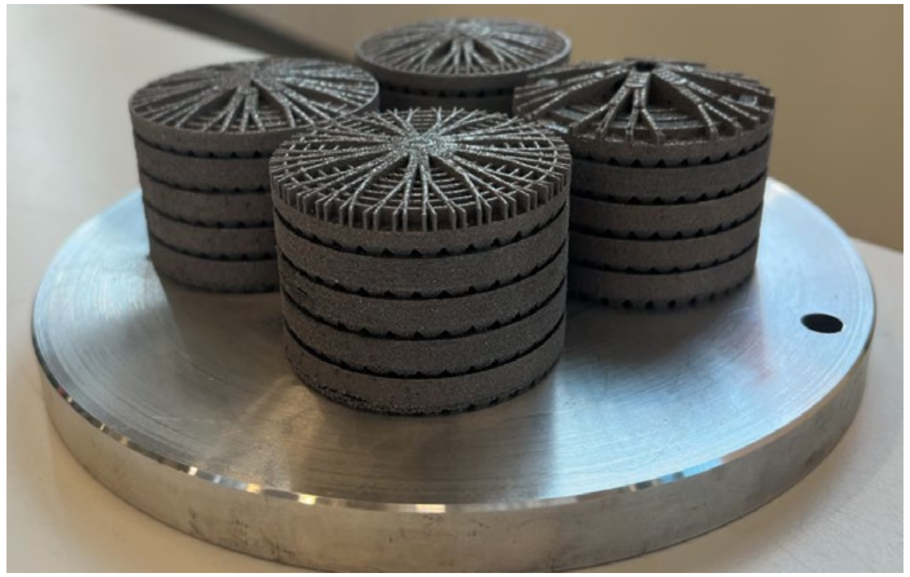
Collaboration with Future Leaders Fellowship and NARIT (January 2020 to Present)

MAPP researchers are continuing to collaborate as a partner with Future Leaders Fellow (FLF), Carolyn Atkins, on AM Optics for mirrors and on leading the AM work in NARIT; a Knowledge Transfer project with Thailand, within which we are teaching a PhD student and several technicians about optics and AM.

Aluminium mirror development

A core component of the continuing mirror work at Sheffield is in being able to achieve defect free surfaces whilst generating a microstructure that still maintains the required properties. One of the options considered in the project has been to post-process the AM parts using Hot Isostatic Pressing (HIP). HIP removes defects but it was found to significantly reduce the hardness of the samples and, therefore, the resulting quality of the mirror finish that can be obtained on polishing the surface.

Work is ongoing in finding the best (*i.e.* least damaging to the surface) way to HIP aluminium mirror samples to tailor the microstructure and resulting properties. The work was originally aimed at removing defects (voids) using HIP but this resulted in an increase in grain size and, consequently, a reduction in hardness of the samples. For this reason, the work on mirrors is moving towards ways of introducing voids that can be HIPed shut to leave the finest microstructure possible, including:



Additively Manufactured aluminium mirrors that are built here as four stacks of five mirrors with different lily-pad lattice designs to reduce the individual component weight. Image courtesy Dr Rob Snell.

- Investigate the HIP to get the best parameters that maximise pore closure but minimise reduction in hardness.
- Deliberately leave small voids that can HIPed shut but leave a fine microstructure which has the required hardness to meet the properties required for a producing a polished mirror.

Outgassing work

Work with the UK-ATC has explored the influence of process parameters and post-processing on the outgassing properties. These are critical properties for telescopes and optical components. For example, a space telescope that outgases will be surrounded by a cloud of that atmosphere that will remain with the satellite for the life of the telescope. Lattice parts and hollow cubes have been built and analysed using a custom outgassing rig. Initial results were shown at SPIE 2022 and the current work will be presented at the next SPIE conference in Yokohama.

Future work

- Titanium mirrors. Basic work in this area could go a long way in terms of impact and exposure.
- Heat exchanges / cooled mirrors. We have C17640 Cupronickel powder and interest from the UK-ATC (Stephen Watson).
- Telescope mount arms with Vik Dhillon from the Physics Department
- Outgassing control. Measuring and improving the performance of AM parts in a vacuum.
- Nature inspired design. Using inspiration from biological structures to make lightweight, stiff optical components.
- Radio horn design. Achieving better performance in radio-astronomy with designs impossible to produce via non-AM means.

Publication links to these projects in MAPP are listed below:

Lightweighting design optimisation for additively manufactured mirrors (2019)

Additively manufactured mirrors for CubeSats (2019)

An additive manufactured CubeSat mirror incorporating a novel circular lattice (2020)

Freeform active mirror designed for additive manufacturing (2020)

Use of 3D printing in astronomical mirror fabrication. (2020)

H2020 opticon WP5 overview: investigating the use of additive manufacturing AM) for the design and build of multifunctional integrated astronomical components (2020)

The OPTICON A2IM Cookbook: an introduction to additive manufacture for astronomy (2022)

Towards understanding and eliminating defects in additively manufactured CubeSat mirrors (2022)

Outgassing properties of additively manufactured aluminium (2022)

Lightweight, aluminum, mirror design optimization for conventional and additive manufacturing processes (2022)

Additively manufactured flexure for astronomy instrumentation (2022)

Understanding the role of additive manufacturing in the development of astronomical hardware (2023)

An introduction to metal mirror fabrication using additive manufacture (2023)

P2.1 CASE STUDY - PREDICTIVE PROCESS DIAGRAM FOR PARAMETER SELECTION IN LASER POWDER BED FUSION PROCESS

Investigators: Prof. Iain Todd (Sheffield)

Researchers: Dr Minh Phan (Sheffield)

Collaborators: Dept. Electronic and Electrical Engineering (Sheffield), European Synchrotron Radiation Facility (ESRF)

In the Laser Powder Bed Fusion (LPBF) process, optimal parameters are obtained via numerous iterations of experiments on cubic or cylindrical samples. This approach can be costly and time-consuming. Moreover, transferring these parameters to real components presents additional challenges as the processing conditions may have changed due to variations in part sizes, scan lengths, etc. In previous work, an LPBF normalised process diagram for parameter selection was developed showing reliability and accuracy up to 75% for the fabrication of 99%-dense cubes. In this work, the diagram was applied to a turbine blade fabrication to evaluate its capability on complex geometrical components. The diagram was assessed for its potential to classify defects such as lack of fusion or keyhole porosity using LPBF-processed IN718 Ni-based alloy data. Subsequently, the builds were conducted with two specific scan strategies, namely controlled and uncontrolled scan lengths. The effect of scan lengths on the processing conditions was analysed by a near-infrared thermal camera imaging system, showing the former resulted in uniform peak temperatures, melt pool widths and dendrite arm spacings. All the fabricated turbine blades achieve 99% density as characterised by synchrotron X-ray tomography and optical microscopy. This indicates that the LPBF process diagram can be applicable as a tool for parameter selections for real components.

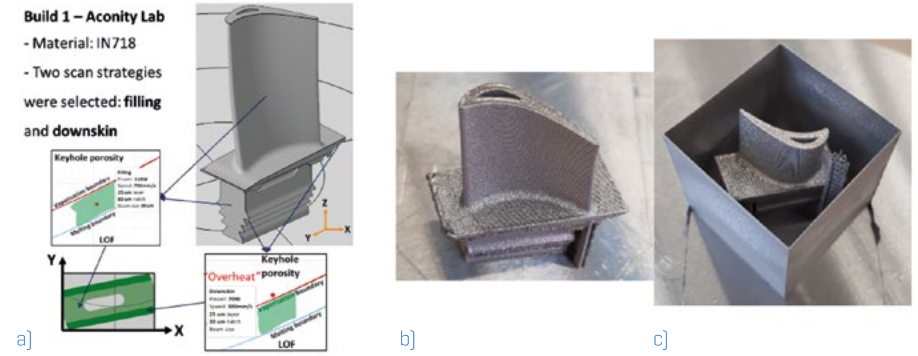
In the LPBF process, parameters are often selected through iterations of experiments using Design of Experiment (DOE) techniques such as Response Surface Methodology (RSM) or the Taguchi method. Multiple parameters are grouped as factors (e.g., laser power, scanning speed, hatch spacing, or layer thickness) and statistically evaluated against a group of output properties, known as responses (e.g., part density, surface roughness, or build rate). A screening design starting with the widest range of equipment capabilities is usually applied for new materials which have not previously been processed. Then, further refinements of the processing space are completed using more advanced techniques such as RSM. Depending on the prioritised property (e.g., hardness, build rate), specific optimal parameters will be obtained accordingly. Cuboidal or cylindrical samples are often chosen for the ease of following metallurgical preparation steps. However, challenges arise when applying these optimal settings on different part geometries such as tensile samples or complex geometry components.

Part geometries have critical impacts on the final microstructure and mechanical properties. The change from simple cuboidal or cylindrical samples to a "real-life" component geometry means that the local processing conditions may have been altered. Larger hatching areas result in longer scan length allowing more time for heat to dissipate through the part, resulting in finer solidified microstructure. As a result, tensile strength or fatigue properties can be influenced. Furthermore, alteration of sample geometries increases higher chances of getting defects such as lack of fusion which can result in premature failings of the builds. Therefore, it is demanding to have an approach to effectively transform parameters obtained from the lab-scale part geometry to "real-life" component geometries.

A normalised LPBF process diagram was developed based on dimensionless numbers adapted from the laser welding process. In addition, specific characteristics of the LPBF process such as scan length, hatch spacing and layer thickness-dependant absorptivity were considered and added to the model to further improve the capability of the normalised diagram for the LPBF process. The LPBF process diagram was evaluated against extensive literature data on numerous metallic materials. The reliability and accuracy of the diagram in predicting good parameters are up to 75%. However, these data were reported only for simple geometrical parts like cuboidal or cylinders. This case study aims to apply the LPBF process diagram for parameter selection to build complex geometry turbine blades with a size of 38 mm x 20 mm x 63 mm.

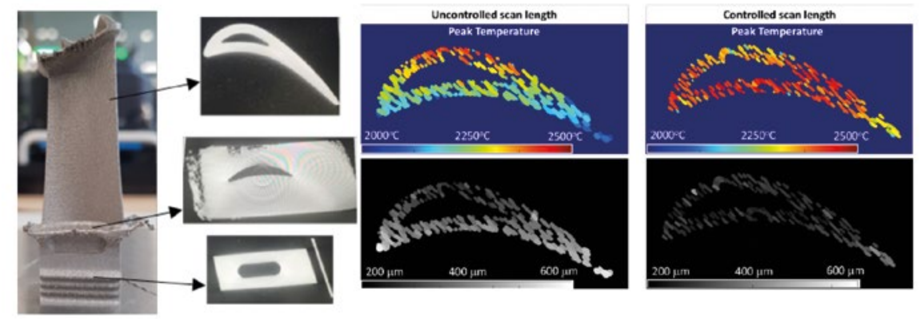
The blades were built with two different strategies, namely uncontrolled scan length and controlled scan length. For the former, the turbine blade was built based on its original geometry which contains different scan lengths along the building direction. These different scan lengths result in different heat accumulation and distribution within the scan tracks and layers that potentially promote defect formation such as swelling or porosity. For the latter strategy, a square envelope covering the blade was used to maintain the same scan length across the built layer. Printing parameters for this specific scan length were directly selected via the LPBF process diagram.

The fabrication processes of the turbine blades were monitored by a thermal imaging system, allowing the extraction of local thermal conditions such as peak temperatures or melt pool dimensions. The as-fabricated blades were characterised by synchrotron X-ray tomography showing all the blades exceeding 99.5% density with the processing parameters selected from the diagram. However, blades built with the uncontrolled scan length strategy were observed with non-uniform heat distribution as evidenced by thermal images. This non-uniformity led to variation in the sizes of the solidified microstructure, consequently affecting the homogeneity of hardness values throughout the component. In contrast, using the controlled scan length strategy results in uniform heat distribution and consistent sizes of the solidified microstructural, as indicated by the thermal images.



a) b) c)

Figure 1. a). Parameter selection using the LPBF diagram for the turbine blade; b). Uncontrolled scan length strategy and c). Controlled scan length strategy



a) b)

Figure 2. a) Turbine blade built with Controlled scan length and b). Thermal images comparing the two strategies regarding peak temperature and melt pool width

The normalised LPBF process diagram was used to select parameters for a complex geometry such as the turbine blade. In addition, the parameters can be properly optimised depending on the specific scan length setting, resulting in more uniform heat distribution and consistent size of the solidified microstructure. For future work, the diagram will be applied to build large-scale components in which parameter selection may need to be combined with a specific scan strategy (e.g., island scanning with a constant scan length) to ensure heat is uniformly distributed within the layer.

MAPP has provided support through funding (Grant EP/P006566/1), access to Henry Royce Institute facilities and collaboration with colleagues from the Department of Electrical and Electronic Engineering in the design and application of the thermal imaging system.

Paper/Publication DOI:

1. Preprint (under review for Journal of Additive Manufacturing): Phan, Minh Anh Luan and Dew, Oliver and Todd, Iain, Predictive Process Diagram for Parameters Selection in Laser Powder Bed Fusion to Achieve High-Density and Low-Cracking Built Parts. Available at SSRN: https://ssrn.com/abstract=4643684 or http://dx.doi.org/10.2139/ssrn.4643684
2. Lai, Yufeng and Phan, Minh Anh Luan and Zhu, Chengxi and Davies, Matthew MJ and Maddison, George and Hobbs, Matthew J. and Todd, Iain and Willmott, Jon R., In-Situ Thermal Imaging of Laser Powder Bed Fusion: Investigating the Influence of Preheating Temperatures on Cooling Rates and Melt Pool Dynamics. Available at SSRN: https://ssrn.com/abstract=4516994 or http://dx.doi.org/10.2139/ssrn.4516994

P2.2 RESEARCH THEME: FIELD ASSISTED SINTERING TECHNIQUE (FAST)

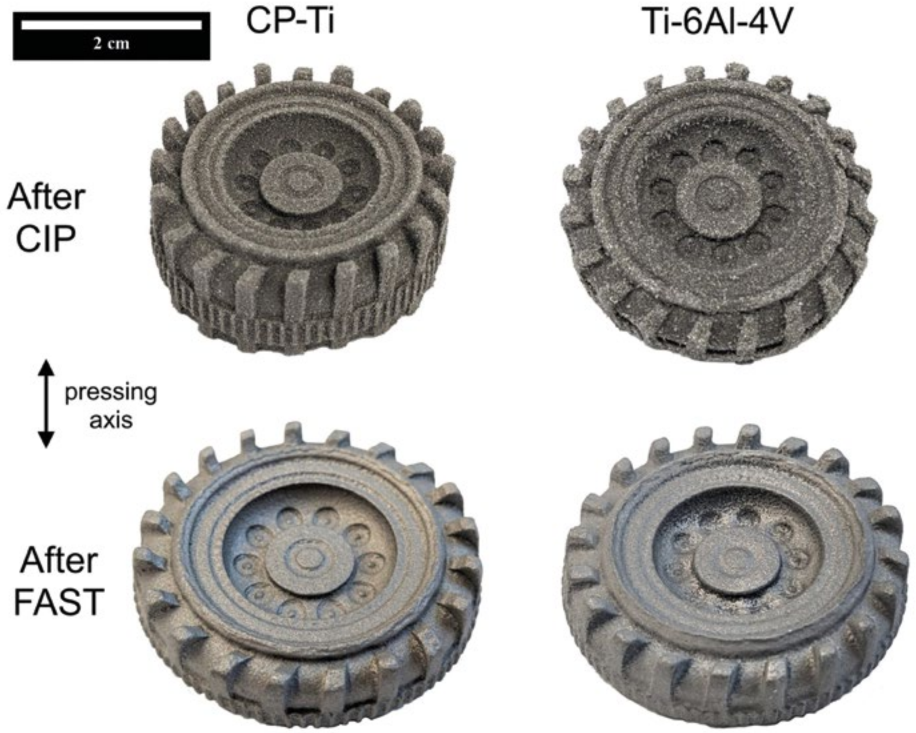
Investigator: Prof Martin Jackson (Sheffield)

Researchers: Dr. Simon Graham (Sheffield), Dr. James Pepper (Sheffield)

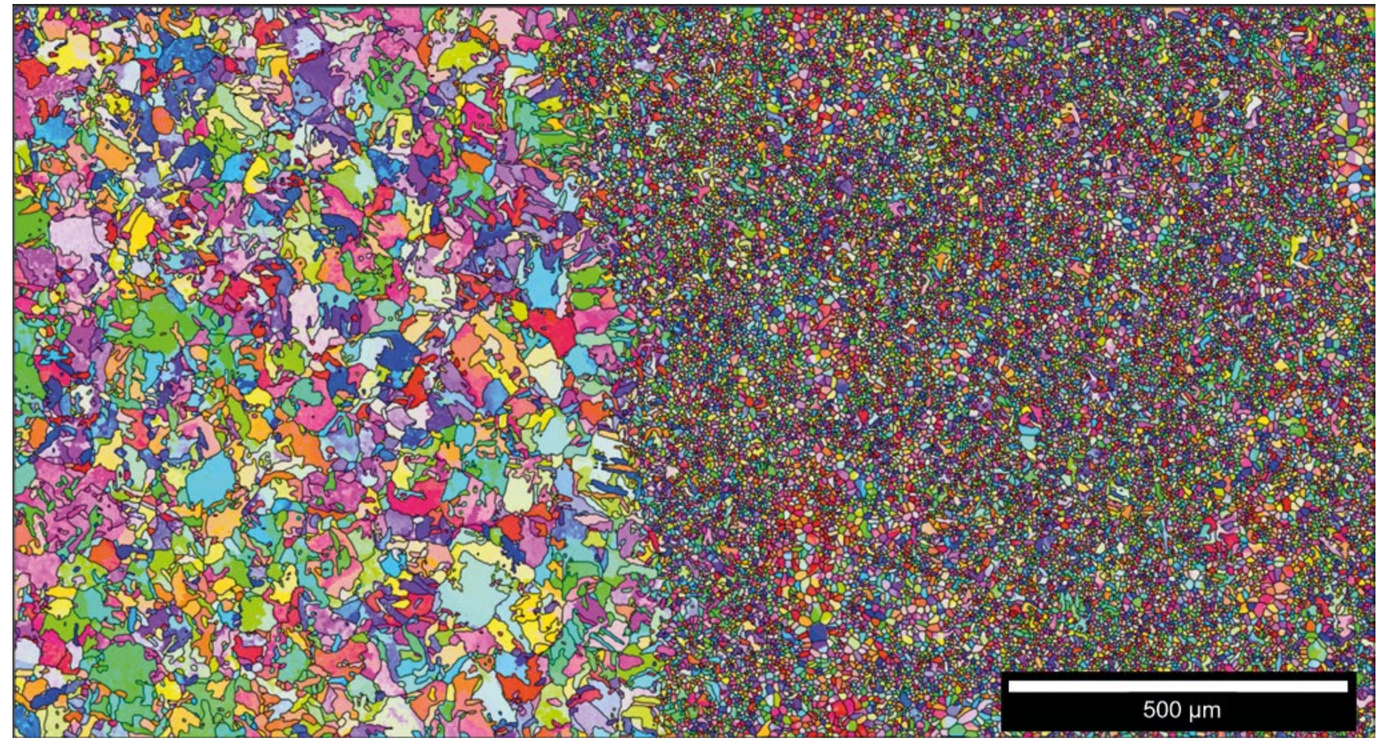
Academic Partners and Collaborators: University of Manchester, Henry Royce Institute

Industrial Collaborators: Rolls Royce plc, ECKART GMBH

The Field Assisted Sintering Technology (FAST) process allows for the efficient conversion of powder materials into consolidated billets. One of its major advantages is that the technique is relatively agnostic to material and powder categories along with near net shape production and material recycling. The flexibility of FAST has allowed MAPP to take a wide variety of directions covering multiple material systems, production routes, and potential applications. The MAPP grant has allowed research in FAST to expand and develop, positively impacting a host of sectors and progress the industry readiness of the technique. The primary focus was directed to the recycling of oversized powders from AM, titanium alloys for aerospace applications and novel material systems which are challenging to produce through competing methods. MAPP has made an important positive impact on the process with further work at the University of Sheffield continuing beyond its timeframe.



Photographs of CP-Ti and Ti-6Al-4V CIP-FAST parts before and after FAST processing at 980°C for 10 min



EBSD image of a 2mm x 1mm section of the 0 wt% TiB (left) to 3wt.% TiB (right) interface for a 1400°C 2 hr Ti-6Al-4V sintered sample demonstrating the grain pinning effect of the TiB inclusions

Cold Isostatic Pressing (CIP) FAST

The one step creation of fully dense complex geometries from powder has been a long-term target of powder processes. To achieve this with FAST, a novel, two-step, solid-state method to produce complex geometry titanium parts was investigated by combining Cold Isostatic Pressing (CIP) with FAST. Hydride-dehydride powders of commercially pure titanium and Ti-6Al-4V alloy were CIPed into shaped compacts using silicone moulds, then further consolidated using FAST, with ZrO2 powder as a secondary pressing media. The final parts retained the complex features from the CIP moulds but were axially compressed. Densities of >99% were achieved with optimised FAST processing parameters required for the different alloys. In addition to providing consumables, MAPP has enabled the funding of a Research Associate to conduct the research. MAPP work has demonstrated that the CIP -FAST process route has been demonstrated to be a fast, low-cost and material-efficient option to produce a wide variety of complex titanium parts.

S.J. Graham *et al.*, (2023), CIP-FAST: assessing the production of complex geometry titanium components from powders by combining Cold Isostatic Pressing (CIP) and Field Assisted Sintering Technology (FAST), *Powder Metallurgy*, https://doi.org/10.1080/00325899.2023.2236907

AddFAST

The flexibility of the FAST technique allows for manipulation of samples to produce internal, complex, interpenetrating microstructures by combining alloy powder with a pre-build AM solid lattice structure. An AM lattice structure yields a columnar grain morphology and texture as opposed to the equiaxed microstructure produced by FAST. *AddFAST* has created components with a designed combination of the two grain sizes and textures with full densification and bonding. The project has also demonstrated the capability of combining dissimilar alloys to retain microstructural quality after deformation in thermomechanical testing. MAPP funding has provided access to consumables, AM platforms, microscopy and part testing. The initial results demonstrated in MAPP have potential which will expanded through material systems, scales, and structural design in future research work.

C. Barrie *et al.* (2022), *AddFAST*: A hybrid technique for tailoring microstructures in titanium-titanium composites, *Journal of Materials Processing Technology*, https://doi.org/10.1016/j.jmatprotec.2023.117920

Current Control

A distinguishing factor of the FAST process is the use of current to generate resistive heating. However, despite initial work to holistically increase or decrease the current density in the sample region, more fine tuning experiments have been overlooked. The research in MAPP has looked at the impacts of fine tuning the current on the microstructure of Ti-6Al-4V using electrically insulating boron nitride spray. Large thermal gradients were predicted using COMSOL FEM simulations demonstrated practically in MAPP using the FAST process. The samples were uniquely analysed by combining a Clemex mosaic microscopy technique with machine learning to plot microstructural heat maps of prior β grain size. MAPP has provided background support with expertise of Research Associates in the creation of the FEA model and sample manufacture. It is expected that this work will assist with the homogenisation of thermal gradients in large scale and complex geometry components and in sintering dissimilar metals where this additional thermal profile control will prove invaluable during part production.

J. Pepper *et al.*, (2023), Channelling electric current during the field-assisted sintering technique (FAST) to control microstructural evolution in Ti-6Al-4V, *Journal of Materials Science*, http://dx.doi.org/10.1007/s10853-023-08884-8

Ti-TiB Metal Matrix Composites Functionally Graded Materials

High hardness ceramics are used globally for armour applications, to prevent piercing projectiles from threatening both lightly armoured vehicles and wearers of body armour. Pure ceramics are intrinsically brittle, which can result in fragmentation and secondary impact damage, as well as low multi hit capacity. In an attempt to resolve this, fully dense 250 mm diameter Ti-6Al-4V discs were produced using FAST with and without stepped functional grading using TiB_2 concentrations between 0 and 9 wt % to investigate their potential to improve ballistic performance. The in-situ generation of a significant quantity of high strength, ceramic TiB needles was confirmed for the samples and the 250 mm diameter plates were ballistically tested and microstructurally examined. The ballistic results indicated a superior behaviour to the monolithic titanium alloy plates without TiB_2 additions. This is encouraging as hot isostatic pressed Ti-TiB composite systems have previously been tested and demonstrated poorer performance. MAPP has provided the researcher expertise, materials and industrial contacts for ballistic testing at Rheinmetall BAE Systems Land Ltd (RBSL).

J. Pepper *et. al.*, (2024), Microstructural Examination and Ballistic Testing of Field Assisted Sintering Technology (FAST) produced Ti-TiB_2 FGM composite armour plates, *Journal of Material Science and Technology* (under review)

Niobium Silicide (Nb-Si) Systems

A Niobium-silicide based alloy designed for high temperature aerospace applications, was produced via a powder metallurgy (PM) route. The raw elements were arc melted, crushed, and milled to powder, then consolidated using FAST. The study demonstrated the production of 60 mm diameter FAST samples from which compressive creep test pieces were extracted and evaluated using electro-thermal mechanical testing (ETMT). This research was initially supported by a MAPP funded Research Associate and is now being carried out by a MAPP-aligned industry funded PhD student.

S. Graham *et. al.*, (2023), Powder production, FAST processing and properties of a Nb-silicide based alloy for high temperature aerospace applications, *Journal of Materials Research and Technology*, https://doi.org/10.1016/j.jmrt.2023.12.190

FAST of Aluminium Powders

Metal AM techniques typically operate using powders with limited particle size ranges. Powder atomisation processes produce a surplus of particles outside the AM FAST can provide an alternative, solid-state processing route to consolidate the surplus powders from atomisation. In MAPP surplus powders of A20X, an aerospace approved aluminium alloy, were processed using FAST and subsequently hot rolled to produce sheet material. Tensile test results were similar to hot rolled conventional cast material and comparable to additively manufactured product, indicating that FAST is an effective option for converting surplus metal powders into useful products, while improving sustainability in the additive supply chain. Research Associates in MAPP managed this this project on A20X powder that was surplus to a MAPP aligned Programme on AM.

S. Graham *et al.*, (2023), Solid-state processing of surplus aluminium alloy powders through a combination of field-assisted sintering technology and hot rolling, *Powder Metallurgy*, http://doi.org/10.1080/00325899.2023.2171582

P2.2 CASE STUDY - BEYOND MULTI-PASS DISSIMILAR WELDS: TOWARDS IMPROVED PRODUCTIVITY AND JOINT PERFORMANCE THROUGH SOLID-STATE BONDING

Investigator: Prof. John Francis (Manchester)

Researcher: Dr Rahul Unnikrishnan (Manchester)

Collaborators: University of Sheffield, Advanced Forming Research Centre (AFRC)

In the primary circuit of pressurised water reactors (PWRs) there are many safety-critical joints between a ferritic low-alloy (SA508) steel pressure vessel and adjoining austenitic (316L) stainless steel pipes. Conventional joining practice involves a multipass buttering step for the pressure vessel, using an arc welding process, which is then followed by post-weld heat treatment (PWHT) and a subsequent multipass weld to each adjoining pipe. These dissimilar metal welds are complex and time-consuming, and the resulting joints sustain high levels of residual stress and are therefore prone to degradation in service. Field-assisted Sintering Technology (FAST), a solid-state process, provides an efficient alternative to arc welding with fewer thermal cycles. Notably, joints formed with this method display superior mechanical properties to the parent austenitic steel, indicating the potential for enhanced structural performance in PWRs and other thermal power plants.

Joints between carbon-manganese or low-alloy pressure vessels and austenitic stainless-steel pipes arise frequently in many industrial sectors, but they are particularly relevant to many types of thermal power plant. In a PWR the pressure vessels are made from SA508 steel and they are joined to austenitic (316L) steel pipes. These are safety-critical joints and the consequences of failure can be severe. Current practice in many sectors involves the multipass buttering of joint preparations on the nozzles by arc welding followed by PWHT and a subsequent multipass weld. The buttering layer is normally an intermediate (nickel-based) material with superior creep resistance, making it difficult to relieve the resulting residual stresses. In PWR's, these residual stresses are high enough to lead to stress-corrosion cracking. There is a requirement to simplify the manufacturing sequence for dissimilar metal welds of this type to reduce lead times and construction costs.

FAST could potentially offer alternative joining routes with fewer thermal cycles, resulting in a joint that requires less post-processing. Researchers at the University of Manchester, in collaboration with the University of Sheffield, developed solid-state transition pieces between SA508 Grade 3 ferritic steel and 316L austenitic stainless steel using FAST on both powder and bulk material using the facilities at the Royce Discovery Centre at the University of Sheffield.

In-situ mechanical testing of a powder joint coupled with digital image correlation in a scanning electron microscope at the University of Manchester showed minimum strain localization

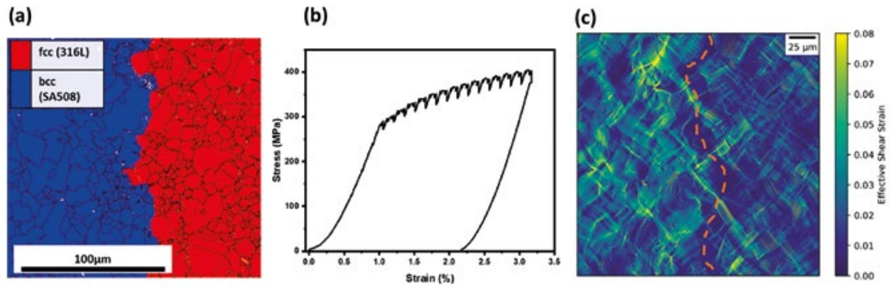


Figure 1 (a) EBSD phase map, (b) Stress-strain curve and (c) 2-D strain maps from digital image correlation of FAST sample (1100oC, 30min dwell, 35 MPa) processed from SA508 and 316L powder. Interface is marked in dashed red lines in (c).

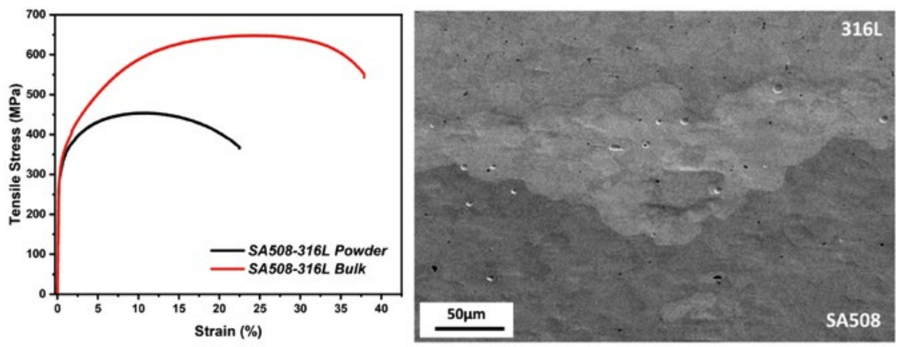


Figure 2 a) Stress-strain curve of the dissimilar joint tested to failure. b) SEM Secondary Electron Image of a FAST joint processed using gas-atomized 316L and SA508 powder at 1100°C with a dwell time of 30 min and 35 MPa pressure.

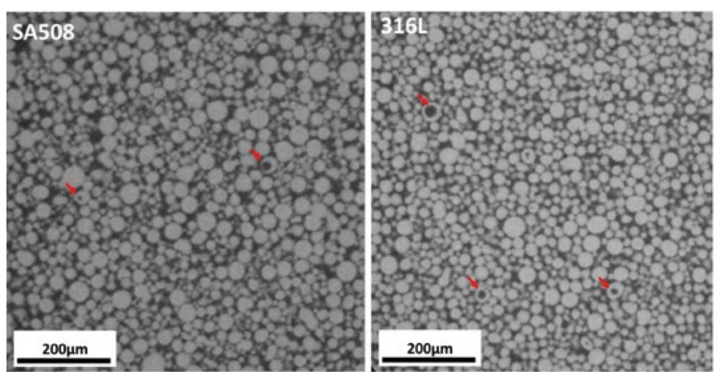


Figure 3 XCT Projection image of SA508 and 316L gas-atomised powders showing internal porosity in the powders (red arrows).

at the interface when compared to the parent materials, Figure 1. Mechanical tests to failure on powder and bulk joints also showed necking occurred within the parent materials, indicating that the bond is stronger than both the parent materials. However, the strength of the FAST joint processed with powder samples was significantly lower than that for bulk materials, Figure 2a. This discrepancy could be attributed to the presence of porosity in the FAST joints, as observed in the SEM Image, Figure 2b. Nevertheless, X-ray computer tomography (XCT) studies on powders at the National X-ray Computed Tomography (NXCT) lab revealed internal porosity in both the SA508 and 316L gas-atomised powders used in this study, Figure 3. The size of the pores seen from the XCT scans correlates with those observed in the FAST sample, suggesting that the source of porosity originates from the powder rather than the FAST process itself. This finding highlights the importance of selecting the right process for powder manufacturing. Gas-atomised powders are known for internal porosity arising from argon trapped during the atomising process.

Future work involves the rapid deposition of a nickel alloy on both parent materials using additive manufacturing followed by joining using FAST or rotary friction welding (RFW). MAPP researchers are currently working with the AFRC to assess whether RFW can create strong joints. If successful, this work will continue beyond MAPP funding to focus on using these advanced welding methods.

P2.3A CASE STUDY - DEVELOPMENTS IN DIODE AREA MELTING

Investigators: Prof Kamran Mumtaz (Sheffield), Dr Candice Majewski (Sheffield), Dr Kristian Groom (Sheffield)

Researchers: Dr Ryan Brown (Sheffield), Dr Anqi Liang (Sheffield)

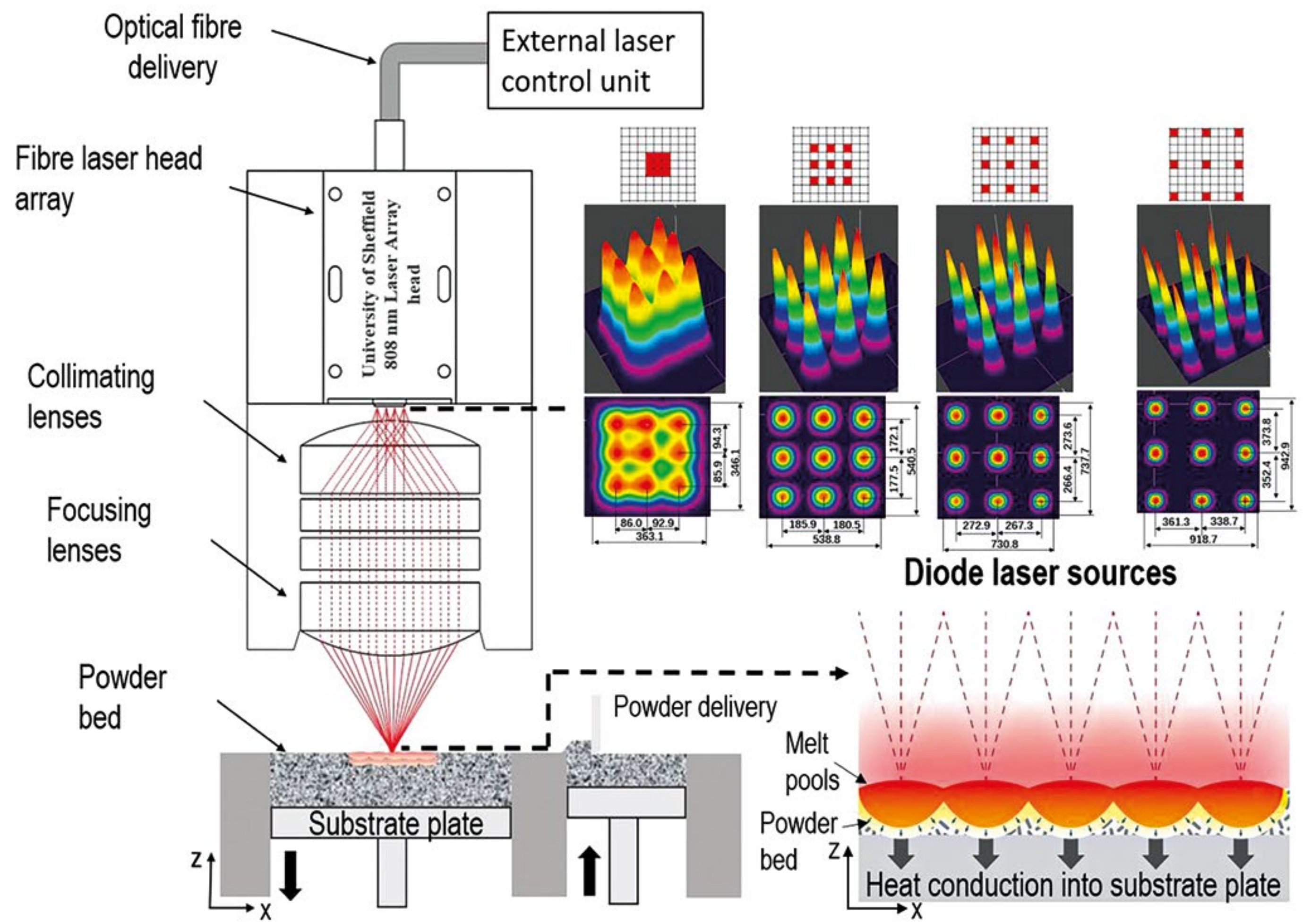
Collaborators: University of Cambridge (UK), Imperial College London (UK), University of Southampton (UK), Renishaw (UK), Thinklaser (UK), Diamond Centre Wales (UK), Ermaksan (Turkey)

Diode area melting (DAM) is a novel additive manufacturing process where the light from an array of independently addressable lasers is used to process parts from metallic powder. By selecting shorter wavelength diode lasers compared to traditional Selective Laser Melting (SLM) fibre lasers, greater absorption can be achieved, reducing overall power consumption. Additionally, by employing a line of lasers traversing the powder bed along one axis only, slower scanning speeds can be achieved. This approach has been shown to reduce cooling rates, enabling varying microstructures to be obtained whilst maintaining high density parts, as well as reducing residual stress and spatter during processing.

Over the course of MAPP, DAM has evolved from an initial benchtop proof of principle to a fully operational prototype system, complete with industrially compatible powder delivery, mechanical platform and software, with work ongoing to implement in-situ temperature monitoring and control. DAM has also been combined with SLM in a hybrid system, has been applied to a number of engineering alloys, including Ti64, and provides the blueprint for expanding into the mid-IR for the processing of polymers.

"With enough power you can melt anything!" This could be the founding principle of conventional SLM, where higher power fibre lasers (1070 nm) enable faster scanning and greater productivity. However, due to a mismatch in emission and absorption wavelengths, only a small percentage of the 100 s of Watts of optical power emitted are absorbed by metallic materials. In contrast, whilst semiconductor lasers have relatively low optical power outputs (typically <5W and often much lower), they are available across a broad palette of wavelengths from UV to the far-IR. By utilising the fact that absorption in metals increases as wavelength is reduced, single diode lasers at these shorter wavelengths (808 nm, 450 nm) are capable of melting common AM alloys with just a few Watts of power. Whilst this does require a reduction in scanning speed compared with SLM (m/min as opposed to m/s), by arranging a series of diode lasers into an array which traverses the powder bed, a broad area can be processed in a single pass to maintain process speed. To provide net shape capability, individual lasers within the array can be turned on/off as the array travels the powder bed.

Initial, proof of principle demonstrations were based on use of standard 808 nm pump laser bars in a customised package to allow individual operation. Trials conducted using 316L stainless



Multi-laser diode area melting - low power short wavelength laser array configurations within a novel 32x32 fibre coupled laser grid, enabling advanced material processing and melt-pool solidification control steel concluded that high density parts were able to be produced from high melting point materials, whilst alleviating concerns related to low power and poor beam quality (Zavala 2017, 2018). However, due to concerns over potential for scale-up issues such as stitching errors between laser bars and the proximity of sensitive diode lasers to the harsh process environment, a transition to a fibre-based optical delivery system was employed. By coupling individual lasers to optical fibres and packaging these fibres into an array, lasers can be kept outside of the processing chamber and easily replaced if required. The award of IAA funds through alignment with MAPP allowed us to realise a prototype system based on this configuration, with MAPP providing staff resources to facilitate this.

Initial system characterisation was based on use of 808nm laser diodes to process 316L stainless steel and Ti-6Al-4V, with studies investigating the effect of different laser beam configurations on melt pool size and shape, cooling rate, and resultant crystal microstructure (Zavala 2018, Alsaddah 2022). Results demonstrated that the cooling rates in DAM are orders of magnitude slower than that of SLM, producing microstructures that are traditionally difficult to obtain. Subsequent availability of low-cost 450nm lasers encouraged the transition to shorter wavelengths, where typically difficult to process materials exhibit greater absorption characteristics (Alsaddah 2021). Using these shorter wavelength lasers, materials including Copper Alloys and Titanium Aluminide, in addition to the previously mentioned Titanium and Steel have all been successfully processed (Caglar 2024), with MAPP funding contributing to material costs as well as facilitating collaborations with partner sites to share expertise and resources. A 450nm array has also been combined with a traditional galvo-scanning fibre laser in a Hybrid-DAM system, combining the fine feature resolution and surface finish of SLM with the microstructural control and scalability of DAM.

All of the above work completed throughout the duration of MAPP has laid the foundation for a successful EPSRC funding bid obtained in 2022, which is being used to manufacture a more robust and industrially relevant DAM platform, enabling us to collaborate with a range of academic and industrial partners to investigate additional novel alloys, microstructures and applications. One of the key features of this improved system is the expansion of the fibre package into 2D via a 32x32 array, providing added functionality in the form of fine-feature flash-melting and enhanced microstructure control. Ongoing research includes the characterisation of the 2D laser array to ascertain the transition point between individual and overlapping melt pools for a variety of processing parameters, in addition to the use of consecutive rows of lasers to employ various preheat, melting and remelting strategies to achieve a variety of microstructures from a single material. To achieve this, a bespoke control system is being developed to automate laser activation and enable multi-layer parts to be produced directly from 3D model data. MAPP has also assisted with the obtaining of funding from the Royce Institute to support the development of in-situ thermal modelling using a high-speed thermal camera, which by combining with real-time laser information can be used to implement closed-loop temperature control in the future.

Alongside the continued development of metal-based DAM systems, trials utilising mid-IR emitting Quantum Cascade Lasers (QCL's) to expand the range of materials that can be processed using DAM to polymers are also being conducted. By applying the same approach of matching laser output wavelengths to absorption peaks common to several groups of polymers, a similar machine architecture can be employed with appropriate changes to the lasers and fibres used. Proof of concept trials have successfully demonstrated that various polymers can be sufficiently heated to achieve single layer parts, with the results forming the basis of an invited talk at ICAM 2023 and an EPSRC funding application currently under review.

As a result of the developments achieved in the area of Diode Area Melting over the course of MAPP, discussions are ongoing with the University of Sheffield's commercialisation team to create a spin-out company to develop low-cost manufacturing instruments. By supplying affordable DAM systems to both academia and industry, it is anticipated that new collaborations will be fostered, whilst simultaneously enhancing our understanding of advanced manufacturing using Additive Manufacturing. These collaborations are expected to drive technological advancements and encourage knowledge exchange, leading to the creation of skilled jobs in the manufacturing sector and ultimately contributing to the global competitiveness and growth of the UK's manufacturing industry.

Further Funding:

- UKRI Impact Acceleration Account: MIAMI - Improving the productivity of industrial additive manufacturing
- EPSRC - EP/W024764/1: Diode area melting - a novel reconfigurable multi-laser approach for efficient additive manufacturing with enhanced thermal process control
- Royce Institute - EP/X527257/1: Novel AM processing: for new functionally graded microstructure materials
- EPSRC - Application: High-Performance Laser Powder Bed Fusion of Polymer Parts Using Quantum Cascade Laser Arrays

Publications:

Zavala 2017 "Laser diode area melting for high speed additive manufacturing of metallic components". M Zavala-Arredondo, N Boone, J Willmott, DTD Childs, P Ivanov, … Materials & Design 117, 305-315, https://doi.org/10.1016/j.matdes.2016.12.095

Zavala 2018a "Diode area melting single-layer parametric analysis of 316L stainless steel powder". M Zavala-Arredondo, KM Groom, K Mumtaz, The International Journal of Advanced Manufacturing Technology 94, 2563-2576, https://doi.org/10.1007/s00170-017-1040-4

Zavala 2018b "Investigating the melt pool properties and thermal effects of multi-laser diode area melting". M Zavala-Arredondo, H Ali, KM Groom, K Mumtaz, The International Journal of Advanced Manufacturing Technology 97, 1383-1396, https://doi.org/10.1007/s00170-018-2038-2

Alsaddah 2021 "Use of 450-808 nm diode lasers for efficient energy absorption during powder bed fusion of Ti6Al4V". M Alsaddah, A Khan, K Groom, K Mumtaz, The International Journal of Advanced Manufacturing Technology 113, 2461-2480, https://doi.org/10.1007/s00170-021-06774-4

Alsaddah 2022 "Diode area melting of Ti6Al4V using 808 nm laser sources and variable multi-beam profiles". M Alsaddah, A Khan, K Groom, K Mumtaz, Materials & Design 215, 110518, https://doi.org/10.1016/j.matdes.2022.110518

Caglar 2024 "Multi-Laser Powder Bed Fusion of Ti6Al4V: Diode Area Melting Utilizing Low-Power 450 nm Diode Lasers". H Caglar, A Liang, K Groom, K Mumtaz, Journal of Materials Processing Technology, 118303, https://doi.org/10.1016/j.jmatprotec.2024.118303

Conference Presentations:

ICAM 2023 (invited speaker) - Towards Quantum Cascade Laser Sintering of Polymer Parts – Extension of Diode Area Melting to the Mid-IR

P2.3C CASE STUDY - FABRICATION OF BIO-INSPIRED CERAMIC COMPOSITES

Investigators: Prof. Eduardo Saiz (Imperial)

Researchers: Dr Erik Poloni (Imperial)

Collaborators: MTC, CIDETEC (Spain), Office of Naval Research (ONR, USA), Azimut Space GmbH (Germany)

Modern technologies, from new engines for aerospace to fusion reactors, demand materials able to work in increasingly harsh environments, at high temperatures, in highly corrosive atmospheres or under heavy radiation. Ceramics are ideal materials for these applications, but their implementation has been challenged by their low fracture resistance. The development of new ceramic-based materials capable of combining high strength and toughness with other functional capabilities (*e.g.* thermal or electrical conductivity) must be based on careful control of their structure at multiple length scales from atomic to macro levels. In this respect, design principles taken from natural composites such as bone or nacre could guide the fabrication of materials with unprecedented combinations of mechanical properties. However, powder processing technologies able to implement these principles in parts with practical dimensions need to be developed. Recent approaches in shaping and sintering, such as Additive Manufacturing (AM), can open new opportunities.

Within the framework of MAPP, the development of processing approaches to fabricate ceramics and ceramic-based materials that mimic the brick-and-mortar design of nacre has been researched. These materials can exhibit a unique mixture of functional and structural capabilities. In collaboration with CIDETEC in Spain, and with additional funding from ONR [1], MAPP has worked on the direct ink writing of re-processable nacre-like Boron Nitride/vitrimer composites with shape memory capabilities. In addition, these ceramic composites exhibit a highly directional thermal conductivity that, combined with the 3-D printing process, enables the fabrication of structures designed to manipulate heat flow (*e.g.* thermal metamaterials).

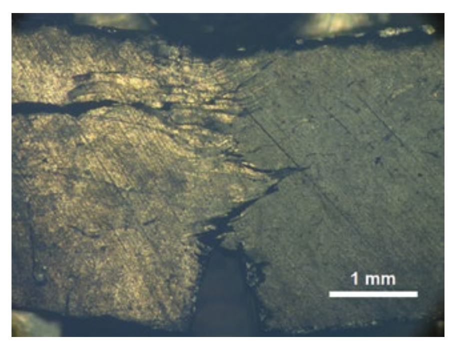


Figure 1. Optical micrograph taken in situ during the fracture of nacre-like graphite showing the action of multiple toughening mechanisms that result in stable crack propagation.

In another ESA-funded project [2], in collaboration with MTC and Azimut Space GmbH (Germany), MAPP researchers have developed new nacre-like graphite materials. In these materials graphite flakes (the bricks) are aligned and consolidated with a refractory mortar using spark plasma sintering. The structure generates improved fracture resistance with respect to pure graphite as well as highly directional thermal conductivity. One of the advantages of the nacre-like graphite is its ability to work at a very wide range of temperatures. Together with collaborators, researchers in MAPP are developing demonstrators to use these new materials in thermal management for space applications.

The MAPP research on bio-inspired materials is a clear example of how current advances in powder processing are opening new opportunities in the structural control of composites combining structural and functional capabilities. The goal is to extend these design concepts and fabrication strategies to a wide range of materials, enabling their practical implementation.

Further Funding:

1. NICOP-Living Materials, ONR, N62909-18-1-2056, $449,333
2. Bioinspired Composite Materials Based Synthetic Mother of Pearl for Space Applications (SYNACRE), 1000002475, ESA, £250,000.

Publications:

1. Additive Manufacturing of Shape Memory Thermoset Composites with Directional Thermal Conductivity, Hong *et* al, Advanced Materials, 2311193, 2023. https://doi.org/10.1002/adfm.202311193
2. 3D printing bioinspired ceramic composites, E. Feilden, C. Ferraro, Q. Zhang, E. García-Tuñón, E. D'Elia, F. Giuliani, Luc Vandeperre, Eduardo Saiz, Scientific reports 7 (1), 13759, 2017. https://doi.org/10.1038/s41598-017-14236-9

Figure 3. Alignment of microscopic inorganic platelets during processing (in this case hBN platelets in a vitrimer during extrusion) can be analysed using X-ray tomography (in collaboration with the Henry Moseley X-ray Imaging Facility at The University of Manchester)

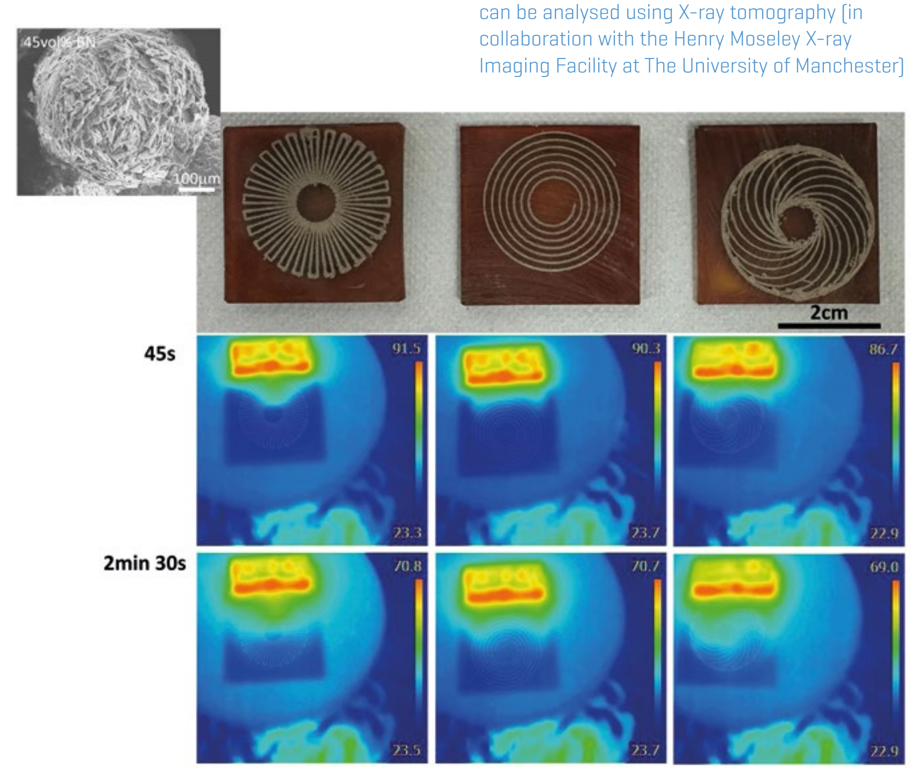


Figure 2. Alignment of hBN platelets during extrusion (inset) combined with direct ink writing enables the printing of materials structures designed to direct heat propagation (from a heat source placed on their side in this example).

P2.3C CASE STUDY - ADDITIVE MANUFACTURING OF CARBIDES

Investigators: Prof. Eduardo Saiz (Imperial)

Researchers: Dr Ollie Osborn (Imperial)

Collaborators: MTC, Photocentric, Kanthal

Silicon carbide (SiC) is one of the most used technical ceramics employed in a very wide range of applications from aerospace engines, specialised heating elements, bearings to applications in the nuclear industry. However, due to its inherent mechanical properties, the machining of SiC parts can be challenging. Additive Manufacturing (AM) can provide a much-needed alternative, enabling the fabrication of new, more efficient components. Between all the emergent AM technologies for ceramics, those based on the use of photocurable powder suspensions to build parts layer by layer present clear advantages in terms of resolution, surface finish and the ability to implement very complex geometries. Digital Light Processing (DLP) in particular, can combine all these advantages in a relatively low-cost system that uses LCD screens to create a mask that enables the fabrication of a whole layer in a single projection. The use of DLP with non-oxide ceramics has, however, been impaired by the mismatch in refractive indices of the powders and the photocurable polymers, limiting the curing depth and, therefore, the layer thickness.

In the framework of MAPP, and in collaboration with MTC and Photocentric, research on DLP of SiC has been developed using a relatively cheap desktop system. By manipulating the particle size distribution, using nano-powder additives as stabilisers and selecting the right photoinitiators, it has been possible to engineer photocurable powder suspensions that exhibit the right rheology for the process and adequate curing depths. Simultaneously, the de-binding and sintering process based on liquid infiltration pyrolysis have been developed to consolidate the printed parts. With additional funds from an Impact Acceleration Account [1] Imperial's research in MAPP is working on advancing the commercial application of the process. The team are collaborating with Kanthal on the fabrication of bespoke heating elements to enhance furnace efficiency. In addition, the long-term stability of the photocurable suspensions is being analysed and a full electrical and thermomechanical characterization of the printed materials is being performed. The process is being extended to the manufacturing of fibre-reinforced composites (with C and SiC fibres in a SiC matrix), taking advantage of the teams' experience on the 3-D printing of these composites using direct ink writing [2].

Beyond MAPP, the AM of non-oxide ceramics can open new possibilities in the fabrication of components for a broad range of applications. However, it will be essential now to ensure that the performance of the ceramics fabricated via AM matches that of those prepared using conventional technologies. This will require a very careful analysis of defect formation during the process and how it can be controlled and minimised.

Further Information:

1. UKRI Impact Acceleration Funding, Digital Light Processing of SiC, £79K.
2. Additive Manufacturing of Carbides and their Composites (MTC top up funding), £50K.

P2.3 Case Studies on the MAPP Website:

1. Graphene-Enhanced Powder Feedstocks for Laser Assisted Manufacturing

Investigators: Prof. Eduardo Saiz (Imperial)

Researchers: Dr I Elizarova (Imperial)

Collaborators: IC/UCL/Sheffield/Graphene First

https://mapp.ac.uk/publications/p2.3-case-study-a-imperial

2. Development of In-situ Micromechanical Testing

Investigators: Prof. Eduardo Saiz (Imperial)

Researchers: Siyang Wang (Imperial)

Collaborators: IC/SECO Tools

https://mapp.ac.uk/publications/p2.3-case-study-b-imperial

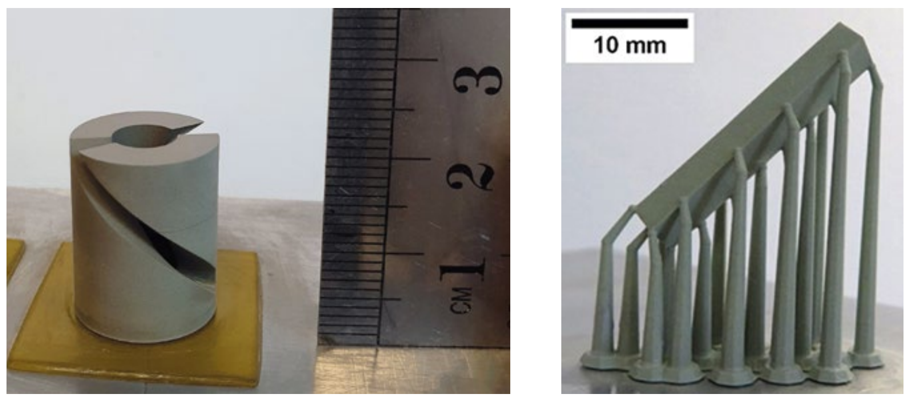


Figure 1. SiC parts fabricated by DLP. The picture on the left shows a small heating element

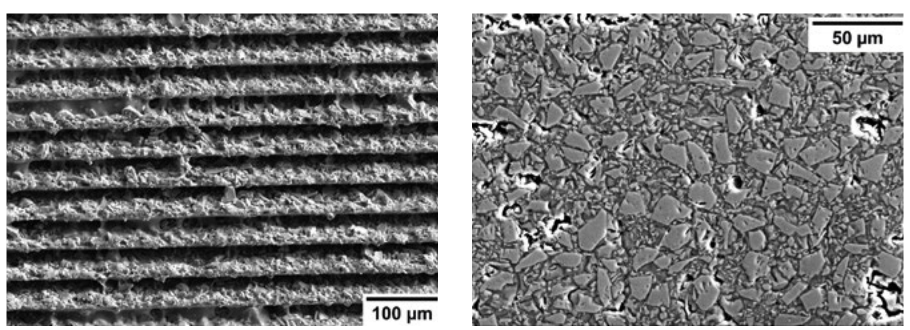


Figure 2. Left, scanning electron micrograph of the surface of a SiC part fabricated using DLP, a characteristic layered surface can be observed. Right, scanning electron micrograph of the microstructure of a SiC part prepared using DLP followed by liquid polymer infiltration pyrolysis. It is possible to densify parts using this process

X1 CASE STUDY: PHOTO-THERMAL EFFECT INDUCED IMPROVED PRINTABILITY FOR LASER POWDER BED FUSION MANUFACTURING OF PURE COPPER

Investigators: Prof. Peter Lee, Dr Chu Lun Alex Leung (UCL), Prof. Eduaro Saiz, Dr Iullia Trichenko (née Elizarova) (ICL)

Researcher: Dr Shishira Bhagavath (UCL)

Collaborators: UKRI Research Complex at Harwell, Imperial College London, University of Sheffield, Graphene First, ESRF, Henry Royce Institute

Laser powder bed fusion (LPBF) additive manufacturing (AM) is a technology capable of manufacturing components with intricate geometries using layer by layer build up of metal powder feedstock. LPBF contributes to <1 % of total metal component manufacturing partly due to the due to the limited commercial availability of feedstock powder types (<50 types). One of the reasons for the small range of powdered metals is the limited laser-matter coupling efficiency. The coupling efficiency of highly reflective powders, such as copper (Cu) and aluminium (Al), is particularly low and these require much higher energies to melt.

The innovative research carried out in MAPP has led to the patenting of a chemically modified graphene (CMG) additive [1, 2] in addressing the challenges of limited coupling efficiency. The functionality of CMG allows for the conversion of photon (laser) energy into heat, improving the effective absorptivity of the powder feedstock. CMG can absorb a large spectrum of laser wavelengths, eliminating the requirement to use different laser sources, and bring down the costs of AM.

The research has investigated the effectiveness of CMG on improving the printability of copper. Different levels of Cu / CMG blends were prepared (Figure 1(a)) and additive manufacturability was trialled at various powers and velocities (Figure 1(b)). UV-VIS spectroscopy revealed a twofold improvement in laser absorptivity with the addition of CMG and allowed for AM at half the power whilst maintaining the manufacturing speed. At typical operating powers for copper AM, the addition of CMG allowed for nearly double the speed, increasing the productivity. Synchrotron fast X-ray imaging on the ID19 beamline at the European Synchrotron Research Facility (ESRF) was used to investigate the melt pool dynamics and spatter (Figure 1(c)) and facilitated the optimisation of defect free AM parameters.

MAPP was instrumental in inception and growth of this collaborative work and provided resources for large sample AM (Figure 1(d)) at University of Sheffield (Prof. Ian Todd and Dr Rob Snell), which allowed the investigation of the entire process from powder to properties of the additively manufactured part. This work has led to a successful Royce Equipment Access Scheme proposal for using ACONITY MINI and ACONITY LAB (LPBF 3D printing machines) at Henry Royce Institute (£8.6k).

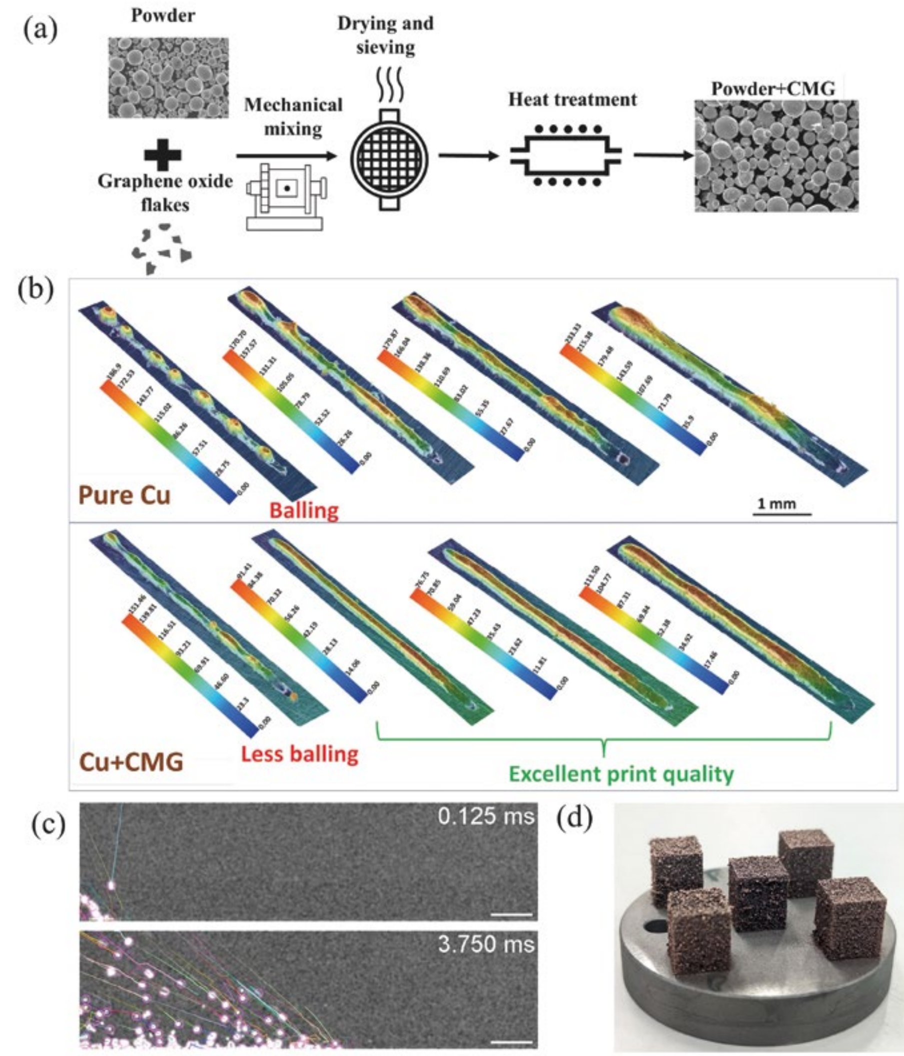


Figure 1. (a) Copper-CMG powder blend preparation. (b) Height map of single tracks for pure copper and Cu+CMG blend showing the improved surface finish and printability with the addition of chemically modified graphene (CMG). (c) Example of in situ process monitoring using synchrotron X-rays where the powder spatter during printing is captured and quantified. (d) Test cubes printed on an industry scale powder bed.

Publications:

[1] Chu Lun Alex Leung, Iuliia Elizarova, Peter D Lee, Eduardo Saiz., 'Enhanced feedstock for additive manufacturing', US Patent No.- US20230415409A1 (2023).

[2] Leung, C.L.A., Elizarova, I., Isaacs, M., Marathe, S., Saiz, E. and Lee, P.D., 2021. 'Enhanced near-infrared absorption for laser powder bed fusion using reduced graphene oxide'. Applied Materials Today, 23, p.101009.

X1 CASE STUDY: PORE EVOLUTION MECHANISMS DURING DIRECTED ENERGY DEPOSITION ADDITIVE MANUFACTURING

Investigators: Prof Peter Lee

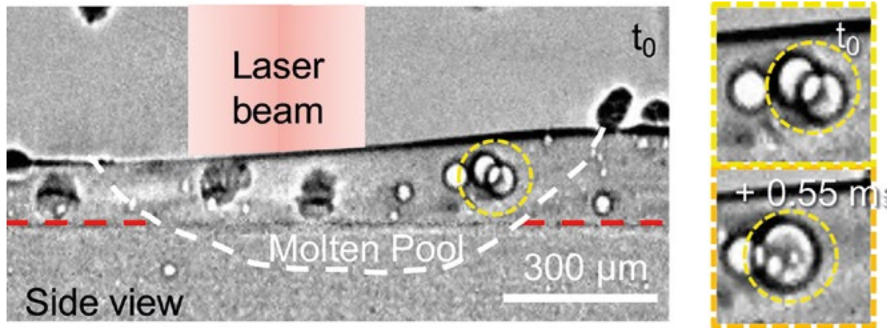
Researchers: Dr Kai Zhang

Collaborators: UCL, ESRF, RMIT, Shimane University, Queen Mary University of London, Rolls-Royce plc

Directed Energy Deposition (DED) is a promising layer-by-layer Additive Manufacturing (AM) technology that fabricates complex geometries for high-value-added products and repair applications. Porosity in DED deteriorates mechanical performances of components, limiting safety-critical applications. How these pores arise and evolve in DED remains unclear. In this work, Zhang *et al.* [1] revealed pore evolution mechanisms during DED using in situ X-ray imaging (Figure 1 left) and multi-physics modelling (Figure 1 right). Five mechanisms contributing to pore formation, migration, pushing, growth, removal and entrapment were quantified: (i) bubbles from gas atomised powder enter the melt pool, and then migrate circularly or laterally; (ii) small bubbles can escape from the melt pool surface, or coalesce into larger bubbles, or be entrapped by solidification fronts; (iii) larger coalesced bubbles can remain in the melt pool for long periods, pushed by the solid/liquid interface; (iv) Marangoni surface shear flow overcomes buoyancy, keeping larger bubbles from being released; and (v) once large bubbles reach critical sizes they escape from the melt pool surface or are trapped in DED tracks. These mechanisms can guide the development of pore minimisation strategies.

MAPP supported the work by bringing together the expertise from different collaborators (*i.e.* UCL, ESRF, RMIT, Rolls-Royce plc, Shimane University, Queen Mary University of London), including development of the Blown Powder Additive Manufacturing Process Replicator II (BAMPR II) that enables in situ multi-modal imaging of the DED process, synchrotron X-ray experiment, image and data processing, multi-physics modelling. More information about this project has been announced by the ESRF: https://www.esrf.fr/home/news/general/content-news/general/researchers-uncover-a-new-mechanism-of-large-pore-formation-during-additive-manufacturing.html

In situ X-ray Imaging of Bubble Coalescence and Pushing



Multi-physics Modelling of Additive Manufacturing

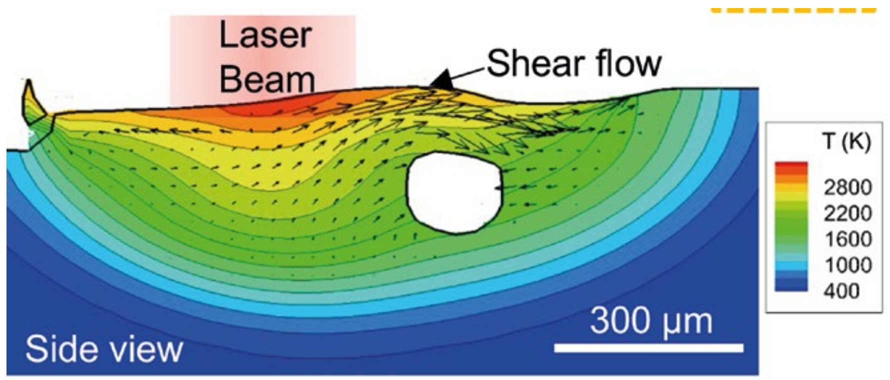


Figure 1. Pore evolution mechanisms in directed energy deposition additive manufacturing revealed with in situ X-ray imaging and multi-physics modelling.

Publications:

[1] Kai Zhang, Yunhui Chen, Xianqiang Fan, Sebastian Marussi, Maureen Fitzpatrick, Shishira Bhagavath, Marta Majkut, Bratislav Lukic, Alexander Rack, Martyn Jones, Junji Shinjo, Chinnapat Panwisawas, Chu Lun Alex Leung, Peter D. Lee, Pore evolution mechanisms during directed energy deposition additive manufacturing. Nature Communications, 15, Article 1715 (2024). https://www.nature.com/articles/s41467-024-45913-9

X1 Case Studies on MAPP Website:

1. AM-SegNet for additive manufacturing in situ X-ray image segmentation and feature quantification

Investigators: Prof Peter Lee, Prof Chu Lan Alex Leung

Researchers: Dr Wei Li

Collaborators: UKRI Research Complex at Harwell, UCL, ESRF

https://mapp.ac.uk/publications/x1-case-study-a-ucl

2. Impact of powder oxidation during additive manufacturing

Investigators: Prof Peter Lee

Researchers: Prof Chu Lun Alex Leung

Collaborators: UKRI Research Complex at Harwell, UKRI STFC, Central Laser Facilities, Diamond Light Source Ltd., Henry Royce Institute, Cardiff University, HarwellXPS, TWI Ltd., National Structural Integrity Research Centre (NSIRC), European Space Agency, Imperial College London , Conventry University, University of Leicester

https://mapp.ac.uk/publications/x1-case-study-b-ucl

3. New insights into laser 3D metal printing provide critical guidance in reducing porosity

Investigators: Prof Peter Lee, Prof Chu Lun Alex Leung

Researchers: Dr Yuze Huang

Collaborators: UKRI-STFC, HRL (USA), Queen's University (Canada), Argone National Laboratory (USA)

https://mapp.ac.uk/publications/x1-case-study-c-ucl

X2 CASE STUDY: CAN POWDER SPREADABILITY BE CORRELATED WITH BULK FLOW AND INDIVIDUAL PARTICLE CHARACTERISTICS IN ADDITIVE MANUFACTURING?

Investigators: Dr Ali Hassanpour

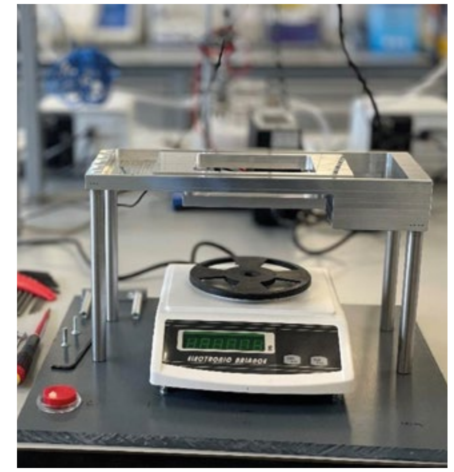
Researchers: Dr Mozhdeh Mehrabi

Collaborators: University of Sheffield (P2.1), Imperial College London (P2.3), University of Cambridge (X3), Carpenter Additive, Royce Transitional Centre (AMRC), University of Edinburgh

For Additive Manufacturing (AM) techniques including Laser Powder Bed Fusion (LPBF), achieving uniform powder layer distribution prior to sintering is essential for maintaining the precision and quality of the final product. Several factors influence the spreading behaviour of powder in AM which can play a crucial role in the properties of the final part. In the past two decades, numerous researchers have been attempting to propose correlations between powder properties, notably the bulk flow behaviour, and spreadability.

Powder flowability refers to the ability of particles to flow smoothly and consistently in various conditions, which is influenced by single particle properties such as particle size, shape, and surface properties as well as the flow conditions, such as degree of powder compaction, strain rate and environment. Several well-known techniques exist to assess powder flowability, the most commonly used methods are based on the Carr Index, Hausner Ratio, Hall and Carney Flowrate, Shear Cell, Static and Dynamic Angle of Repose, Avalanche Test, and Powder Rheometer.

The journey of powders in AM starts with transportation from the manufacturing site to the storage location for the AM process, usually taking place under controlled environmental conditions. Handling powders in AM initiates at the feeding stage by gravity discharge from hoppers (gravity) or using a die and piston arrangement (force fed). The powder flow behaviour is established based on particles' physical and surface characteristics. However, the powder flow during the spreading stage in AM is rather complex. It takes place under dynamic conditions from a relatively loose state and into a narrow gap, typically 2-3 particle diameter across, between the spreader and build plate, inducing a high shear strain rate. For this stage, none of the standard techniques can simulate the spreading conditions. While devices have been specifically designed to measure powder spreadability, scientists have focused on establishing correlations between powder flowability metrics and spreading behaviour during AM processes. Given the need for reasonable and acceptable results, usually a combination of different experimental techniques and mathematical modelling should be employed to achieve the desired accuracy.



Prototype of spreading rig designed at University of Leeds

The research conducted at the University of Leeds has developed a comprehensive understanding of the concepts of powder spreading in AM and its correlation with single particle and bulk flow characteristics. To accomplish this, a wide range of partner-supplied AM powders were analysed to measure their physical properties, flowability characteristics, and spreading behaviour. This investigation involved powder with a wide range of properties and various spreading conditions such as gap size (spread layer thickness), blade speed, using an in-house designed spreading rig with two different build plate configurations.

A Principal Component Analysis (PCA) was conducted to evaluate the correlation between powder flowability techniques and powder spreadability. Despite attempts to experimentally correlate standardised flowability tests to powder spreadability, the existing flowability measurement techniques only partially correlated with spreadability and, in some cases, led to contradictory results.

It became evident in this research that to identify and choose the appropriate powder for AM, a direct assessment of powder spreading should be carried out. An in house prototype powder spreading rig has been designed at Leeds with a build plate that can be moved vertically to achieve different spreading gaps and is controlled by a PC to operate at a range of spreading velocities. The system has been designed with an automated dosing system in a temperature and humidity controlled chamber. The effectiveness of this rig is being evaluated with funding through an Impact Acceleration Award; *A new device to assess the spreadability of powders for AM.*

X2 CASE STUDY - IN-SITU X-RAY IMAGING OF POWDERS UNDER BALL INDENTATION VIA X-RAY MICRO CT

Investigators: Prof Philip Withers

Researchers: Dr Zihan Song

Collaborators: University of Leeds

This study used X-ray micro-computed tomography (XMCT) to reveal the ball indentation process in 3D and develop a further understanding of the powder packing behaviour during the process. The XMCT also allows us to quantify the packing density of powders at different regions of the powder bed during ball indentation at different penetration depths and track the powder movement.

Flow resistance and flowability are important properties of powders for additive manufacturing, which have great influences on the mechanical properties of the end products. The ball indentation technique provides a measure of hardness which can be related to flow resistance and flowability of powders. However, it is challenging to attain a reliable indentation process. In-situ XMCT is a non-destructive method that can reveal the movement of powders during the indentation process. It also allows the quantification of different layer packing fractions and locally consolidated regions.

The experiment was carried out at the National X-ray Computed Tomography (NXCT) lab, University of Manchester. As shown in Figure 1, CT 5000 rig (Deben, UK) was installed on top of the rotation stage of Versa 620 CT scanner (Zeiss, Germany). Ti alloy powders that were manufactured via gas atomization were sieved and loosely filled into a 10 mm diameter container. It was then mounted on the bottom grip of the rig, while a glass ball indenter was fixed on the top grip of the rig. This allows precise control of the indentation to different penetration depths (from 10% to 40% of the ball diameters). Before scanning, the rig was held for another 30 minutes to achieve a stable condition. Voltage of 140 kV, Power of 21 W and an exposure time of 21 s were chosen to achieve a good balance between the image quality and the scanning time. A series of projections were acquired while the rig was rotating within the CT scanner.

The scanned images provide a 12 mm x 12 mm field of view with a voxel size of 6.17 μm. Figure 2 shows examples of the vertical XZ slices of the CT images at different indentation depths and an example of 3D volume particles. The individual particles and their internal pores can be easily distinguished. The movement of powders under indentation can be tracked.

The experimental cost has been funded by MAPP. The collaboration between the University of Manchester and the University of Leeds team is funded by MAPP.

Figure 1: experiment setup at NXCT, Manchester

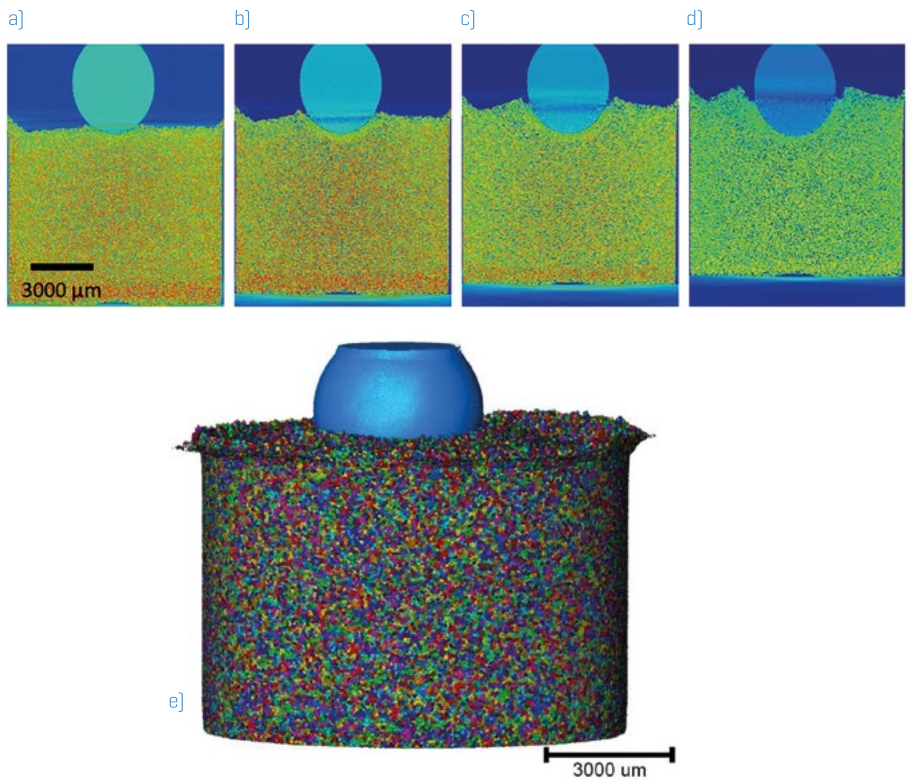


Figure 2: vertical XZ slices of CT images of powders at different indentation depth, (a) 10% (b) 20% (c) 30% (d) 40% scale bar: 3000 μm; (e) 3D volume of particles.

X3 CASE STUDY – DATA DRIVEN CONTROLLER DESIGN VIA REINFORCEMENT LEARNING USING SURROGATE MODELS

Investigators: Prof. George Panoutsos (Sheffield)

Researchers: Dr Scott Notley, Dr Emad Grais

Modelling work in MAPP has demonstrated the successful application of reinforcement learning, in a high fidelity physics based simulation environment, to optimise a multi-input (power and velocity) feedback controller for achieving consistent melt pool depths compared to a desired level (Grais *et al*, 2023). The developed computational framework is based on Proximal Policy Optimization (PPO) reinforcement learning which requires many thousands of interactions with the simulation environment and poses major lead time challenges. A single optimisation process typically can take days to perform on a high performance computing cluster. A possible solution to this is the replacement of the physics based simulation environment with a data-driven, computationally efficient surrogate environment.

Surrogate models are computationally cheap *approximating* the dominant features and responses of more complex high fidelity models. A new modelling framework has been adapted from a method previously developed in MAPP which estimates uncertainty and requires no prior assumptions on data distributions and covariance (Notley *et al*, 2022).

A key question is how to make best use of the extra information, the uncertainty of the surrogate prediction, within the reinforcement learning paradigm. Reinforcement learning utilises a reward function that indicates how appropriate a control action is based, in this case, on how close the resulting melt pool depth is to the desired target depth; a typical reward function being the double exponential function. Since the surrogate model prediction is only an approximation, control actions based only on the mean prediction may result in high levels of inappropriate reward and this leads to instability when the *surrogate designed* controller is applied to the 'true' environment. It is expected that the appropriate use of the surrogate model uncertainty will mitigate this effect leading to more robust control optimisation.

In this case we replace the scalar reward function with our proposed probabilistic version given by:

$$R_{prob}(\mu,\sigma) = \int R_{scaler}(\delta)p(\delta;\mu,\sigma)d\delta$$

where $p(\delta;\mu,\sigma)$ is the probability density of the uncertainty function and $R_{scaler}(\delta)$ is the scalar reward function. This reward is the summation of rewards, across all melt pool depths, weighted by the probability of that melt pool depth being generated by the surrogate model. The final probabilistic reward is a function of both the mean predicted melt pool depth, μ, and the prediction uncertainty, σ. In this case we assume a Gaussian probability density for the uncertainty given by:

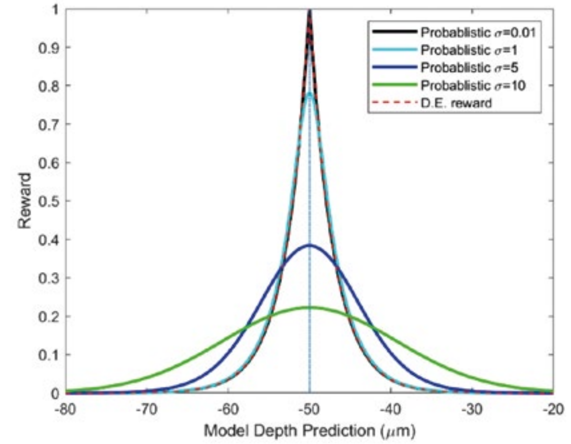


Figure 1. The probabilistic reward function for different levels of prediction uncertainty and a desired target melt pool depth of -50μm. The scaler reward function is shown as a dotted red line.

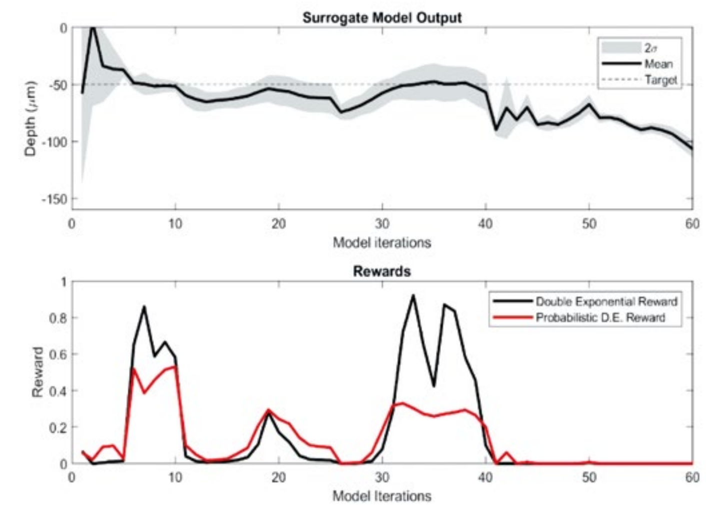


Figure 2. A comparative example between the scaler and probabilistic reward function for a single run of the surrogate model.

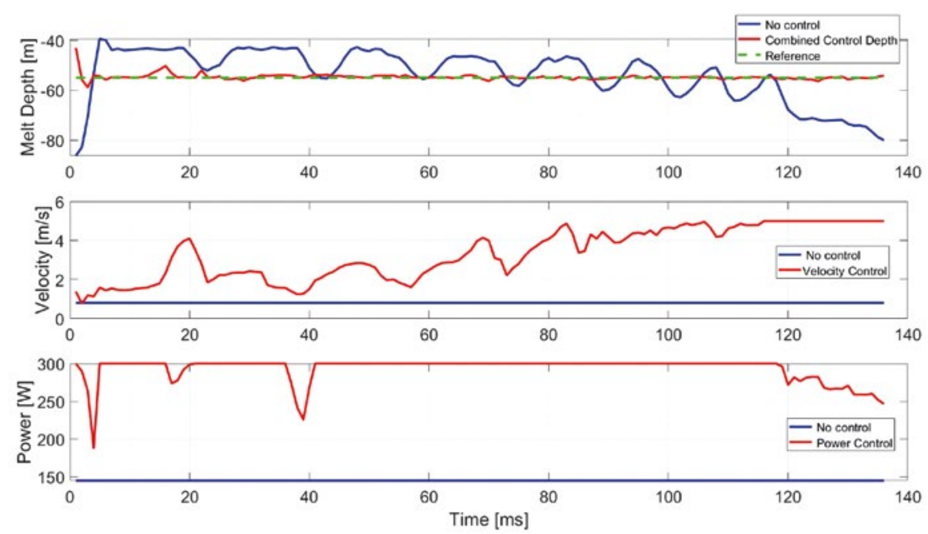


Figure 3. Application of the reinforcement learning, using probabilistic rewards, to the control of the surrogate model.

$$p(\delta;\mu,\sigma) = \frac{1}{\sqrt{2\pi\sigma}}e^{-\frac{(\delta-\mu)^2}{2\sigma^2}}$$

The scaler reward, in this case, is the is double exponential given by:

$$R_{scaler}(\delta) = e^{-\frac{|\delta - T|}{\alpha}}$$

where T is the desired target melt pool depth, δ is the melt pool depth and α is a hyperparameter that governs the decay of the function.

Figure 1 shows comparative examples of the probabilistic reward function for a target melt pool depth of -50 μm for different levels of prediction uncertainty. It may be seen that for low levels of uncertainty the function is close to that of the scalar reward function (red dotted line). As the uncertainty increases the probabilistic reward function broadens and attenuates the maximum level of reward available.

Figure 2 shows an example of rewards generated from a single run of the surrogate model. It may be seen that for mean predictions close to the desired target level, but with high uncertainty, the probabilistic reward function is attenuated in comparison to the scaler reward. It may also be seen that for mean predictions further from the target values, but still with two standard deviations of the target value, the reward is greater than that produced by the scalar reward. Intuitively this makes sense since even though the mean predicted depth is not at the desired level, there is a significant chance the control action is a 'good' one.

Figure 3 shows the results of incorporating the probabilistic reward function into the reinforcement learning paradigm demonstrating the ability to optimise a controller using probabilistic rewards. In this case the desired melt pool depth was -55 μm; the blue line shows the output of the surrogate model in a no control situation for velocity of 0.8 m/s and a power of 145 Watts. The red line shows the application of the optimised controller. The lower two plots show the power and velocity control actions taken to maintain the melt pool depth close to the target value.

For the first time in the literature, the proposed methodology opens a pathway for robust multivariable control for AM processes, where the use of fast (computationally efficient) surrogates is a key enabler. High fidelity, expensive to run simulations (FE, CDF etc.) can be used to capture desired properties and behaviours indirectly for advanced process control. This is a significant achievement for the MAPP hub. Further work is investigating the transferability of surrogate designed controllers to the physics based environment (hence, moving closer to high TRL implementation).

MAPP SECOND INTERNATIONAL CONFERENCE

The MAPP Second International Conference was held at the Novotel Hotel in Sheffield on 28th – 29th June 2023

Article by Rachel Park,
RP Editorial Services.

At the end of June, the MAPP Second International Conference took place in Sheffield, United Kingdom. The event was hosted to highlight, share and celebrate the breadth and diversity of the research that is being conducted across the MAPP research programme and to bring together many experts from across the interdisciplinary field of manufacturing using advanced powder processes.

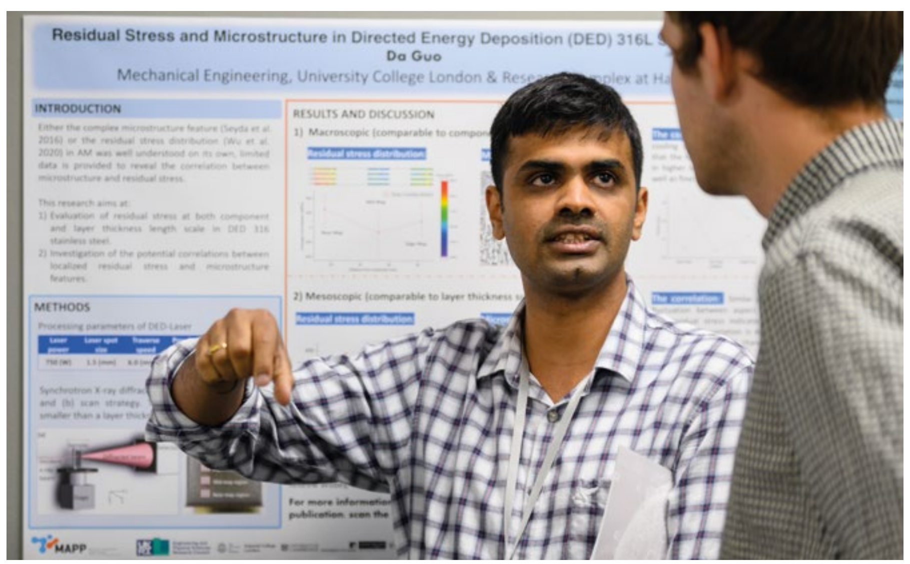
Originally scheduled to end in September 2023 after 7 years, the MAPP research programme has now been extended to the end of June 2024. Professor Iain Todd, MAPP Director, took some time to explain this: "Like all of the UK's research hubs, Covid affected MAPP, particularly in terms of outreach and deliverables, one of its key goals, between 2020 and 2022. On this basis, EPSRC has granted a 9-month extension. There are no extra funds, just additional time to facilitate wrapping up the research programmes and allow people to get to where they want/need."

If this event has shown anything, it is that there is a wealth of talent and research going on both across UK universities and internationally. Moreover, a great deal of it is being tested and applied through strong industrial collaborations. Professor Todd went on to emphasise what he believes to be MAPP's greatest success: "I think the biggest thing we've achieved with MAPP is the introduction of 'big science' to the manufacturing sector and we are just starting to see the dial moving on this."

The MAPP conference programme was very science intense and sessions reflected the five key themes of the research hub. This intensity is unsurprising given the high numbers of extremely intelligent scientists – proven experts in their field/s — who are contributing to MAPP projects. Delving deep into the science, they are working out how to apply that science to powder materials, advanced processes and systems. There was lots of physics and copious amounts of chemistry, both supported by a great deal of maths. There was just one, tenuous, reference to biology (that I spotted): Erik Poloni's mother of pearl inspiration. There were also a considerable number of data science references too.

It is hard to get into one short review the vast breadth and depth, as well as the aforementioned intensity, of the research that the MAPP hub has enabled. I doubt the full two days of the conference covered it all, to be honest; and they tried really hard. No more so than during the session dedicated to Flash presentations given by early career researchers (ECRs). 19 of them squeezed, brutally, into 40 minutes. Each of these ECRs also had the opportunity to showcase a poster demonstrating their research, which were judged by conference attendees across various categories, the winners were announced at the end of the conference and you can see who won each category below. There were also some additional posters, supplied by students from Aerospace Engineering at the University of Sheffield to showcase some recent student-led project work involving additive manufacturing technologies, including the design, manufacture and testing of a student-built liquid rocket engine.

ECR Jiaqi Xu presenting her flash presentation.



MAPP Speaker Dr Mozhdeh Mehrabi (University of Leeds) Advanced Characterisation of AM Powders

Invited speaker Prof Diego Barletta (University of Salerno, Italy)
Spreading of Polymeric Powders at Different Temperatures for the SLS Process

The conference programme was packed with speakers both from MAPP projects and external, invited speakers who were all fully invested in their subjects. It showed in the content and the delivery. Passion, practical knowledge and professionalism were evident throughout the whole programme.

I think the overarching takeaway from this conference is PROGRESS – MAPP has achieved this in spades with new technology in development along with projects that focus on established tech to extend and improve it.

Which leads into another very positive MAPP outcome: the number of talks that highlighted specific research for specific industry sectors. Just some of these are Aerospace & Defence, satellites and nuclear energy. The specificity was notable and a good thing in that narrower research often produces better results, faster. It was striking how dedicated commitment — and investment — leads to progress.

The networking opportunities afforded by this event were numerous, and perhaps more valued than they were just over three years ago. I suspect it will be a while before the ability to meet, talk and share valuable research in person will be taken for granted again. Professor Martin Jackson, from the University of Sheffield, perhaps captured this post-Covid feeling the best when he said: "this is the first time we've met in 3-dimensions, since Covid, it feels good."

In this vein, Candice Majewski, from the University of Sheffield, delivered a wonderful presentation, her composure and delivery of the many AM polymer powder projects that she is overseeing was truly inspiring. The work with anti-bacterial materials for AM parts in particular continues to gather momentum. But perhaps the highlight of her talk was her invitation to the audience not just to ask questions but to pose new ideas to her and her team, and to any other speakers who sparked an idea – "that's how the big projects happen, from ideas and conversations at events like this."

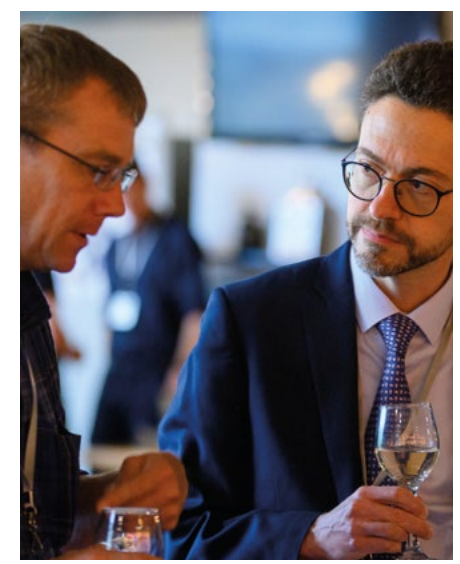
WINNERS OF THE POSTER & FLASH PRESENTATION PRIZES, AS VOTED BY DELEGATES:

Category 1:
Best Poster Content
Caterina Iantaffi: UCL

Category 2:
Best Poster Layout
Kieren Nar: University of Sheffield

Category 3:
Best Poster Image
Alistair John: University of Sheffield

Category 4:
Best Flash Presentation
Xianqiang Fan: UCL



MAPP
PROJECT PARTNERS

University of Sheffield · University of Cambridge · Imperial College London · University of Leeds · Manchester 1824 The University of Manchester · University of Oxford · UCL

MAPP is led by the University of Sheffield and brings together leading research teams from the Universities of Cambridge, Leeds, Manchester and Oxford, Imperial College London and University College London, together with industry partners and the UK's High Value Manufacturing Catapult Centres.

HIGH VALUE MANUFACTURING CATAPULT CENTRES

- AMRC Advanced Manufacturing Research Centre / The University Of Sheffield.
- AFRC Advanced Forming Research Centre University of Strathclyde
- Catapult High Value Manufacturing
- cpi
- mtc Manufacturing Technology Centre
- National Composites Centre
- Nuclear AMRC
- WMG Innovative Solutions

INDUSTRY PARTNERS

- Atomising Systems Limited
- Eastman
- element six
- Carpenter Additive
- freemantechnology
- GKN Aerospace
- JM Johnson Matthey Inspiring science, enhancing life
- Maher
- Metalysis
- Morgan Advanced Materials
- Photocentric
- PSI
- Renishaw apply innovation™
- Rolls-Royce
- Safran Messier-Bugatti-Dowty
- Seco
- Wayland Additive
- Weir
- Xaar
- Zeiss

ADDITIONAL COLLABORATING AND CONTRIBUTING INDUSTRIES

Throughout the seven years of research, MAPP has worked with additional industries through; collaboratively funded aligned projects (some of which are listed at the end of this report), directly funded programmes and projects or through indirect and in-kind industrial funding. In total, over 125 companies have collaborated and contributed to the MAPP and MAPP-aligned research across a wide range of advanced powder-based processes.

- Additive Industries
- Addmaster
- AddUp
- Airbus
- Alfa Laval
- Alloyed
- Amexci AB
- Arcelor Mittal
- AREVA Group
- Argonne National Laboratory
- Aubert and Duval
- Autodesk
- Azimut Space
- Baltic Scientific Instruments
- BEAMIT
- Bentley Motors
- Boeing
- Braskem
- Britishvolt
- Carbolite Gero
- CCFE
- Central Laser Facility
- CFMS
- Cidetec
- Constellium
- Diamond Centre Wales
- Diamond Light Source
- Dr Fritsch
- DSTL
- Eckhart
- EDF Energy
- ESA
- ESRF
- Force Technology
- Ford
- Granutools
- HBK
- Heita
- HRL Laboratories
- Illika
- Inovar Communications
- IPG Photonics (UK)
- Insphere
- Jaguar Cars
- JLR
- Kanthal
- KTN
- Liberty Powder Metals
- LSN Diffusion
- Lucideon
- Malvern
- Materialise
- McClaren
- Meggit
- Metal Powder Emergence Ltd
- Metron
- Multilase
- Netzsch
- Northern Automotive Alliance
- NPL
- Oerlikon
- Olympus
- Oxford Instruments
- Oxford Lasers Ltd
- Phoenix Materials Testing
- PowderLoop Technology Ltd
- Qdot
- Quintus Technologies
- Relequa
- Reliance
- Reliance Precision
- Retsch UK
- Rheinmetall BAE Systems Land (RBSL)
- SABIC
- Sandvik Osprey
- Sheffield Assay Office
- Shell
- Siemens
- Solar Turbines
- St Gobain
- STFC
- Tata Steel
- Thermocalc
- Thinklaser
- Timet
- TISICS
- Tokamak
- Transition International Ltd
- Tripal
- TWI
- UKAEA
- US Office of Naval Research Global
- Verder Scientific
- Victoria Drop Forgings Ltd
- WH Tildsley
- Wilde Analysis

The recently upgraded ACONITYMINI (ACONITY3D GmbH) Laser Powder Bed Fusion (LPBF) machine at the Royce Discovery Centre (RDC) in Sheffield.

PUBLICATIONS

2023 - 2024 has seen the publication of an additional 36 MAPP Journal and Conference papers, bringing further understanding to a wide range of advanced powder processes across our research themes including in-situ process monitoring, advanced characterisation, enhanced product performance, and modelling, optimisation and control.

2017 (THEME: P2.1)

Tammas-Williams, S., Todd, I., (2017), Design for additive manufacturing with site-specific properties in metals and alloys, Scripta Materialia, **135**, 105-110, https://doi.org/10.1016/j.scriptamat.2016.10.030

Tammas-Williams, S., Withers, P.J., Todd, I., Prangnell, P., (2017), The Influence of Porosity on Fatigue Crack Initiation in Additively Manufactured Titanium Components, *Scientific Reports*, **7**, 7308, https://doi.org/10.1038/s41598-017-06504-5

Smith, P.J., Tammas-Williams, S., Hernández-Nava, E., Todd, I., (2017), 42983, Tailoring the thermal conductivity of the powder bed in Electron Beam Melting (EBM) Additive Manufacturing, *Scientific Reports*, **7**, 10514, https://doi.org/10.1038/s41598-017-11243-8

Todd, I., (2017), 42998, Metallurgy: No more tears for metal 3D printing, *Nature*, **549**, 342–343, https://doi.org/10.1038/549342a

2017 (THEME: P2.2)

Mousavi, T., Hong, Z., Morrison, A., London, A., Grant, P., Grovenor, C., Speller, S., (2017), A new approach to fabricate superconducting NbTi alloys, *Superconductor Science and Technology*, **30** (9), 094001, https://doi.org/10.1088/1361-6668/aa793d

2017 (THEME: P2.3)

Feilden, E., Giovannini, T., Ni, N., Ferraro, C., Saiz, E., Vandeperre, L., Giuliani, F., (2017), Micromechanical strength of individual Al2O3 platelets, *Scripta Materialia*, **131**, 55-58, https://doi.org/10.1016/j.scriptamat.2017.01.008

García-Tuñón, E., Feilden, E., Zheng, H., Elia, E., Leong, A., Saiz, E., (2017), Graphene Oxide: An All-in-One Processing Additive for 3D Printing, *ACS applied materials & interfaces*, **9**(38), 32977-32989, https://doi.org/10.1021/acsami.7b07717

Feilden, E., Ferraro, C., Zhang, Q., García-Tuñón, E., D'Elia, E., Giuliani, F., Vandeperre, L., Saiz, E. , 2017, 3D Printing Bioinspired Ceramic Composites, *Scientific Reports*, **7**, 13759, https://doi.org/10.1038/s41598-017-14236-9

2017 (THEME: X1)

Poologasundarampillai, G., Todd, N., Devlin-Mullin, A., Moore, K.L., Golrokhi, Z., Gilchrist, J.B., Jones, E., Potter, R.J., Sutcliffe, C., O'Brien, M., Hukins, D.W.L., Cartmell, S., Mitchell, C.A., Lee, P.D., (2017), Biotransformation of Silver Released from Nanoparticle Coated Titanium Implants Revealed in Regenerating Bone, *ACS Applied Materials and Interfaces*, **9**(25), 21169-21180, https://doi.org/10.1021/acsami.7b05150

2018 (THEME: P2.1)

Todd, I., (2018), Metallurgy: Printing steels, *Nature Materials*, **17**, 13-14, https://doi.org/10.1038/nmat5042

Boone, N., Zhu, C., Smith, C., Todd, I., Willmott, J.R., (2018), Thermal near infrared monitoring system for electron beam melting with emissivity tracking, *Additive Manufacturing Journal*, **22**, 601-605, https://doi.org/10.1016/j.addma.2018.06.004

Thompson, A., Tammas-Williams, S., Senin, N., Todd, I., Leach, R., (2018), Correlating volume and surface features in additively manufactured metal parts, *ASPE 2018 Advancing Precision in Additive Manufacturing Conference, July, Berkeley USA*, 116-120, https://core.ac.uk/download/pdf/159994089.pdf

Smith, C.J., Tammas-Williams, S., Mahoney, P.S., Todd, I., (2018), 3D printing a jet engine: An undergraduate project to exploit additive manufacturing now and in the future, *Materials Today Communications*, **16**, 22-25, https://doi.org/10.1016/j.mtcomm.2018.03.006

Hancock, D., Homfray, D., Porton, M., Todd, I., Wynne, B., (2018), Exploring complex high heat flux geometries for fusion applications enabled by additive manufacturing, *Fusion Engineering and Design*, **136**(A), 454-460, https://doi.org/10.1016/j.fusengdes.2018.02.097

Freeman, F.S.H.B., Lincoln, A., Sharp, J., Lambourne, A., Todd, I., (2018), Exploiting thermal strain to achieve an in-situ magnetically graded material, *Materials & Design*, **161**, 14-21, https://doi.org/10.1016/j.matdes.2018.11.011

Bajaj, P., Wright, J., Todd, I., A.Jägle, E., (2018), Predictive process parameter selection for Selective Laser Melting Manufacturing: applications to high thermal conductivity alloys, *Additive Manufacturing*, **27**, 246-258, https://doi.org/10.1016/j.addma.2018.12.003

Hancock, D., Homfray, D., Porton, M., Todd, I., Wynne, B., (2018), Refractory metals as structural materials for fusion high heat flux components, *Journal of Nuclear Materials*, **512**, 169-183, https://doi.org/10.1016/j.jnucmat.2018.09.052

2018 (THEME: P2.2)

Auger, M.A., Huang, Y., Zhang, H., Jones, C.A., Hong, Z., Moody, M.P., Roberts, S.G., Grant, P.S., (2018), Microstructural and mechanical characterisation of Fe-14Cr-0.22Hf alloy fabricated by spark plasma sintering, *Journal of Alloys and Compounds*, **762**, 678-687, https://doi.org/10.1016/j.jallcom.2018.05.196

2018 (THEME: P2.3)

Ali, H., Ghadbeigi, H., Mumtaz, K., (2018), Effect of scanning strategies on residual stress and mechanical properties of Selective Laser Melted Ti6Al4V, *Materials Science and Engineering: A*, **712**, 175-187, https://doi.org/10.1016/j.msea.2017.11.103

Zavala-Arredondo, M., Groom, K., Mumtaz, K., (2018), Diode area melting single-layer parametric analysis of 316L stainless steel powder, *The International Journal of Advanced Manufacturing Technology*, **94**, 2563-2576, https://doi.org/10.1007/s00170-017-1040-4

Ali, H., Ghadbeigi, H., Mumtaz, K., (2018), Residual stress development in selective laser-melted Ti6Al4V: a parametric thermal modelling approach, *The International Journal of Advanced Manufacturing Technology*, **97**(5-8), 2621-2633, https://doi.org/10.1007/s11665-018-3477-5

Zavala-Arredondo, M., Ali, H., Groom K.M., Mumtaz, K., (2018), Investigating the melt pool properties and thermal effects of multi-laser diode area melting, *The International Journal of Advanced Manufacturing Technology*, **97**(1-4), 1383-1396, https://doi.org/10.1007/s00170-018-2038-2

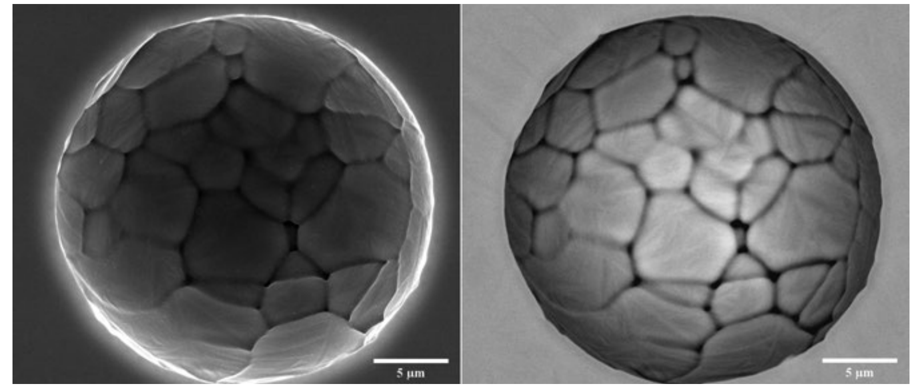
Ali, H., Ghadbeigi, H., Mumtaz, K., (2018), Processing Parameter Effects on Residual Stress and Mechanical Properties of Selective Laser Melted Ti6Al4V, *Journal of Materials Engineering and Performance*, **27**(8), 4059-4068, https://doi.org/10.1007/s11665-018-3477-5

Hong, Z., Morrison, A., Zhang, H., Roberts, S., Grant, P.S., (2018), Development of a Novel Melt Spinning-Based Processing Route for Oxide Dispersion-Strengthened Steels, *Metallurgical and Materials Transactions A*, **49**(2), 604-612, https://doi.org/10.1007/s11661-017-4398-x

Lee, S., Li, K., Huang, C., Evans, J., Grant, P., (2018), Spray-Printed and Self-Assembled Honeycomb Electrodes of Silicon-Decorated Carbon Nanofibers for Li-Ion Batteries, *ACS Applied Materials & Interfaces*, **11**(1), 603-612, https://doi.org/10.1021/acsami.8b15164

2018 (THEME: X1)

Leung, C.L.A., Marussi, S., Atwood, R.C., Towrie, M., Withers, P.J., Lee, P.J., (2018), In-situ X-Ray Imaging of defect and molten pool dynamics in laser additive manufacturing, *Nature Communications*, **9**, 1355, https://doi.org/10.1038/s41467-018-03734-7



Secret Structures from James Pepper.
A BSE image and a SE at 10000x magnification of a void in a polished Ti-6Al-4V powder particle reveals the internal grain boundaries created during formation.

Wang, Y., Liu, B., Yan, K., Wang, M., Kabra, S., Chiu, Y., Dye, D., Lee, P.D., Liu, Y., Cai, B., (2018), Probing deformation mechanisms of a FeCoCrNi high-entropy alloy at 293 and 77 K using in situ neutron diffraction, *Acta Materialia*, **154**, 79-89, https://doi.org/10.1016/j.actamat.2018.05.013

Lee, T., Mi, J., Ren, S., Zhao, S., Fan, J., Kabra, S., Zhang, S., Grant, P.S., (2018), Modelling and neutron diffraction characterization of the interfacial bonding of spray formed dissimilar steels, *Acta Materialia*, **155**, 318-330, https://doi.org/10.1016/j.actamat.2018.05.055

Leung, C.L.A., Marussi, S., Towrie, M., Garcia, J.D.V., Atwood, R.C., Bodey, A.J., Jones, J.R., Withers, P.J., Lee, P.D., (2018), Laser-matter interactions in additive manufacturing of Stainless Steel SS316L and 13-93 bioactive glass revealed by in situ X-ray imaging, *Additive Manufacturing*, **24**, 647-657, https://doi.org/10.1016/j.addma.2018.08.025

Leung, C.L.A., Marussi, S., Towrie, M., Atwood, R.C., Withers, P.J., Lee, P.D., (2018), The effect of powder oxidation on defect formation in laser additive manufacturing, *Acta Materialia*, **166**, 294-305, https://doi.org/10.1016/j.actamat.2018.12.027

2018 (THEME: X3)

Rubio-Solis, A., Martinez-Hernandez, U., Panoutsos, G., (2018), Evolutionary Extreme Learning Machine for the Interval Type-2 Radial Basis Function Neural Network: A Fuzzy Modelling Approach, *2018 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE), 08-13 July 2018, Rio de Janeiro, Brazil*, 1-8, https://doi.org/10.1109/FUZZ-IEEE.2018.8491583

Rubio-Solis, A., Melin, P., Martinez-Hernandez, U., Panoutsos, G., (2018), General Type-2 Radial Basis Function Neural Network: A Data-Driven Fuzzy Model, *IEEE Transactions on Fuzzy Systems*, **27**(2), 333-347, https://doi.org/10.1109/TFUZZ.2018.2858740

2019 (THEME: P2.1)

Mullis, A.M., (2019), The Physical Mechanism for Melt Pulsation during Close-Coupled Atomization, *Atomization and Sprays*, **29**(2), 143-159, https://doi.org/10.1615/AtomizSpr.2019030110

Pham, M., Liu, C., Todd, I., Lertthanasarn, J., (2019), Damage-tolerant architected materials inspired by crystal microstructure, *Nature*, **565**, 305-311, https://doi.org/10.1038/s41586-018-0850-3

Hernández-Nava, E., Mahoney, P., Smith, C.J., Donoghue, J., Todd, I., Tammas-Williams S., (2019), Additive manufacturing titanium components with isotropic or graded properties by hybrid electron beam melting/hot isostatic pressing powder processing, *Scientific Reports*, **9**, 4070, https://doi.org/10.1038/s41598-019-40722-3

Martinez, R., Todd, I., Mumtaz, K., (2019), In situ alloying of elemental Al-Cu12 feedstock using selective laser melting, *Virtual and Physical Prototyping*, **14**(3), 242-252, https://doi.org/10.1080/17452759.2019.1584402

Snell, R., Tammas-Williams, S., Chechik, L., Lyle, A., Hernández-Nava, E., Boig, C., Panoutsos, G., Todd, I., (2019), Methods for Rapid Pore Classification Metal AM, *JOM*, **72**, 101-109, https://doi.org/10.1007/s11837-019-03761-9

Atkins, C., Brzozowski, W., Dobson, N., Milanova, M., Todd, S., Pearson, D., Bourgenot, C., Brooks, D., Snell, R., Sun, W., Cooper, P., Alcock, S.G., Nistea, I.T., (2019), Lightweighting design optimisation for additively manufactured mirrors, *SPIE Optical Engineering + Applications, 2019, San Diego, California, United States*, 1111617, https://doi.org/10.1117/12.2528105

Atkins, C., Brzozowski, W., Dobson, N., Milanova, M., Todd, S., Pearson, D., Bourgenot, C., Brooks, D., Snell, R., Sun, W., Cooper, P., Alcock, S.G., Nistea, I.T., (2019), Additively manufactured mirrors for CubeSats, *SPIE Optical Engineering + Applications, 2019, San Diego, California, United States*, 1111616, https://doi.org/10.1117/12.2528119

Freeman, F.S.H.B., Sharp, J., Xi, J., Todd, I., (2019), Influence of solidification cell structure on the martensitic transformation in additively manufactured steels, *Additive Manufacturing*, **30**, 100917, https://doi.org/10.1016/j.addma.2019.100917

Velasco-Castro, M., Hernández-Nava, E., Figuero, I.A., Todd, I., Goodall, R., (2019), The effect of oxygen pickup during selective laser melting on the microstructure and mechanical properties of Ti-6Al-4V lattices, *Heliyon*, **5**(12), e02813, https://doi.org/10.1016/j.heliyon.2019.e02813

Fieber, L., Evans, J.D., Huang, C., Grant, P.S., (2019), Single-operation, multi-phase additive manufacture of electro-chemical double layer capacitor devices, *Additive Manufacturing*, **28**, 344-353, https://doi.org/10.1016/j.addma.2019.05.001

Wu, Y., Vallecchi, A., Yang, Y., You, Z., Stevens, C., Shamonina, E., Grant, P., (2019), 3D Printed Modular Origami Inspired Dielectrics for Frequency Tunable Antennas, *2019 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting 07-12 July 2019, Atlanta, GA, USA*, https://doi.org/10.1109/APUSNCURSINRSM.2019.8889209

2019 (THEME: P2.2)

Pope, J., Jackson, M., (2019), Fast Forge of Diffusion Bonded Dissimilar Titanium Alloys: A novel Hybrid Processing Approach for Next Generation Near Net Shape Components., *Metals*, **9**(6), 654, https://doi.org/10.3390/met9060654

Weston, N., Thomas, B., Jackson, M., (2019), Exploitation of Field Assisted Sintering (FAST) for titanium alloy, *Proceedings of the 14th World Titanium Conference, Nantes, France*, **321**, 17, https://doi.org/10.1051/matecconf/202032102006

Childerhouse, T., Jackson, M., (2019), Near Net Shape Manufacture of Titanium Alloy Components from Powder and Wire: A Review of State-of-the-Art Process Routes, *Metals*, **9**(6), 689, https://doi.org/10.3390/met9060689

PUBLICATIONS

Weston, N.S., Thomas, B., Jackson, M., (2019), Processing metal powders via field assisted sintering technology (FAST): a critical review, *Materials Science and Technology*, **35(**11), 1306-1328, https://doi.org/10.1080/02670836.2019.1620538

2019 (THEME: P2.3)

Zhu, Z., Lou, S., Majewski, C., (2019), Characterisation and correlation of areal surface texture with processing parameters and porosity of high speed sintered parts, *Additive Manufacturing*, **36**, 101402, https://doi.org/10.1016/j.addma.2020.101402

Feilden, E., Glymond, D., Saiz, E., Vandeperre, L., (2019), High temperature strength of an ultra high temperature ceramic produced by additive manufacturing, *Ceramics International*, **45**(15), 18210-28214, https://doi.org/10.1016/j.ceramint.2019.05.032

Bharaj, K., Sourabh, P., Mumtaz, K., Chisholm, M., Hopkinson, N., (2019), Fabricating poly(methyl methacrylate) parts using high-speed sintering, Proceedings of the Institution of Mechanical Engineers, Part B: *Journal of Engineering Manufacture*, **234**(1-2), 118-125, https://doi.org/10.1177/0954405419851690

Ali, H., Ghadbeigi, H., Hosseinzadeh, F., Oliveira, J., Mumtaz, K., (2019), Effect of pre-emptive in situ parameter modification on residual stress distributions within selective laser-melted Ti6Al4V components, *The International Journal of Advanced Manufacturing Technology*, **103**(9-12), 4467-4479, https://doi.org/10.1007/s00170-019-03860-6

Zhu, Z., Majerski, C., (2019), Understanding pore formation and the effect on mechanical properties of high speed sintered polyamide-12 parts: a focus on energy input, *Materials & Design*, **194,** 108937, https://doi.org/10.1016/j.matdes.2020.108937

Elizarova, I., Vandeperre, L., Giuliani, F., Saiz, E., (2019), Conformable green bodies: plastic forming of robocasted advanced ceramics, European Journal Ceramic Society, **40**(2), 552-557, https://doi.org/10.1016/j.jeurceramsoc.2019.10.010

2019 (THEME: X1)

Chen, Y. , Han, P., Vandi, L., Dehghan-Manshadi, A., Humphry, J., Kent, D., Stefani, I, Lee, P.D., Heitzmann, M., White, J.C., Dargusch, M., (2019), A biocompatible thermoset polymer binder for Direct Ink Writing of porous titanium scaffolds for bone tissue engineering, *Materials Science and Engineering: C*, **95**, 160-165, https://doi.org/10.1016/j.msec.2018.10.033

Clark, S.J., Rahnama, A., Janik, V., Sridhar, S., Lan, Y., (2019), A Gibbs Energy balance model for Growth via diffusional Growth edges, *ISIJ International*, **59**(3), 573-582, https://doi.org/10.2355/isijinternational.ISIJINT-2018-621

Østergaard, M., Cai, B., Petersen, R., König, J., Lee, P.D., Yue, Y., (2019), Impact of pore structure on the thermal conductivity of glass foams, *Materials Letters*, **250**, 72-74, https://doi.org/10.1016/j.matlet.2019.04.106

Liotti, E., Kirk, C.A., Todd, I., Knight, K.S., Hogg, S.C., (2019), Synchrotron X-ray and neutron investigation of the structure and thermal expansion of the monoclinic Al13Cr2 phase, *Journal of Alloys and Compounds*, **781**, 1198-1208, https://doi.org/10.1016/j.jallcom.2018.12.132

Atwood, R.C., Pankhurst, M.J., Kashyap, Y., Cai, B., Zhou, T., Lee, P.D., Drakopoulos, M., Sawhney, K., (2019), High-energy, high-resolution, fly-scan X-ray phase tomography., *Scientific Reports*, **9**, 8913, https://doi.org/10.1038/s41598-019-45561-w

2019 (THEME: X2)

Irukuvarghula, S., Hassanin, H., Cayronc, C., Aristizabald, M., Attallah, M.M., Preuss, M., (2019), Effect of powder characteristics and oxygen content on modifications to the microstructural topology during hot isostatic pressing of an austenitic steel, *Acta Materialia*, **172**, 6-17, https://doi.org/10.1016/j.actamat.2019.03.038

Abrams, K.J. ,Dapor, M., Stehling, N., Azzolini, M., Kyle, S.J., Schäfer, J., Quade, A., Mika, F., Kratky, S., Pokorna, Z., Konvalina, I., Mehta, D., Black, K., Rodenburg, C., (2019), Making Sense of Complex Carbon and Metal/Carbon Systems by Secondary Electron Hyperspectral Imaging, *Advanced science*, **6**(19), 719, https://doi.org/10.1002/advs.201900719

Leung, C.L.A., Tosi, R., Muzangaza, E., Nonni, S., Withers, P.J., Lee, P.D., (2019), Effect of preheating on the thermal, microstructural and mechanical properties of selective electron beam melted Ti-6Al-4V components, *Materials & Design*, **174**, 107792, https://doi.org/10.1016/j.matdes.2019.107792

2019 (THEME: X3)

Baraka, A., Panoutsos, G., (2019), Long-term Learning for Type-2 Neural-Fuzzy Systems, *Fuzzy Sets and Systems*, **368**, 59-81, https://doi.org/10.1016/j.fss.2018.12.014

2020 (THEME: P2.1)

Mullis, A.M., Jedge, O.E., Bigg, T., Cochrane, R.F., (2020), Dynamics of core shell particle formation in drop-tube processed metastable monotectic alloys, *Acta Materialia*, **188**, 591-598, https://doi.org/10.1016/j.actamat.2020.02.017

Freeman, F., Chechik, L., Todd, I., (2020), Beat the machine (learning): metal additive manufacturing and closed loop control, *Physics Education*, **55**, 055012, https://doi.org/10.1088/1361-6552/ab9957

He, Y., Gardy, J., Hassanpour, A., Bayly, A.E., (2020), A digital-based approach for characterising spread powder layer in additive manufacturing, *Materials & Design*, **196**, 109102, https://doi.org/10.1016/j.matdes.2020.109102

Snell, R., Atkins, C., Schnetler, H., Todd, I., Hernández-Nava, E., Lyle, A.R., Maddison, G., Morris, K., Miller, C., Roulet, M., Hugot, E., Sanginés, F.T., Vega-Moreno, A., Vorst, L.T.G., Dufils, J., Brouwers, L., Farkas, S., Mező, G., Beardsley, M., Harris, M., (2020), An additive manufactured CubeSat mirror incorporating a novel circular lattice, *SPIE Astronomical Telescopes + Instrumentation, 2020, Online Only*, 114510C,https://doi.org/10.1117/12.2562738

Chechik, L., Boone, N.A., Stanger, L.R., Honniball, P., Freeman, F.S.H.B., Baxter, G.J., Willmott, J.R., Todd, I., (2020), Variation of texture anisotropy and hardness with build parameters and wall height in directed-energy-deposited 316L steel, *Additive Manufacturing*, **38**, 101806, https://doi.org/10.1016/j.addma.2020.101806

2020 (THEME: P2.2)

Matthews, G.A.B., Santra, S., Ma, R., Grovenor, C.R.M., Grant, P.S., Speller, S.C., (2020), Effect of the sintering temperature on the microstructure and superconducting properties of MgB2 bulks manufactured by the field assisted sintering technique, *Superconductor Science and Technology*, **33**, 054003, https://doi.org/10.1088/1361-6668/ab7c53

Boone, N., Davies, M., Willmott, J., Marin-Reyes, H., French, R., (2020), High-Resolution Thermal Imaging and Analysis of TIG Weld Pool Phase Transitions, *Sensors*, **20**(23), 6952, https://doi.org/10.3390/s20236952

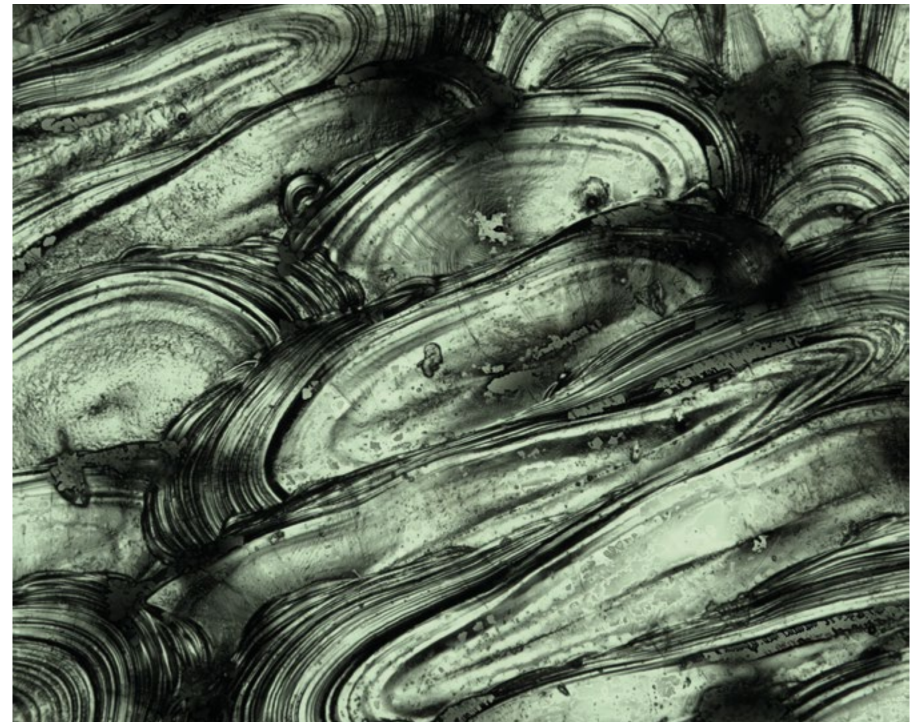
2020 (THEME: P2.3)

Wingham, J., Turner, R., Shepherd, J., Majewski, C., (2020), Micro-CT for analysis of Laser Sintered micro-composites, *Rapid Prototyping Journal*, **26**(4), 649-657, https://doi.org/10.1108/RPJ-08-2019-0211

Turner, R., Wingham, J., Paterson, T., Shepherd, J., Majewski, C., (2020), Use of silver-based additives for the development of antibacterial functionality in Laser Sintered polyamide 12 parts, *Scientific Reports*, **10**, 892, https://doi.org/10.1038/s41598-020-57686-4

Rocha, V.G., Saiz, E., Tirichenko, I.S., Garcia-Tunon, E., (2020), Direct ink writing advances in multi-material structures for a sustainable future, *Journal of Materials Chemistry A*, **8**(31), 15646-15657, https://doi.org/10.1039/D0TA04181E

Groom, K., (2020), Multi-laser processing for high speed powder bed additive manufacturing and opportunities for photonic integration, Proc. *SPIE 11580, SPIE Photonex Industry, 4 October 2020*, 1158004, https://doi.org/10.1117/12.2584834



Ponds of Steel from Ben Thomas. Multi-stack macro-image of melt-pools created in stainless steel 316L. The discontinuities in the melt-pools were created by the laser turning off and on unexpectedly during an experiment into laser power modulation. A little bit of beauty came from a day of failures.

Mousavi, T., Grant, P.S., Speller, S.C., Grovenor, C., (2020), New nanoscale artificial pinning centres for NbTi superconductors, *Materials & Design*, **198**, 109285, https://doi.org/10.1016/j.matdes.2020.109285

Wang, S., Giulani, F., Britton, T.B., (2020), Slip-hybrid interactions in Zircaloy-4: Multiscale mechanical testing and characterisation, *Acta Materialia*, **200**, 537-550, https://doi.org/10.1016/j.actamat.2020.09.038

2020 (THEME: X1)

Ostergaard, M.B., Zhang, M., Shen, X., Peterson, R.R., Konig, J., Lee, P.D., Yue, Y., Cai, B., (2020), High-speed synchrotron X-ray imaging of glass foaming and thermal conductivity simulations, *Acta Materialia*, **189**, 85-92, https://doi.org/10.1016/j.actamat.2020.02.060

Kao, A., Boller, E., Magdysyuk, O., Atwood, R.C., Vo, N.T., Pericleous, K., Lee, P.D., (2020), Revealing the mechanisms by which magneto-hydrodynamics disrupts solidification microstructures, *Acta Materialia*, **196**, 200-209, https://doi.org/10.1016/j.actamat.2020.06.041

Sinclair, L., Leung, C.L.A., Marussi, S., Clark, S., Chen, Y., Olbinado, M.P., Rack, A., Gardy, J., Baxter, G.J., Lee, P.D., (2020), In situ radiographic and ex situ tomographic analysis of pore interactions during multilayer builds in laser powder bed fusion, *Additive Manufacturing*, **36**, 101512, https://doi.org/10.1016/j.addma.2020.101512

Prasad, A., Yuan, L., Lee, P.D., Patel, M., Qui, D., Easton, M., StJohn, D., (2020), Towards understanding grain nucleation under Additive Manufacturing solidification conditions, *Acta Materialia*, **195**, 392-403, https://doi.org/10.1016/j.actamat.2020.05.012

Kao, A., Shevchenko, N., He, S., Lee, P.D., Eckert, S., Pericleous, K., (2020), Magnetic effects on the microstructure and solute plume dynamics of a directionally solidifying Ga-In alloy, *JOM*, **72**, 3645-3651, https://doi.org/10.1007/s11837-020-04305-2

Chen, Y., Clark, S.J., Leung, C.L.A., Sinclair, L., Marussi, S., Olbinado, M.P., Boller, E., Rack, A., Todd, I., Lee, P.D., (2020), In-situ synchrotron imaging of keyhole mode multi-layer laser powder bed fusion additive manufacturing, *Applied Materials Today*, **20**, 100650, https://doi.org/10.1016/j.apmt.2020.100650

Chen, Y, Clark, S.J., Huang, Y., Sinclair, L., Leung, C.L.A., Marussi, S., Connoley, T., Magdysyuk, O.V., Atwood, R.C., Baxter, G.J., Jones, M.A., Todd, I., Lee, P.D., (2020), In situ X-ray Quantification of Melt Pool Behaviour during Directed Energy Deposition Additive Manufacturing of Stainless Steel, *Materials Letters*, **286**, 129205, https://doi.org/10.1016/j.matlet.2020.129205

Clark, S.J., Leung, C.L.A., Chen, Y., Sinclair, L., Marussi, S., Lee, P.D., (2020), Capturing marangoni flow via synchrotron imaging of selective laser melting, *Conference - IOP Conference Series: Materials Science and Engineering*, **861**, 012010, https://doi.org/10.1088/1757-899X/861/1/012010

Yuan, L., Sabau, A.S., StJohn, D., Prasad, A, Lee, P.D., (2020), Columnar-to-equiaxed transition in a laser scan for metal additive manufacturing, *Conference - IOP Conference Series: Materials Science and Engineering*, **861**, 012007, https://doi.org/10.1088/1757-899X/861/1/012007

Chen, Y., Clark, S., Leung, C.L.A., Sinclair, L., Marussi, S., Atwood, R.C., Connoley, T., Jones, M., Baxter, G.J., Lee, P.D., (2020), Melt pool morphology in directed energy deposition additive manufacturing process, *Conference - IOP Conference Series: Materials Science and Engineering*, **861**, 012012, https://doi.org/10.1088/1757-899X/861/1/012012

Prasad, A., Lee, P.D., StJohn, D., 2020, Numerical simulation of wave-like nucleation events, *Conference - IOP Conference Series: Materials Science and Engineering*, **527**, 012043, https://doi.org/10.1088/1757-899X/529/1/012043

2020 (THEME: X2)

Matthews, G.A.B., Liu, J., Grovenor, C.R.M., Grant, P.S., Speller, S., (2020), Design and characterisation of ex situ bulk MgB2 superconductors containing a nanoscale dispersion of artificial pinning centres, *Superconductor Science and Technology*, **33**, 034006, https://doi.org/10.1088/1361-6668/ab6959

McDonald, S.A., Burnett, T.L., Donoghue, J., Gueninchault, N., Bale, H., Holzner, C., Lauridsen, E.M., Withers, P.J., (2020), Tracking polycrystal evolution non-destructively in 3D by laboratory X-ray diffraction contrast tomography, *Materials Characterization*, **172**, 110814, https://doi.org/10.1016/j.matchar.2020.110814

Bigg, T., Mullis, A.M., (2020), Spatially resolved velocity mapping of the melt plume during high pressure gas atomisation of liquid metals, *Metallurgical and Materials Transactions B*, **51**, 1973-1988, https://doi.org/10.1007/s11663-020-01899-5

Davis, T.P., Haley, J.C., Connolly, S., Auger, M.A., Gorley, M.J., Grant, P.S., Bagot, P.A.J., Moody, M.P., Armstrong, D.E.J., (2020), Electron microscopy and atom probe tomography of nanoindentation deformation in oxide dispersion strengthened steels, *Materials Characterization*, **167**, 110477, https://doi.org/10.1016/j.matchar.2020.110477

PUBLICATIONS

2020 (THEME: X3)

Mycroft, W., Katzman, M., Tammas-Williams, S., Hernandez-Nava, E., Panoutsos, G., Todd, I., Kadirkamanathan, V., (2020), A data-driven approach for predicting printability in additive manufacturing processes, *Journal of Intelligent Manufacturing*, **31**, 1769-1781, https://doi.org/10.1007/s10845-020-01541-w

Bayly, A.E., Fouda, Y.M., (2020), A DEM study of powder spreading in additive layer manufacturing, *Granular Matter*, **22**, 10, https://doi.org/10.1007/s10035-019-0971-x

He, Y., Muller, F., Hassanpour, A., Bayly, A.E., (2020), A CPU-GPU cross-platform coupled CFD DEM approach for complex particle-fluid flows, *Chemical Engineering Science*, **223**, 115712, https://doi.org/10.1016/j.ces.2020.115712

He, Y., Hassanpour, A., Benjani, M.A., Bayly, A.E., (2020), A novel stiffness scaling methodology for discrete element modelling of cohesive fine powders, *Applied Mathematical Modelling*, **90**, 817-844, https://doi.org/10.1016/j.apm.2020.08.062

He, Y., Hassanpour, A., Bayly, A.E., (2020), Linking particle properties to layer characteristics; discrete element modelling of cohesive fine powder spreading in additive manufacturing, *Additive Manufacturing*, **36**, 101685, https://doi.org/10.1016/j.addma.2020.101685

2021 (THEME: P2.1)

Jeffs, S., Lancaster, R., Davies, G., Hole, W., Roberts, B., Stapleton, D., Thomas, M., Todd, I., Baxter, G.J., (2021), Effect of Process Parameters and Build Orientation on Microstructure and Impact Energy of Electron Beam Powder Bed Fused Ti-6Al-4V, *Materials*, **14**(18), 5376, https://doi.org/10.3390/ma14185376

He, Y., Hassanpour, A., Bayly, A.E., (2021), Combined effect of particle size and surface cohesiveness on powder spreadability for additive manufacturing, *Powder Technology*, **392**, 191-203, https://doi.org/10.1016/j.powtec.2021.06.046

Miller, D., Song, B., Farnsworth, M., Tiwari, D., Freeman, F.S.H.B., Todd, I., Tiwaria, A., (2021), IoT and Machine learning for in-situ process control using Laser Based Additive Manufacturing (LBAM) case study, *Procedia CIRP*, **104**, 1813-1818, https://doi.org/10.1016/j.procir.2021.11.306

Freeman, F.S.H.B., Thomas, B., Chechik, L., Todd, I., (2021), Multi-faceted monitoring of powder flow rate variability in directed energy deposition, *Additive Manufacturing Letters*, **2**, 100024, https://doi.org/10.1016/j.addlet.2021.100024

Soundarapandiyan, G., Johnstone, C., Khan, R., Leung, C.L.A., Lee, P.D., Hernandez, E., Chen, B., Fitpatrick, M., (2021), The effects of powder reuse on the mechanical response of electron beam additively manufactured Ti6A14V parts, *Additive Manufacturing*, **46**, 1102101, https://doi.org/10.1016/j.addma.2021.102101

2021 (THEME: P2.2)

Blanch, O., Lunt, D., Baxter, G.J., Jackson, M., (2021), Deformation behaviour of a FAST diffusion bond processed from dissimilar titanium alloy powder, *Metallurgical and Materials Transactions A*, **52**, 3064-3082, https://doi.org/10.1007/s11661-021-06301-w

Salmasi, A., Graham, S.J., Galbraith, Q., Graves, A.D., Jackson, M., Norgren, S., Guan, D., Larsson, H., Höglund, L., (2021), Short communication: Mobilities of Ti and Fe in disordered Tu-Fe-BCC assessed from new experimental data, *Calphad Journal*, **74**, 102300, http://doi.org/10.1016/j.calphad.2021.102300

Cui, W., Flinders, K., Hancock, H., Grant, P.S., (2021), Joining and cycling performance of ultra-thick tungsten coatings on patterned steel substrates for fusion armour applications, *Materials & Design*, **212**, 110250, https://doi.org/10.1016/j.matdes.2021.110250

2021 (THEME: P2.3)

Williams, R., Smith, P., Majewski, C., (2021), Is ink heating a relevant concern in the high speed sintering process?, *The International Journal of Advanced Manufacturing Technology*, **113**, 1073-1080, https://doi.org/10.1007/s00170-020-06508-y

Alsaddah, M., Khan, A., Groom, K., Mumtaz, K., (2021), Use of 450-808 nm diode lasers for efficient energy absorption during powder bed fusion of Ti6Al4V, *The International Journal of Advanced Manufacturing Technology*, **113**, 2461-2480, https://doi.org/10.1007/s00170-021-06774-4

Lou, S., Zhu, Z., Zeng, W., Majewski, C., Scott, P.J., Jiang, X., (2021), Material Ratio Curve of 3D Surface Topography of Additively manufactured Parts: An Attempt to Characterise Open Surface Pores, *Surface Topography : Metrology and Properties*, **9**, 015029, https://doi.org/10.1088/2051-672X/abedf9

Williams, R.J., Al-Dirawi, K.H., Brown, R., Burt, J., Bayly, A.E., Majewski, C., (2021), Correlations between powder wettability and part colour in the High Speed Sintering process, *Additive Manufacturing*, **47**, 102361, https://doi.org/10.1016/j.addma.2021.102361

Gavalda-Diaz, O., Lyons, J., Wang, S., Emmanuel, M., Marquardt, K., Saiz, E., Giuliani, F., (2021), Basal Plane Delamination Energy Measurement in a Ti3SiC2 MAX Phase, *JOM*, **73**, 1582-1588, https://doi.org/10.1007/s11837-021-04635-9

Williams, R., Fox, L., Majewski, C., (2021), The effect of powder age in high speed sintering of poly(propylene), *Rapid Prototyping Journal*, **27**(4), 707-719, https://doi.org/10.1108/RPJ-05-2020-0090

Alharbi, A., Khan, A., Todd, I., Ramadan, M., Mumtaz, K., (2021), Semisolid heat treatment processing window of Pb-40% Sn alloy for feedstock in the 3D printing thixo-forming process, *Materials Today Proceedings*, **51**(1), 403-410, https://doi.org/10.1016/j.matpr.2021.05.549

Li, C., Li, M., Ni, Z., Guan, Q., Blackman, B.R.K., Saiz, E., (2021), Stimuli-responsive surfaces for switchable wettability and adhesion, *Journal of the Royal Society Interface*, **18**(179), 20210162, https://doi.org/10.1098/rsif.2021.0162

Shackleford, A., Williams, R., Brown, R., Wingham, J., Majewski, C., (2021), Degradation of Laser Sintered polyamide 12 parts due to accelerated exposure to ultraviolet radiation, Additive Manufacturing, **46**, 102132, https://doi.org/10.1016/j.addma.2021.102132

Li, M., Li, C., Blackman, B.R.K., Saiz, E., (2021), Mimicking nature to control bio-material surface wetting and adhesion, *International Materials Reviews*, **67**(2), 658-681, https://doi.org/10.1080/09506608.2021.1995112

Li, M., Li, C., Blackman, B.R.K., Saiz, E., (2021), Energy conversion based on bio-inspired superwetting interfaces, *Matter*, **4**(11), 3400-3414, https://doi.org/10.1016/j.matt.2021.09.018

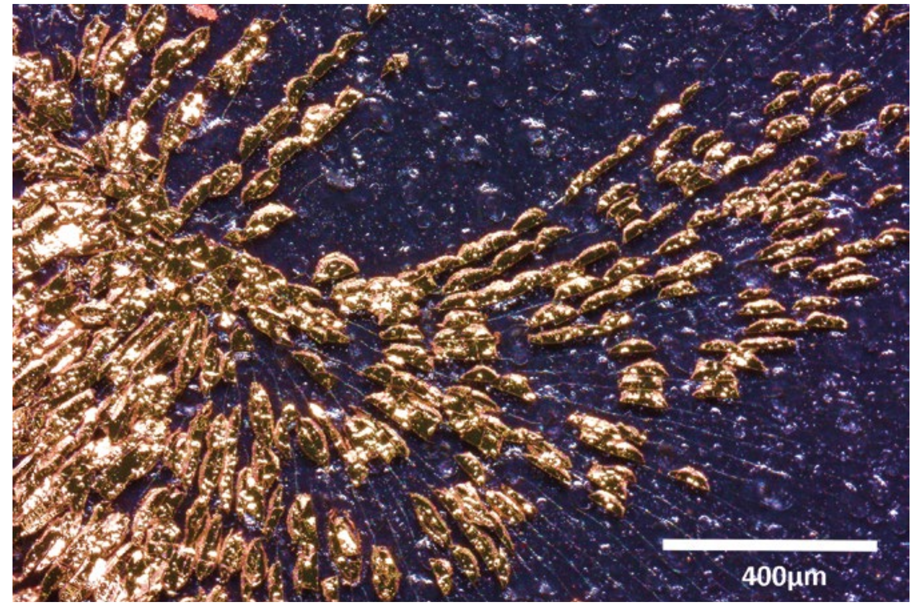
Nar, K., Majewski, C., Lewis, R., (2021), A comprehensive characterisation of Laser Sintered Polyamide-12 surfaces, *Polymer testing*, **106**, 107450, https://doi.org/10.1016/j.polymertesting.2021.107450

Li, M., Li, W., Guan, Q., Dai, X., Lv, J., Xia, Z., Ong, W.J., Saiz, E., Hou, X., (2021), A Tough Reversible Biomimetic Transparent Adhesive Tape with Pressure-Sensitive and Wet-Cleaning Properties, *ACS nano*, **15**(12), 19194-19201, https://doi.org/10.1021/acsnano.1c03882

2021 (THEME:X1)

Karagadde, S., Leung, C.L.A., Lee, P.D, (2021), Progress on In Situ and Operando X-ray Imaging of Solidification Processes, *Materials*, **14**(9), 2374, https://doi.org/10.3390/ma14092374

Leung, C.L.A., Elizarova, I., Isaacs, M., Marathe, S., Saiz, E., Lee, P.D., (2021), Enhanced near-infrared absorption for laser powder bed fusion using reduced graphene oxide, *Applied Materials Today*, **23**, 101009, https://doi.org/10.1016/j.apmt.2021.101009



Hybrid Sensor Peel Test from Alisha Bhatt. A hybrid sensor that consists of three layers, which include a base layer, dielectric layer, and a conductive layer. The base layer is printed using laser powder bed fusion (LPBF) Ti-6Al-4V. The dielectric layer is directly deposited on the base layer, which is printed using roll-to-roll (R2R) printing. The dielectric layer 100 nm thin film of tripropylene glycol diacrylate (TPGDA). The final conductive layer of the sensor is deposited directly on the dielectric layer, which is printed using direct ink write (DIW). The conductive layer is printed using 50 wt. %, dispersion in tripropylene glycol mono methyl ether (TPM) silver nanoparticle ink. The conductive layer is stabilised using thermal curing. Using a test the durability of the sensor was tested. To image this, optical microscopy was used.

Rowson, M., Bennett, C.J., Azeem, M.A., Magdysyuk, O., Rouse, J.P., Lye, R., Davies, J., Bray, S., Lee, P.D., (2021), Observation of microstructure evolution during inertia friction welding using in-situ synchrotron X-ray diffraction, *Journal of Synchrotron Radiation*, **28**, 790-803, https://doi.org/10.1107/S1600577521001569

Chen, Y.H., Clark, S.J., Sinclair, L., Leung, C.L.A., Marussi, S., Connolley, T., Atwood, R.C., Baxter, G.J., Jones, M.A., Todd, I., Lee, P.D., (2021), Synchrotron X-ray Imaging of Directed Energy Deposition Additive Manufacturing of Titanium Alloy Ti-6242, *Additive Manufacturing*, **41**, 101969, https://doi.org/10.1016/j.addma.2021.101969

Bhagavath, S., Gong, Z., Wigger, T., Shah, S., Ghaffari, B., Li, M., Marathe, S., Lee, P.D., Karagadde, S., (2021), Role of the local stress systems on microstructural inhomogeneity during semisolid injection experiments, *Acta Materialia*, **214**, 117015, https://doi.org/10.1016/j.actamat.2021.117015

Ahmed, F.F., Clark, S.J., Leung, C.L.A., Stanger, L., Willmott, J., Marussi, S., Honkimaki, V., Haynes, N., Zurob, H.S., Lee, P.D., Phillion, A.B., (2021), Achieving homogeneity in a high-Fe b-Ti alloy laser-printed from blended elemental powders, *Materials & Design*, **210**, 110072, https://doi.org/10.1016/j.matdes.2021.110072

Bhagavath, S., Gong, Z., Wigger, T., Shah, S., Ghaffari, B., Li, M., Marathe, S., Karagadde, S., Lee, P.D., (2021), Mechanisms of gas and shrinkage porosity formation in solidifying shear bands, *Journal of Materials Processing Technology*, **299**, 117338, https://doi.org/10.1016/j.jmatprotec.2021.117338

Chen, Y.H., Clark, S.J., Collins, D.M., Marussi, S., Hunt, S.A., Fenech, D.M., Connolley, T., Atwood, R.C., Magdysyuk, O.V., Baxter, G.J., Jones, M.A., Leung, C.L.A., Lee, P.D., (2021), Correlative Synchrotron X-ray Imaging and Diffraction of Directed Energy Deposition Additive Manufacturing, *Acta Materialia*, **209**, 116777, https://doi.org/10.1016/j.actamat.2021.116777

Jakumeit, J., Zheng, G., Laqua, R., Clark, S.J., Zielinski, J., Schleifenbaum, J.H., Lee, P.D., (2021), Modelling the complex evaporated gas flow and its impact on particle spattering during laser powder bed fusion, *Additive Manufacturing*, **47**, 102332, https://doi.org/10.1016/j.addma.2021.102332

Massimi, L., Clark, S.J., Marussi, S., Doherty, A., Schulz, J., Marathe, S., Rau, C., Endrizzi, M., Lee, P.D., Olivo, A., (2021), Dynamic Multicontrast X-Ray Imaging Method Applied to Additive Manufacturing, Physical Review Letters, **217**, 215503, https://doi.org/10.1103/PhysRevLett.127.215503

Iantaffi, C., Leung, C.L.A., Chen, Y., Guan, S., Atwood, R.C., Lertthanasarn, J., Pham, M., Meisnar, M., Rohr, T., Lee, P.D., (2021), Oxidation induced mechanisms during directed energy deposition additive manufactured titanium alloy builds, *Additive Manufacturing Letters*, **1**, 100022, https://doi.org/10.1016/j.addlet.2021.100022

2021 (THEME: X2)

Emmanuel, M., Gavalda-Diaz, O., Sernicola, G., M'saoubi, R., Persson, T., Norgren, S., Marquardt, K., Britton, T.B., Giuliani, F., (2021), Fracture Energy Measurement of Prismatic Plane and Σ2 Boundary in Cemented Carbide, *JOM*, **73**, 1589-1596, https://doi.org/10.1007/s11837-021-04638-6

Mehrabi, M., Hassanpour, A., Bayly, A.E., (2021), An X-ray microtomography study of behaviour metal powders during filling, compaction and ball indentation processes, *Powder Technology*, **385**, 250-263, https://doi.org/10.1016/j.powtec.2021.02.069

2021 (THEME: X3)

Notley, S.V., Chen, Y., Lee, P.D., Panoutsos, G., (2021), Variance Stabilised Optimisation of Neural Networks: A Case Study in Additive Manufacturing, *International Joint Conference on Neural Networks (IJCNN), 18-22 July 2021, Shenzhen, China*, 1-7, https://doi.org/10.1109/IJCNN52387.2021.9533311

2022 (THEME: P2.1)

Salehi, H., Cummins, J., Gallino, E., Harrison, N., Hassanpour, A., Bradley, M. , (2022), A new approach to quantify powder's bed surface roughness in additive manufacturing, *Powder Technology*, **407,** 117614, https://doi.org/10.1016/j.powtec.2022.117614

Farquhar, L., Maddison, G., Hardwick, L., Livera, F., Todd, I., Goodall, R.D., (2022), In-Situ Alloying of CoCrFeNiX High Entropy Alloys by Selective Laser Melting, *Metals*, **12**(3), 456, https://doi.org/10.3390/met12030456

Paenoi, J., Bourgenot, C., Atkins, C., Snell, R., Todd, I., White, P., Parkin, K., Ryder, D., Kotlewski, R., McPhee, S., Chanchaiworawit, K., Chartsiriwattana, P., Laoyang, A., Kuha, T., Leckngam, A., Buisset, C., Rujopakarn, W., Poshyachinda, S., (2022), Lightweight, aluminum, mirror design optimization for conventional and additive manufacturing processes, *SPIE Astronomical Telescopes + Instrumentation, 2022, Montréal, Québec, Canada*, 121880U, https://doi.org/10.1117/12.2627757

PUBLICATIONS

Snell, R., Atkins, C., Schnetler, H., Chahid, Y., Beardsley, M., Harris, M., Zhang, C., Pears, R., Thomas, B., Saunders, H., Sloane, A., Maddison, G., Todd, I., (2022), Towards understanding and eliminating defects in additively manufactured CubeSat mirrors, *SPIE Astronomical Telescopes + Instrumentation, 2022, Montréal, Québec, Canada*, 121880V, https://doi.org/10.1117/12.2629935

Unnikrishhnan, R., Gardy, J., Spenvcer, B.F., Kurinjimala, R., Dey, A., Nekouie, V., Irukuvarghula, S., Hassanpour, A., Eisenmenger-Sittner, C., Francis, J., Preuss, M., (2022), Functionalization of metallic powder for performance enhancement, *Materials & Design*, **221**, 110900, https://doi.org/10.1016/j.matdes.2022.110900

Markanday, F., Conduit, G., Conduit, B., Pürstl, J., Christofidou, K., Chechik, L., Baxter, G.J., Heason, C., Stone, H., (2022), Design of a Ni-based superalloy for laser repair applications using probabilistic neural network identification, *Data-Centric Engineering*, **3**, E30, https://doi.org/10.1017/dce.2022.31

Freeman, F.S.H.B., Chechik, L., Thomas, B., Todd, I., (2022), Calibrated closed-loop control to reduce the effect of geometry on mechanical behaviour in directed energy deposition, *Journal of Materials Processing Technology*, **311**, 117823, https://doi.org/10.1016/j.jmatprotec.2022.117823

Chechik, L., Christofidou, K.A., Markanday, J.F.A., Goodall, A.D., Miller, J.R., West, G., Stone, H., Todd, I, (2022), Hardness variation in inconel 718 produced by laser directed energy deposition, Materialia, **26**, 101643, https://doi.org/10.1016/j.mtla.2022.101643

Gao, Z., Wang, H., Sun, H., Sun, T., Wu, T., Leung, C.L.A., Wang, H., (2022), Additively manufactured high-energy-absorption metamaterials with artificially engineered distribution of bio-inspired hierarchical microstructures, *Composites PartB: Engineering*, **247**, 110345, https://doi.org/10.1016/j.compositesb.2022.110345

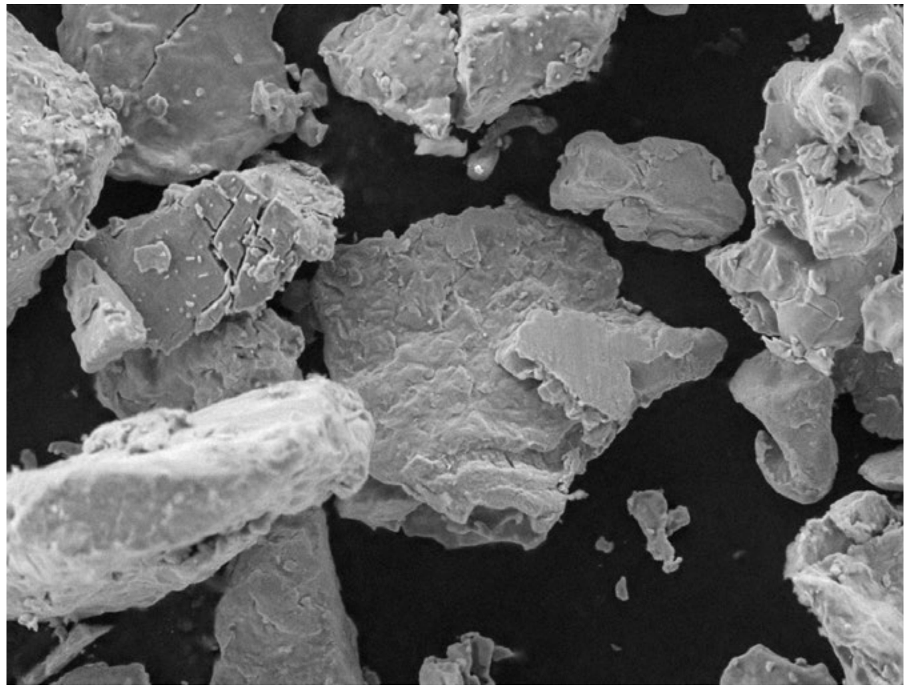
2022 (THEME: P2.2)

Barrie, C., Fernandez-Silva, B., Snell, R., Todd, I., Jackson, M., (2022), Addfast: A Hybrid Technique for Tailoring Microstructures in Titanium-Titanium Composites., *SSRN Electronic Journal*, https://dx.doi.org/10.2139/ssrn.4286297

2022 (THEME: P2.3)

Majewski, C., (2022), Making our parts work harder: getting started with functional materials for 3D printing, *Journal of 3D Printing in Medicine*, **6**(1), 1-4, https://doi.org/10.2217/3dp-2021-0030

Busra, K., Smith, P., Fairclough, P., Mumtaz, K., (2022), Additive manufacturing of high density carbon fibre reinforced polymer composites, *Additive Manufacturing*, **58**, 103044, https://doi.org/10.1016/j.addma.2022.103044



Cracked HDH Ti64 Powder from Milo Maguire. SEM, SE image of Titanium 64 hydrogen dihydride powder particles ~100 micron in size. Here instead of atomisation, hydrogen embrittlement has been used to produce the powder. This process allows for brittle fracture of the metal resulting in rough angular morphologies generally detrimental to powder flow. Taken on Hitachi desktop SEM.

Li, M., Zhou, S., Guan, Q., Li, W., Bouville, F., Bai, H., Siaz, E., (2022), Robust Underwater Oil-Repellent Biomimetic Ceramic Surfaces: Combining the Stability and Reproducibility of Functional Structures, *ACS Applied Materials & Interfaces*, **14**(40), 46077-460805, https://doi.org/10.1021/acsami.2c13857

Alsaddah, M., Khan, A., Groom, K., Mumtaz, K., (2022), Diode area melting of Ti6Al4V using 808 nm laser sources and variable multi-beam profiles, *Materials & Design*, **215**, 110518, https://doi.org/10.1016/j.matdes.2022.110518

Cai, Q., Meille, S., Chevalier, J., Zhou, S., Bouville, F., Tirichenko, I., Saiz, E., (2022), 3D-printing of ceramic filaments with ductile metallic cores, *Materials & Design*, **225**, 1111463, https://doi.org/10.1016/j.matdes.2022.111463

Mohammed Alsaddah, Ashfaq Khan, Kristian Groom, Kamran Mumtaz, (2022), Diode area melting of Ti6Al4V using 808 nm laser sources and variable multi-beam profiles, *Materials & Design*, **215**, 110518, https://doi.org/10.1016/j.matdes.2022.110518

Wang, S., Douglas, J.O., Lovell, J., Wilson, N., Guo, L., Gault, B., Ryan, M.P., Giuliani, F., (2022), Near-atomic scale chemical analysis of interfaces in a La(Fe,Mn,Si)13-based magnetocaloric material, *Scripta Materialia*, **224**, 115143, https://doi.org/10.1016/j.scriptamat.2022.115143

2022 (THEME: X1)

Huang, Y., Fleming, T.G., Clark, S.J., Marussi, S., Fezzaa, K., Thiyagalingam, J., Leung, C.L.A., Lee, P.D., (2022), Keyhole fluctuation and pore formation mechanisms during laser powder bed fusion additive manufacturing, *Nature Communications*, **13**, 1170, https://doi.org/10.1038/s41467-022-28694-x

Sinclair, S., Clark, S., Chen, Y., Marussi, S., Shah, S., Magdysyuk, O., Atwood, R.C., Baxter, G.J., Jones, M., McCartney, G., Leung, C.L.A., Lee, P.D., (2022), Sinter formation during directed energy deposition of titanium alloy powders, International Journal of Machine Tools and Manufacture, **221**, 110900, https://doi.org/10.1016/j.matdes.2022.110900

Soundarapandiyan, G., Leung, C.L.A., Johnston, C., Bhatt, A., Khan, R.H.U., McNutt, P., Atwood, R.C., Lee, P.D. Chen, B., Fitzpatrick, M., (2022), Effects of Ti6Al4V powder oxidation on process dynamics in laser powder bed fusion additive manufacturing, *SSRN Electronic Journal*, http://dx.doi.org/10.2139/ssrn.4102476

Sun, T., Wang, H., Gao, Z., Wu, Y., Wang, M., Jin, X., Leung, C.L.A., Lee, P.D., Fu, Y., Wang, H., (2022), The role of in-situ nano-TiB2 particles in improving the printability of noncastable 2024Al alloy, *Materials Research Letters*, **10**, 656-665, https://doi.org/10.1080/21663831.2022.2080514

Tosi, R., Leung, C.L.A., Tan, X., Muzangaza, E., Attallah, M.M., (2022), Revealing the microstructural evolution of electron beam powder bed fusion and hot isostatic pressing Ti-6Al-4V in-situ shelling samples using X-ray computed tomography, *Additive Manufacturing*, **57**, 102962, https://doi.org/10.1016/j.addma.2022.102962

Massimi, L., Clark, S.J., Marussi, S., Doherty, A., Shah, S.M., Schulz, J., Marathe, S., Rau, C., Lee, P.D., Olivo, A., (2022), Time resolved in-situ multi-contrast X-ray imaging of melting in metals, *Scientific Reports*, **12**, 12136, https://doi.org/10.1038/s41598-022-15501-2

Leung, C.L.A., Luczyniec, D., Guo, E., Marussi, S., Atwood, R.C., Meisnar, M., Saunders, B., Lee, P.D., (2022), Quantification of interdependent dynamics during laser additive manufacturing using X-ray imaging informed multi-physics and multiphase simulation, *Advanced Science*, **9**, 2203546, https://doi.org/10.1002/advs.202203546

Guo, L., Wang, H., Liu, H., Huang, Y., Wei, Q., Leung, C.L.A., Wu, Y., Wang, H., (2022), Understanding keyhole induced-porosities in laser powder bed fusion of aluminium and elimination strategy, *International Journal of Machine Tools and Manufacture*, **184**, 103977, https://doi.org/10.1016/j.ijmachtools.2022.103977

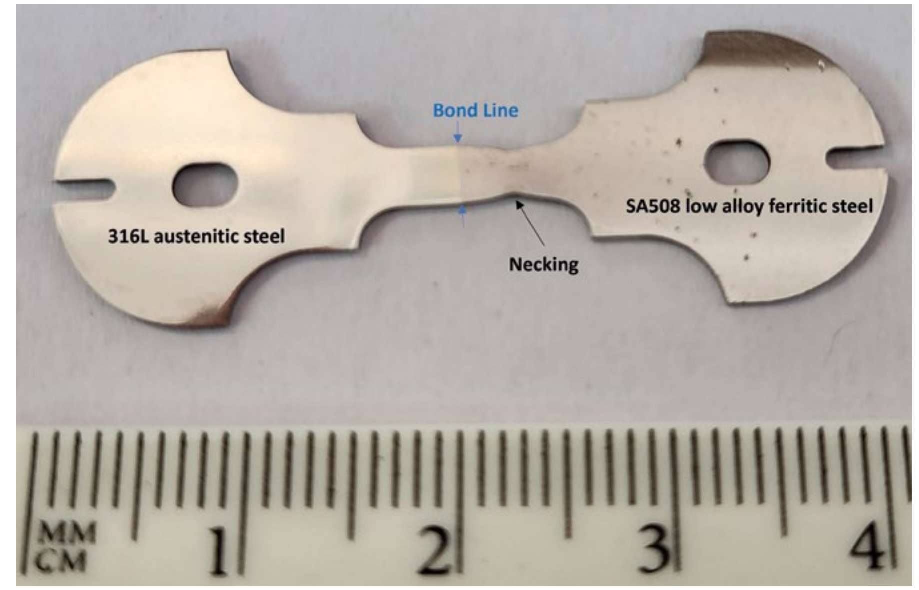
2022 (THEME: X3)

Aftab, M., Rossiter, J.A., Panoutsos, G., (2022), Predictive functional control for difficult second-order dynamics with a simple pre-compensation strategy, *2022 UKACC 13th International Conference on Control (CONTROL), Plymouth, United Kingdom*, 12-17, https://doi.org/10.1109/Control55989.2022.9781367

Atwya, M., Panoutsos, G., (2022), Structure optimization of prior-knowledge-guided neural networks, *Neurocomputing*, **491**, 464-448, https://doi.org/10.1016/j.neucom.2022.03.008

Sahin, A., Ray, P., Panoutsos, G., (2022), Self-tuning multi-model statistical process control for process monitoring in additive manufacturing, *2022 8th International Conference on Control, Decision and Information Technologies (CoDIT), 17-20 May 2022, Istanbul, Turkey*, 1049-1054, https://doi.org/10.1109/CoDIT55151.2022.9803964

Al-Saadi, T., Rossiter, A., Panoutsos, G., (2022), Fuzzy Logic Control in Metal Additive Manufacturing: A Literature Review and Case Study, Control, Optimization and Automation in Mining, Mineral and Metal Processing, IFAC-Papers online, **55**(21), 37-42, https://doi.org/10.1016/j.ifacol.2022.09.240



The Power of Unity: A Dissimilar Joint Stronger Than Its Parent Materials from Rahul Unnikrishnan. Photo of a tensile test sample of a dissimilar joint between 316L austenitic and SA508 low alloy steel powder processed using FAST tested up to failure. The low alloy steel necked down, demonstrating that the joint is stronger than the parent materials.

Aftab, M., Rossiter, J., Panoutsos, G., Gonzalez-Villarreal, O., (2022), A Novel Approach to PFC for Nonlinear Systems, *European Journal of Control*, **68**, 100668, https://doi.org/10.1016/j.ejcon.2022.100668

2023 (THEME: P2.1)

Mehrabi, M., Gardy, J., Talebi, F., Farschi, A., Hassanpour, A., Bayly, A.E., (2023), An investigation of the effect of powder flowability on the powder spreading in additive manufacturing, *Powder Technology*, **413**, 117997, https://doi.org/10.1016/j.powtec.2022.117997

Chechik, L., Goodall, A.D., Christofidou, K.A., Todd, I., 2023, Controlling grain structure in metallic additive manufacturing using a versatile, inexpensive process control system, *Scientific Reports*, **13**, 10003, https://doi.org/10.1038/s41598-023-37089-x

Chechik, L., Todd, I., 2023, Inconel 718 two ways: Powder bed fusion vs. directed energy deposition, *Additive Manufacturing Letters*, **6**, 100145, https://doi.org/10.1016/j.addlet.2023.100145

Goodall, A.D., Yiannakou, G., Chechik, L., Mitchell, R.L., Jewell, G.W., Todd, I., 2023, Geometrical control of eddy currents in additively manufactured Fe-Si, *Materials and Design*, **230**, 112002, https://doi.org/10.1016/j.matdes.2023.112002

Goodall, A.D., Nishanth, F.N.U., Severson, E.L., Todd, I., 2023, Loss performance of an additively manufactured axial flux machine stator with an eddy-current limiting structure, *Materials Today Communications*, **35**, 105978, https://doi.org/10.1016/j.mtcomm.2023.105978

Goodall, A.D., Chechik, L., Mitchell, R.L., Jewell, G.W., Todd I., 2023, Cracking of soft magnetic FeSi to reduce eddy current losses in stator cores, *Additive Manufacturing*, **70**, 103555, https://doi.org/10.1016/j.addma.2023.103555

Atkins, C., Chahid, Y., Wells, J.T., Westsik, M., Morris, K., Breen, C., Macleod, A., Bisslee, L., Cochrane, W., Kotlewski, R., McPhee, S., Snell, R.M., Todd, I., Beardsley, M., Harris, M., Pimentel, M., Mckegney, S., Orr, J., Alcock, S.G., Nistea, I.T., Cottarelli, S., Tammas-Williams, S., 2023, Understanding the role of additive manufacturing in the development of astronomical hardware, *SPIE Optical Engineering and Applications 2023*, https://doi.org/10.1117/12.2677452

2023 (THEME: P2.2)

Graham, S., Patel, A., Silva, B.F., Stott, W., Baxter, G.J., Roscher, M., Jackson, M., (2023), Solid-state processing of surplus aluminium alloy powders through a combination of field assisted sintering technology and hot rolling, *Powder Metallurgy*, **1-8**, http://doi.org/10.1080/00325899.2023.2171582

PUBLICATIONS

Graves, A, Salmasi, A, Graham, S, Wan, W, Xiao, C, Jackson, M, Larrson, H, Norgren, S, (2023), An experimental and theoretical investigation on Ti-5553/WC-Co(6%) chemical interactions during machining and in diffusion couples, *WEAR*, **516-517**, 204604, https://doi.org/10.1016/j.wear.2022.204604

Graham, S.J, Azakli, Y., Withey, J., Jackson, M., 2023, CIP-FAST: assessing the production of complex geometry titanium components from powders by combining Cold Isostatic Pressing (CIP) and Field Assisted Sintering Technology (FAST), *Powder Metallurgy*, https://doi.org/10.1080/00325899.2023.2236907

Pepper, J., Levano Blanch, O.,Thomas, B.,Jackson, M., 2023, Channelling electric current during the Field-Assisted Sintering Technique (FAST) to control microstructural evolution in Ti-6Al-4V, *Journal of Material Science*, **58**, 44945, https://doi.org/10.1007/s10853-023-08884-8

Wang, S.,Shen, Z., Omirkhan, A., Gavalda-Diaz, O., Ryan, M.P., Giuliani, F. , 2023, Determining the fundamental failure modes in Ni-rich lithium ion battery cathodes, *Journal of the European Ceramic Society*, **43**, 7553-7560, https://doi.org/10.1016/j.jeurceramsoc.2023.08.021

Graham, S., Gallagher, E., Baxter, G., Azakli, Y., Weeks, J., Gelmetti, M., D'Souza, N., Boettcher, C., Roebuck, B., Tsakiropoulos, P., Utton, C., 2023, Powder production, FAST processing and properties of a Nb-silicide based alloy for high temperature aerospace applications, *Journal of Materials Research and Technology*, **28**, 3217-3224, https://doi.org/10.1016/j.jmrt.2023.12.190

Lekas, S., Drummond, R., Grant, P.S., Duncan, S.R., 2024, Control of Additive Manufacturing for Radio Frequency Devices With Spatially Varying Dielectric Properties, *IEEE Transactions on Control Systems Technology*, https://doi.org/10.1109/TCST.2023.3345176

Zhang, J.S, Tang, Y. T., Jin, R., Lui, A., Grant, P.S., Alabort, E., Cocks, A.C.F.,, Reed, R.C., 2023, On the size-dependent fatigue behaviour of laser powder bed fusion Ti-6Al-4V, *Additive Manufacturing*, **79**, 103922, https://doi.org/10.1016/j.addma.2023.103922

Mee, B.C, Morris, S.M., Coon, J.P., Elston, S.J., Stevens, C.J., Grant, P.S., Zheng, Q., 2023, Reconfigurable Bowtie Antenna Using a Nematic Liquid Crystal, *IEEE Explore*, https://doi.org/10.1109/CAMA57522.2023.10352709

2023 (THEME: P2.3)

Zhou, S., Cai, Q., Tirichenko, I., Vinchez, V., Gavalda-Diaz, O., Bouville, F., Siaz, E., (2023), Additive Manufacturing of Al2O3 with Engineered Interphases and High Toughness Through Multi-Material Co-Extrusion, *Acta Materialia*, **246**, 118704, https://doi.org/10.1016/j.actamat.2023.118704

Nar, K., Majewski, C., Lewis, R., 2023, Evaluating the effect of solid lubricant inclusion on the friction and wear properties of Laser Sintered Polyamide-12 components, *WEAR*, **522**, 204873, https://doi.org/10.1016/j.wear.2023.204873

Pedrazzini, S., Pek, M.E., Ackerman, A.K., Cheng, Q., Ali, H., Ghadbeigi, H., Mumtaz, K., Dessolier, T., Britton, T.B., Bajaj, P., Jagle, E., Gault, B., London, A.J., Galindo-Nava, E., 2023, Effect of substrate bed temperature on solute segregation and mechanical properties in Ti-6Al-4V produced by laser powder bed fusion, *Metallurgical and Materials Transactions A: Physical Metallurgy and Materials Science*, **54**, 3069-3085, https://doi.org/10.1007/s11661-023-07070-4

Zhou, S., Tirichenko, I.S., Zhang, X., Hong, Y., Payne, H., Withers, P.J., Bouville, F., Saiz, E., 2023, *Embedded 3D printing of microstructured multi-material composites, Matter*, https://doi.org/10.1016/j.matt.2023.10.031

Hong, Y., Azcune, I., Rekondo, A., Jiang, T., Zhou, S., Lowe, T., Saiz, E., 2023, Additive Manufacturing of Shape Memory Thermoset Composites with Directional Thermal Conductivity, *Advanced Functional Materials*, https://doi.org/10.1002/adfm.202311193

Wang, S., Gavalda-Diaz, O., Lyons, J., Giuliani, F., 2023, Shear and delamination behaviour of basal planes in Zr3AlC2 MAX phase studied by micromechanical testing, *Scripta Materialia*, **240**, 115289, https://doi.org/10.1016/j.scriptamat.2023.115829

Wang, S., Shen, Z., Omirkhan, A., Gavalda-Diaz, Ryan, M.P., Giuliani, F., 2023, Determining the fundamental failure modes in Ni-rich lithium ion battery cathodes, *Journal of the European Ceramic Society*, **43**, 7553-7560, https://doi.org/10.1016/j.jeurceramsoc.2023.08.021

Tarver, J., Nar, K., Majewski, C., 2024, An investigation into the mechanisms that influence laser sintered polyamide-12 top surfaces, *Rapid Prototyping Journal*, https://doi.org/10.1108/RPJ-09-2023-0317

Caglar, H., Liang, A., Groom, K., Mumtaz, K., 2024, Multi-Laser Powder Bed Fusion of Ti6Al4V: Diode Area Melting Utilizing Low-Power 450 nm Diode Lasers, *Journal of Materials Processing Technology*, https://doi.org/10.1016/j.jmatprotec.2024.118303

2023 (THEME: X1)

Guo, L., Wang, H., Liu, H., Wei, Q., Leung, C.L.A., Wu, Y., Wang, H., 2023, Quantifying the effects of gap on the molten pool and porosity formation in laser butt welding, *International Journal of Heat and Mass Transfer*, **209**, 124123, https://doi.org/10.1016/j.ijheatmasstransfer.2023.124143

Gao, Z., Wang, H., Letov, N., Zhao, Y.F., Zhang, X., Wu, Y., Leung, C.L.A., Wang, H., 2023, Data-driven design of biometric composite metamaterials with extremely recoverable and ultrahigh specific energy absorption, *Composites Part B: Engineering*, **251**, 110468, https://doi.org/10.1016/j.compositesb.2022.110468

Fan, X., Shevchenko, N., Tonry, C., Clark, S.J, Atwood, R.C., Eckert, S. Pericleous, K., Lee, P.D., Kao, A., 2023, Controlling solute channel formation using magnetic fields, *Acta Materialia*, **236**, 119107, https://doi.org/10.1016/j.actamat.2023.119107

Fan, X., Fleming, T.G., Rees, D.T., Huang, Y., Marussi, S., Leung, C.L.A., Atwood, R.C., Kao, A., Lee, P.D., 2023, Thermoelectric magnetohydrodynamic control of melt pool flow during laser directed energy deposition additive manufacturing, *Additive Manufacturing*, **71**, 203587, https://doi.org/10.1016/j.addma.2023.103587

Ma, S., Shang, Z., Shang, A., Zhang, P., Tang, C., Huang, Y., Leung, C.L.A., Lee, P.D., Zhang, X., Wang, X., 2023, Additive manufacturing enabled synergetic strengthening of bimodal reinforcing particles for aluminum matrix composites, *Additive Manufacturing*, **70**, 103543, https://doi.org/10.1016/j.addma.2023.103543

Fleming, T.G, Rees, D.T., Marussi, S., Connolley, T., Atwood, R.C., Jones, M.A., Fraser, J.M., Leung, C.L.A., Lee P.D, 2023, In situ correlative observation of humping-induced cracking in directed energy deposition of nickel-based superalloys, *Additive Manufacturing*, **71**, 103579, https://doi.org/10.1016/j.addma.2023.103579

Chen, Y., Tang, Y.T., Collins, D.M., Clark, S.J., Ludwig, W., Rodriguez-Lamas, R., Detlefs, C., Reed, R.C., Lee, P.D., Withers, P.J., Yildirim, C., 2023, High-resolution 3D strain and orientation mapping within a grain of a directed energy deposition laser additively manufactured superalloy, *Scripta Materialia*, **234**, 115579, https://doi.org/10.1016/j.scriptamat.2023.115579

Rees, D.T., Leung, C.L.A., Elambasseril, J., Marussi, S., Shah, S., Marathe, S., Brandt, M., Easton, M., Lee, P.D., 2023, In situ X-ray imaging of hot cracking and porosity during LPBF of Al-2139 with TiB2 additions and varied process parameters, *Materials and Design*, **231**, 112031, https://doi.org/10.1016/j.matdes.2023.112031

Soundarapandiyan, G., Leung, C.L.A., Johnston, C., Chen, B., Khan, R.H.U., McNutt, P., Bhatt, A., Atwood, R.C., Lee, P.D., Fitzpatrick, M.E., 2023, In situ monitoring the effects of Ti6Al4V powder oxidation during laser powder bed fusion additive manufacturing, *International Journal of Machine Tools and Manufacture*, **190**, 104049, https://doi.org/10.1016/j.ijmachtools.2023.104049

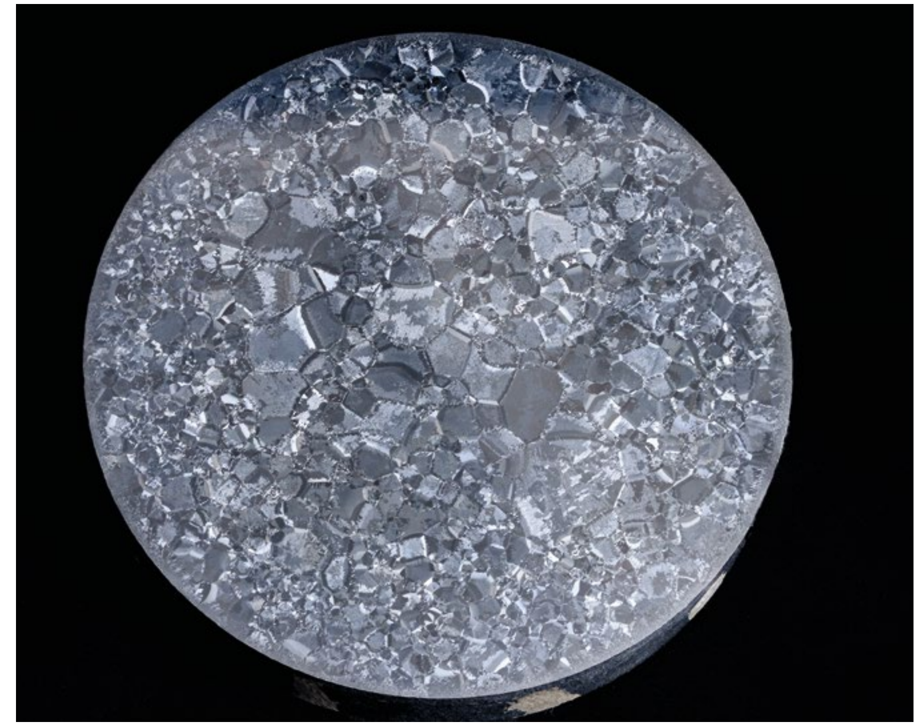
Iantaffi, C., Bele, E., McArthur, D., Lee, P.D., Leung, C.H.U., 2023, Auxetic response of additive manufactured cubic chiral lattices at large plastic strains, *Materials and Design*, **233**, 112207, https://doi.org/10.1016/j.matdes.2023.112207

Bhatt, A., Huang, Y., Leung, C.L.A., Soundarapandiyan, G., Marussi, S., Shah, S., Atwood, R., Fitxpatrick, M.E., Tiwari, M.K., Lee, P.D., 2023, In situ characterisation of surface roughness and its amplification during multilayer single-track laser powder bed fusion additive manufacturing, *Additive Manufacturing*, **77**, 103809, https://doi.org/10.1016/j.addma.2023.103809

Fleming, T.G., Clark, S.J., Fan, X. Fezzaa, K., Leung, C.L.A., Lee P.D., Fraser, J., 2023, Synchrotron validation of inline coherent imaging for tracking laser keyhole depth, *Additive Manufacturing*, **77**, 103798, https://doi.org/10.1016/j.addma.2023.103798

Guo, L., Hanjie, L., Wang, H., Wei, Q., Zhang, J., Chen, Y., Leung, C.L.A., Lian, Q., Wu, Y., Zou, Y., Wang, H., 2023, A high-fidelity comprehensive framework for the additive manufacturing printability assessment, *Journal of Manufacturing Processes*, **105**, 219-231, https://doi.org/10.1016/j.jmapro.2023.09.041

Li, X., Yang, X., Xue, C., Wang, S., Zhang, Y., Wang, B., Wang, J., Lee, P.D., 2023, Predicting hydrogen microporosity in long solidification range ternary Al-Cu-Li alloys by coupling CALPHAD and cellular automata model, *Computational Materials Science*, **222**, 112120, https://doi.org/10.1016/j.commatsci.2023.112120



A Look Beneath the Surface from Dennis Premoli. A Ti-64 powder 80mm sample, sintered through FAST, polished and etched (courtesy of Rolls Royce). An attempt at demonstrating the grain growth obtainable through this process and its use is validating new in-process analysis techniques, such as Machining Force Feedback.

2023 (THEME: X2)

Song, Z., Boller, E., Rack, A,. Lee, P.D., Cai, B., 2023, Magnetic field-assisted solidification of W319 Al alloy qualified by high-speed synchrotron tomography, *Journal of Alloys and Compounds*, **938**, 168691, https://doi.org/10.1016/j.jallcom.2022.168691

Salehi, S., Cummins, J., Gallino, E., Garg, V., Tong, D., Hassanpour, A., Bradley, M., 2023, Optimising Spread-Layer Quality in Powder Additive Manufacturing: Assessing Packing Fraction and Segregation Tendency, *Processes*, **2276**, https://doi.org/10.3390/pr11082276

2023 (THEME: X3)

Wu, K., Panoutsos, G., 2023, High dimensional many objective optimisation through diverse creation and categorisation of reference vectors, *GECCO '23 Companion: Proceedings of the Companion Conference on Genetic and Evolutionary Computation*, **423-426**, https://doi.org/10.1145/3583133.3590612

Atwya, M., Panoutsos, G., 2023, In-situ porosity prediction in metal powder bed fusion additive manufacturing using spectral emissions: a prior-guided machine learning approach, *Journal of Intelligent Manufacturing*, http://dx.doi.org/10.1007/s10845-023-02170-9

Notley, S.V., Chen, Y., Thacker, N.A., Lee, P.D., Panoutsos, G., 2023, Synchrotron imaging derived relationship between process parameters and build quality for directed energy deposition additively manufactured IN718, *Additive Manufacturing Letters*, **6**, 100137, https://doi.org/10.1016/j.addlet.2023.100137

Grais, E.M., Notley, S.V., Panoutsos, G., 2023, Reinforcement Learning for Multiple-Input Multiple-Output Control in Metal Additive Manufacturing, *IEEE Explore*, https://doi.org/10.1109/ICNSC58704.2023.10319015

2024 (THEME: X1)

Zhang, K., Chen, Y., Marussi, S. et al, 2024, Pore evolution mechanisms during directed energy deposition additive manufacturing. *Nat Commun* **15**, 1715, https://doi.org/10.1038/s41467-024-45913-9

EVENTS

2023–2024

MAPP has continued to host hybrid and in-person events throughout 2023 and into 2024. MAPP colleagues have been involved across a wide range of over 35 conferences and public engagement events, both online and in person. This included 63 presentations and 20 invited/keynote lectures.

The MAPP Second International Conference was held at the Novotel Hotel in Sheffield on the 28th and 29th June 2023. Two MAPP lectures were included as part of in-person quarterly review meetings.

The events attended included:

TMS 2023
[19/03/2023 - 23/03/2023]
The Materials Structure and Manufacturing group was held in San Diego, California. Attendees from MAPP gave 3 invited talks, 8 presentations and a number of poster presentations. MAPP speakers included Prof. Peter Lee, Dr Chu Lun Alex Leung, Rubén Lambert-Garcia, Dr Kai Zhang, Caterina Iantaffi, Anna Getley, David Rees, Cameron Barrie, Elaine Livera and Sam Lister.

MAPP Quarterly Review Meeting
[28/03/2023 - 29/03/2023]
A MAPP Quarterly Review Meeting was held at Sheffield University in March 2023. The meeting included flash presentations from 15 MAPP Early Career Researchers, the presentation of over 25 posters and a tour of the Royce Translational Centre (RTC) and Royce Discovery Centre (RDC). Dr Tom Flint from Manchester University gave a MAPP Lecture on "Recent Developments in Mathematical Modelling Frameworks for Advanced Manufacturing Processes".

MAPP Quarterly Review Meeting
[October 2023]
A MAPP Quarterly Review Meeting was held at Imperial College London in October 2023. The meeting included a presentation by Angus Baker from the Royal Academy of Engineering on "How to Commercialise Research Through a Spinout Company" and a MAPP Lecture by Prof. Richard Todd from Oxford University on "Accelerated Sintering through Rapid Heating: Evidence, Mechanisms and Prospects".

World Titanium Conference
[12/6/2023 - 16/06/2023]
The World Titanium Conference was held in Edinburgh in June 2023. Martin Jackson gave the Chairman's welcome presentation and a plenary session presentation on "Titanium Research Developments in the United Kingdom". MAPP attendees, Cameron Barrie, Sam Lister, James Pepper, Hugh Banes and Jiaqi Xu gave presentations at the conference.

Design for AM - A focus on Polymers
[22/06/2023]
Dr Candice Majewski organised and led a one day seminar at the University of Sheffield on Polymer Additive Manufacturing featuring a range of speakers from Industry and academia with over 100 attendees.

MAPP Second International Conference
[28/06/2023 - 29/06/2023]
This successful MAPP hosted event was held in Sheffield in June 2023 and was attended by over 120 delegates - see pages 28 and 29 for more details.

ECerS 2023
[02/07/2023 - 06/07/2023]
The Conference and Exhibition of the European Ceramic Society was held in Lyon, France in July 2023. MAPP attendee Dr Rohit Malik gave a presentation on "Processing and Properties of Robocasted Alumina-based Ceramic Matrix Composites".

9th UK-China Powder Technology Forum
[21/8/2023 - 24/08/2023]
This event was held in Greenwich, London in August 2023. Dr Ali Hassanpour gave a plenary talk on "Particle Technology and Additive Manufacturing: Current Advances" and Dr Mozhdeh Mehrabi gave a presentation on "The Effect of Temperature on Spreading Behaviour of Metal Powders for Additive Manufacturing".

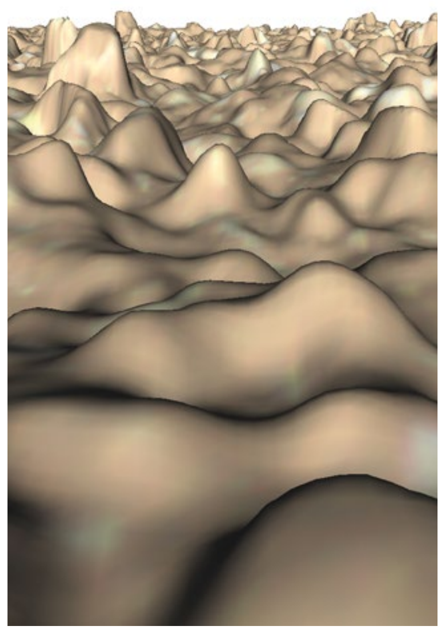
FEMS EUROMAT 2023
[03/09/2023 - 07/09/2023]
This conference was held in Frankfurt, Germany in September 2023 and MAPP attendees Dr Kai Zhang and Dr Xianqiang Fan gave presentations at the event.

IWAC 09
[26/09/2023 - 29/09/2023]
The 9th edition of the International Workshop on Advanced Ceramics was held in Limoges, France in September 2023. MAPP Attendee Dr Rohit Malik gave a presentation on "Processing and Properties of Direct Light Processed Alumina-based Ceramic Matrix Composites".

AAMS Madrid
[27/09/2023 - 29/09/2023]
The Alloys for Additive Manufacturing Symposium was held in September 2023 in Madrid. MAPP attendees Dr Rob Snell, Frances Livera, Elaine Livera, Oli Dew and Lucy Farquhar gave presentations at the conference. Dr Samy Hocine gave an invited talk on "Operando Monitoring of Multi-laser Powder Bed Fusion Process during High-speed Synchrotron Imaging".

Rolls Royce Service Technology Student Conference
[29/09/2023]
This conference was held at the Rolls-Royce Learning and Development Centre in Derby in September 2023. 4 Rolls-Royce sponsored MAPP early career researchers gave presentations at this well attended event.

ICAM 2023
[30/10/2023 - 03/11/2023]
The International Conference on Advanced Manufacturing was held in Washington, USA. MAPP Attendee Dr Ryan Brown gave an invited talk on "Towards Quantum Cascade Laser Sintering of Polymer Parts - Extension of Diode Area Melting to the Mid-IR".



Surface Level from Kieran Nar. A focus variation microscopy obtained surface scan of a polymer laser sintered surface

MAPP OUTREACH ACTIVITIES

Primary Engineer Grading and Judging Days
[27/03/2023 and 28/04/2023]
In the Primary Engineer 'If you were an engineer, what would you do?' (IYWAE) Leaders Award competition, learners aged 3 to 19 in the United Kingdom are challenged to create their own annotated engineering design and write a persuasive letter to convince an engineer why their design is needed and should be built. Following on from Dr Chu Lun Alex Leung taking part in a national online interview for Primary Engineer in October 2022, 4 MAPP Early Career Researchers and the MAPP Project Manager took part in Primary Engineer IYWAE grading and judging days in the South Yorkshire region.

Primary Engineer judging day in South Yorkshire

Exploring STEM Event
[04/05/2023]
The Exploring STEM event was held in the Octagon Centre at Sheffield University in May 2023. Around 280 pupils from 10 local schools attended the event and tried out 3D pens, a powder matching game and learnt about 3D printing at the MAPP stand.

MAPP Researchers Dr George Maddison, Lucy Farquhar and Dr Simon Graham helping on the MAPP stand at the Exploring Stem event

MAPP'S THIRD IMAGE COMPETITION

The competition, which was open to MAPP researchers at all levels, showcased some of the fantastic photographs captured during the powder and processing studies taking place across partner sites. Researchers from across the MAPP programme submitted more than 30 entries in either the technical or artistic categories.

The prize winners were as follows:

TECHNICAL CATEGORY

First prize:
Harry Chapman for "Powder Profile" featured on the back page.

Runner up:
Frances Livera for "The Complexity of an AM Surface" featured on the back page.

Commended:
Mozhdeh Mehrabi for "Crowded Family" featured on this page (right).

Commended:
Milo Maguire for "Popped Ti64 Atomised Powder" featured on this page (right).

Commended:
James Pepper for "Secret Structures" featured on page 33.

ARTISTIC CATEGORY

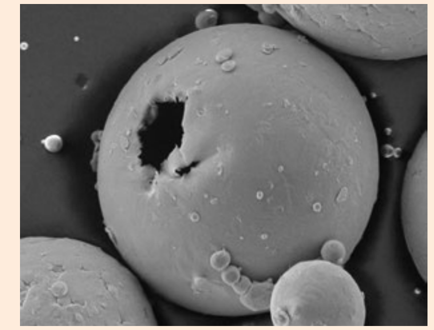
First prize:
Milo Magure for "Atomisation Melt RTC" featured on the back page.

Runner up:
James Pepper for "Titanium Hourglass" featured on the back page.

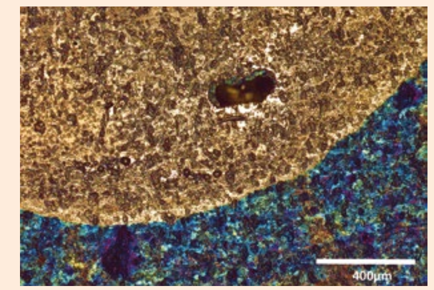
Commended:
Ben Thomas for "Ponds of Steel" featured on page 35.

Commended:
Dennis Premoli for "Regicide" featured on this page (right).

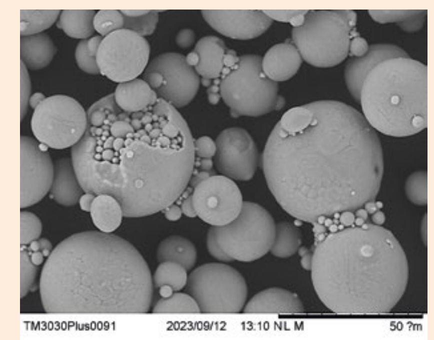
Commended:
Alisha Bhatt (UCL) for "Hybrid Printing" featured on this page (right).



Milo Magure was commended in the technical category for "Popped Ti64 Atomised Powder"



Alisha Bhatt was commended in the artistic category for "Hybrid Printing"



Mozhded Mehrabi was commended in the technical category for "Crowded Family"

Dennis Premoli was commended in the artistic category for "Regicide"

MAPP

EXECUTIVE TEAM

Professor Iain Todd, MAPP Director, Theme Lead for Metal Additive Manufacturing (P2.1)

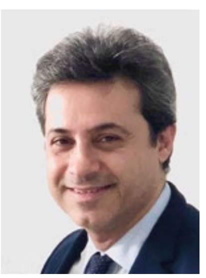
Iain Todd is a Professor of Metallurgy at the University of Sheffield, and the Director of the MAPP EPSRC Future Manufacturing Hub. His research is focused on both the development of new alloys and the development of new processes to enable engineering structures to be manufactured from them. Iain's manufacturing research is conducted on the near-industrial scale and actively supported by industry. Iain is a Fellow of the IOM3 and Director of the Materials Made Smarter Research Centre.

In September 2023, Iain was elected to the Royal Academy of Engineering in recognition of his outstanding contributions to engineering and technology. In 2023, he was also awarded a Gold Medal by the IoM3 for significant contributions within the materials, minerals or mining sector.

Professor John Francis, Theme Co-Lead for P2.2a FAST/SPS/HIP

John is a fellow of the Institute of Materials, Minerals and Mining and is accredited as a European/International Welding Engineer (EWE/IWE). John has been working with welding and cladding technologies for 25 years, having started his career with CSIRO in Australia, where he spent 7 years developing welding procedures to solve issues in the aerospace, power generation and minerals processing sectors.

John's research focuses on understanding the evolution of microstructures and stresses in joints during welding, with a view to developing welding procedures that can mitigate cracking and deliver either improvements in productivity or through-life structural performance. More recently he has developed an interest in the application of powder-based processes to the joining of dissimilar alloys.



Associate Professor Ali Hassanpour

Ali is an associate professor at the school of chemical and process engineering, University of Leeds.

His research is mainly focused on the characterisation of single-particle properties and analysis of particles' collective properties and behaviours using multi-scale modelling approaches such as Discrete Element Modelling (DEM).

His research is supported by Innovate UK, EU, EPSRC and industry. Ali has more than 100 journal publications.

Professor Visakan Kadirkamanathan, Theme Co-Lead for X3 Modelling, Optimisation and Control

Visakan, University of Sheffield, is Director of Rolls-Royce University Technology Centre (UTC) in Control and Monitoring Systems Engineering.

His primary research field is signal and information processing, dynamic and spatio-temporal modelling, intelligent health monitoring and fault detection with applications in aerospace and biomedicine.

His multi-disciplinary research is funded by the UK research councils, EU, Innovate UK and Industry with more than £25M in grants.

He has published more than 200 papers and was awarded the PNAS Cozzarelli Prize (2012).

His research in manufacturing focuses on data analytics and informatics for process design, monitoring and prediction for additive and subtractive manufacturing processes.

He advances model-based signal processing and machine learning algorithms for in-process monitoring from spatial and temporal sensor data such as thermal imaging and acoustic emissions data.

Professor Peter Lee, Theme Lead for X1 *In-situ* Process Monitoring

Peter is Professor of Materials Science at University College London and holds the Royal Academy of Engineering Chair in the Emerging Technology of Additive Manufacturing.

He is an expert in characterising microstructural evolution during manufacturing using *in-situ* synchrotron imaging.

He uses these results to inform Integrated Computational Materials Engineering (ICME) models to predict processing-structure-property relationships, based on more than 30 years experience at Alcan, Imperial, Harwell, and now University College London.

He has published more than 300 journal papers and is a Fellow of the Royal Academy of Engineering, Institute of Materials, Minerals and Mining (IOM3) and the Institute of Cast Metals Engineers. IOM3 awarded him the John Hunt Medal in 2021.

Dr Enzo Liotti, Theme Co-Lead for P2.2b Fundamentals of Solid State Processing

Enzo is a Departmental Lecturer in the Processing of Advanced Materials at the Department of Materials, University of Oxford.

His research focus is on using and developing X-ray synchrotron techniques for the investigation of fundamental dynamic phenomena in metal processing and material science, with a particular interest in solidification of metal alloys.

He obtained his BSc (2004) and MSc (2006) in Material Engineering from Politecnico di Milano.

He gained a PhD in Materials Science from the University of Loughborough (2011), working on the characterisation of a nano-quasicrystalline containing Al alloy with high-temperature mechanical properties.

From 2011 to 2019 he was a PDRA at the department of Materials, University of Oxford, working on *in-situ* imaging of solidification within Prof. Patrick Grant's Processing of Advanced Materials Group.

Professor Eduardo Saiz, Theme Lead for P2.3c Ceramics

Eduardo directs the Centre for Advanced Structural Ceramics (CASC) at Imperial College London.

His research interests include the development of new processing techniques for the fabrication of ceramic-based composites, in particular, hierarchical composites with bioinspired architectures.

He has published more than 120 papers, including high impact journals such as Science and Nature Materials and holds several US patents.

His work on the 3D printing of ceramics and graphene inks has been highlighted internationally from New York Times to Wired.

In 2021 the Institute of Materials, Minerals and Mining awarded him the Verulam Medal and Prize which is presented in recognition of distinguished contributions to ceramics.

Professor Phillip Stanley-Marbell, University of Cambridge.

Phillip is a Professor and Chair of Physical Computation in the Department of Engineering at the University of Cambridge, where he leads the Physical Computation Lab.

Prior to joining the University of Cambridge, he was a researcher at MIT, from 2014 to 2017. He received his PhD from CMU in 2007, was a postdoc at TU Eindhoven until 2008, and then a permanent Research Staff Member at IBM Research—Zurich. In 2012 he joined Apple where he led the development of a new system component now used across all iOS, watchOS, and macOS platforms.

His research focus is on exploiting an understanding of properties of the physical world to make computing systems more efficient.

INDUSTRIAL ADVISORY BOARD (IAB)

Dr Lee Aucott, United Kingdom Atomic Energy Authority (UKAEA), Manufacturing Lead for the STEP programme

Lee received his undergraduate and doctorate degrees in the fields of mechanical and materials engineering from the University of Leicester.

He has significant experience working in the UK nuclear sector in a variety of roles focussed on the development of emerging manufacturing technologies.

In his current role, Lee is responsible for the manufacture and inspection of the UKAEA's Spherical Tokamak for Energy Production (STEP) reactor.

Powder metallurgy processes will be essential to realise the materials and component geometries required for STEP.

Marko Bosman, Chief Technologist Additive Manufacturing, GKN Aerospace

Director of the Materials Innovation Institute M2i in the Netherlands

Marko Bosman has an MSc degree in Materials Science and Engineering from the Technical University of Delft and has extensive experience in the field of aerospace materials and manufacturing technology.

Since 1999 he worked in different roles at Fokker, where he started exploring the potential of additive manufacturing in 2011, resulting in several product implementations.

In his current role as Chief Technologist, he coordinates the global additive manufacturing developments of GKN Aerospace.

Dr Gael Guetard, Rapid Alloy Research Centre Director, Alloyed

Gael graduated in 2016 with a PhD from the University of Cambridge where he investigated the use of powder metallurgy for rolling bearings.

He then joined Aubert & Duval, one of Europe's main producers of high-performance alloys. There, he worked on improving the quality of metal powders as well as the efficiency of the production process.

In 2018, he moved back to the UK to join Alloyed, a company specialised in the computational development of alloys and additive manufacturing technologies. There, he leads the Rapid Alloy Research Centre, a laboratory focused on accelerating Alloyed's technologies by providing experimental validation and proof-of-concept.

Dr Hugh Hamilton, Scientific Consultant, Johnson Matthey

Hugh has been with the Johnson Matthey Technology Centre since 1988, during which time he has worked in a variety of technical areas including catalysts for automotive applications, modified atmosphere packaging, PEM fuel cell membrane electrode assembly design and manufacture, hydrogen storage alloys and separation membranes, electrochemical processing and PM processing of titanium and other alloy powders.

Professor Neil Hopkinson, VP AM technology, Stratasys

Neil spent 20 years in academia conducting research in the field of additive manufacturing. His academic research has generated a strong Intellectual Property/Patent portfolio which has been licensed globally from small start-ups to global multinationals.

His research and IP portfolio has had a transformational impact on the additive manufacturing/industrial 3D printing industry with thousands of machines sold and over $1Bn revenues from businesses selling licensed products.

In 2016 Neil left academia to join Cambridge based inkjet printhead manufacturer Xaar and is now with global leading 3D Printing company Stratasys.

Nick Jones, Technology Development Manager, Renishaw's Additive Manufacturing Group

Based at the company head office in Gloucestershire, UK, Nick leads a team of engineers and scientists undertaking research and design. He has worked in or around laser powder bed fusion for fifteen years.

He has been with the company for more than twenty-five years, working in a number of product divisions as well as in process development and manufacturing roles. He holds bachelors and masters degrees in Mechatronic Engineering.

Ian Laidler, Chief Technology Officer, Wayland Additive

Ian is a physicist and engineer with 30 years of experience directing complex technical developments of high value capital equipment for the semiconductor and medical industries.

Following a career that has included working on a superconducting electron synchrotron for IBM's X-ray Lithography program, superconducting proton cyclotrons for PET scanners, X-ray beamlines for the world's third generation synchrotrons and electron beam lithography systems for the semiconductor and nanotechnology industries, Ian has cofounded Wayland Additive.

Wayland Additive is a Yorkshire based start-up developing and manufacturing a new capability in electron beam additive manufacturing systems, drawing on the experience of a highly skilled team of electron and ion beam system engineers coupled with the strong additive manufacturing expertise present in Yorkshire.

Dr Ian Mitchell, Chief of Technology – Repair & Services, Rolls-Royce

Ian has been with Rolls-Royce plc since 2009 following an undergraduate degree and engineering doctorate at the University of Birmingham in the fields of engineering and materials science.

Since joining Rolls-Royce plc he has worked in various roles in technology development, mechanical testing and validation, project management, and led the highly innovative blisk additive repair R&D project.

In his current role, Ian leads the global repair and services research portfolio and is responsible for defining the strategy for the development of innovative technologies to support Rolls-Royce products in service.

This diverse portfolio includes both *in-situ* repair (utilising advanced robotics and miniaturisation of technologies, i.e. 'key-hole surgery for jet engines'), as well as the next generation of component repair and inspection technologies for use in overhaul facilities.

Dr Sozon Tsopanos, Head of Additive Manufacturing, The Weir Group

Sozon's specialities are rapid prototyping and manufacturing, Selective Laser Melting, laser welding, additive manufacturing and STL file manipulation.

He is currently Head of Additive Manufacturing (AM) at Weir and was AM Technology Lead at Weir Minerals. Before joining Weir he was Principal Project Leader at TWI.

Professor Ken Young, Chief Technology Officer, Manufacturing Technology Centre (MTC)

Ken did both his BSc in Mechanical Engineering and his PhD in the Mechanical Engineering Department at the University of Nottingham, before spending six years in industry writing CAD based programming systems for industrial systems including robots, machine tools and CMMs.

He then spent 20 years at Warwick Manufacturing Group during which time he led their IMRC and the Manufacturing Technologies research group.

In his current role, he oversees research in fields as diverse as additive manufacturing, electronics, informatics, simulation, friction welding, advanced fixturing and intelligent automation.

The MTC specialises in maturing manufacturing processes from laboratory proof of concept through to being proven at low volume.

Since he joined the MTC in 2011 it has grown from two people to more than 800 and has become a £100M turnover business.

THE SCIENTIFIC ADVISORY BOARD (SAB)

Professor Tresa Pollock,
SAB Chair, Alcoa Professor of Materials at the University of California, Santa Barbara

Tresa graduated with a B.S. from Purdue University in 1984, and a PhD from MIT in 1989.

She was employed at General Electric Aircraft Engines from 1989 to 1991, where she conducted research and development on high-temperature alloys for aircraft turbine engines.

She was a professor in the Department of Materials Science and Engineering at Carnegie Mellon University from 1991 to 1999 and the University of Michigan from 2000 - 2010.

Her current research focuses on the processing and properties of structural materials and coatings and on the use of ultrafast lasers for micro-fabrication and materials diagnostics.

Prof. Pollock was elected to the U.S. National Academy of Engineering in 2005, the German Academy of Sciences Leopoldina in 2016, is a Fellow of TMS and ASM International, Editor in Chief of Metallurgical and Materials Transactions and was the 2005-2006 President of The Minerals, Metals and Materials Society.

Professor Carolin Körner,
Friedrich-Alexander-University (FAU)

Carolin is the head of the Institute of Science and Technology for Metals (WTM) in the Materials Science Department, a member of the Collegial Board and head of the E-Beam Additive Manufacturing group of the Central Institute of Advanced Materials and Processes (ZMP) and the head of the Additive Manufacturing group of Neue Materialien Fürth GmbH (research company of the Bavarian state).

She studied theoretical physics at the FAU. She earned her PhD with distinction at the Materials Science Department of the FAU Faculty of Engineering in 1997 with a thesis on "Theoretical Investigations on the Interaction of Ultra-short Laser Radiation with Metals" under the supervision of Prof. H.W. Bergmann. Habilitation and venia legendi in Materials Science followed at FAU in the group of Prof. R.F. Singer in 2008 for "Integral Foam Molding of Light Metals: Technology, Foam Physics and Foam Simulation" (Springer Textbook). In 2011 she took up her current position at FAU. At present, she is advising some 25 PhD students and postdocs in the fields of additive manufacturing, casting technology, alloy development and process simulation.

Professor Javier Llorca,
Polytechnic University of Madrid & IMDEA Materials Institute

Javier is the scientific director and founder of the IMDEA Materials Institute and head of the research group on Advanced Structural Materials and Nanomaterials at the Polytechnic University of Madrid.

He has held visiting appointments at Brown University, Shanghai Jiao Tong University, Indian Institute of Science and Central South University.

Prof. Llorca, a Fulbright scholar, is a Fellow of the European Mechanics Society and of the Materials Research Society and a member of the Academia Europaea and has received the Research Award from the Spanish Royal Academy of Sciences and the Career Award for the Spanish Society of Materials.

His research activities have been focused on the systematic application of computational tools and multiscale modelling strategies to establish the link between processing, microstructure and properties of structural materials.

A key feature of his contributions is the use of novel experimental techniques to determine the properties of the phases and interfaces in the material at the nm and μm scale.

So, simulations are fed with experimental values independently obtained and free of "adjusting" parameters.

Some of these developments have become the foundation of the modern techniques of virtual testing of composites, which are starting to be used by the aerospace industry to minimise the number of costly mechanical tests to characterise and certify composite structures.

His current research interests – within the framework of Integrated Computational Materials Engineering – are aimed at the design of advanced materials for engineering applications in transport, health care (implants) as well as energy (catalysis), so new materials can be designed, tested and optimized *in silico* before they are actually manufactured in the laboratory.

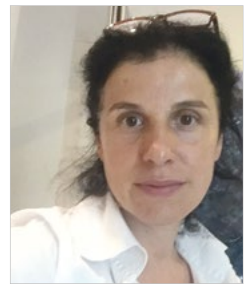
Professor Jin Ooi,
University of Edinburgh

Jin received a B.Eng.(Hons.) degree from The University of Auckland, a PhD degree from The University of Sydney and is currently the Professor of Particulate Solid Mechanics.

His principal research interests lie in the mechanics of particulate solids, from soils and rocks to many industrial powders and solids.

He co-founded EDEM (DEM Solutions Ltd) and Particle Analytics Ltd, bringing the impact of his research to many industrial and scientific problems.

He collaborates actively with academic and industrial partners, providing leadership as Coordinator for the TUSAIL EU ITN Consortium on upscaling of particulate manufacturing processes (www.tusail.eu) and previously for the T-MAPPP ITN on multiscale analysis of particulate processes, and the PARDEM ITN on DEM calibration and validation.



Professor Barbara Previtali,
Politecnico di Milano

Barbara is Full Professor in the Department of Mechanical Engineering of Politecnico di Milano.

She is the director of SITEC— Laboratory for Laser Applications at Politecnico di Milano and leads PromozioneL@ser within AITeM association, which connects Italian laser users in industry and academia.

Her research interests lie in the area of advanced manufacturing processes, specifically laser processes and additive manufacturing.

Her current focus is on monitoring and close-loop control of laser cutting, development of innovative SLM solutions, such as single point exposure pulsed SLM or dynamic and adaptive beam shaping techniques in SLM, and robotic laser and arc metal deposition of large components in aluminium and titanium alloys.

Dr Fabrice Rossignol,
Institute of Research for Ceramics (IRCER)

Fabrice received his PhD in 1995 at the University of Limoges in the field of Ceramic Processes and Surface Treatments.

He was a post-doc fellow in the Agency of Industrial Science and Technology in Japan from 1996 to 1998.

Then he joined industry as a technical manager for the Bosch Company from 1999 to 2001. In 2002 he returned to the academic field at the French National Research Council (CNRS) working in the Institute of Research for Ceramics (IRCER-200 members) in Limoges, France.

From 2007 to 2017, he was the Team Leader of the Ceramic Processes Team at IRCER. He is now Deputy Director of IRCER.

He conducts integrated research ranging from powder synthesis to the fabrication of prototype objects with improved or new properties using various shaping and consolidation techniques.

He aims to control preparation steps to obtain micro(nano)structures and macroscopic architectures adapted to specific functionalities of technical ceramics.

Dr Rossignol's personal research interests are more in the shaping of nanostructured ceramics (top-down and bottom-up approaches) and in the development of additive manufacturing technologies (inkjet printing).

One key application field of his research is energy, for example supported catalysts for H_2 production.

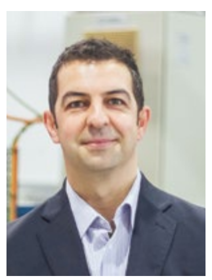
MAPP
INVESTIGATORS

Professor Andrew Bayly, University of Leeds, P2.1a Laser Powder Bed Fusion Theme Co-Lead. Andrew is a chemical engineer with more than 20 years of experience in the development of particulate products and processes. He had significant experience in industry before moving to academia in 2013, including the position of Principal Scientist at Proctor and Gamble. His research focuses on the link between process, particle structure and process/product performance and application to optimisation and scale-up. His research is supported by ATI, AMSCI, EPSRC, EU and industry.

Dr Finn Giuliani, Imperial College London. Finn's research interests are in ceramic materials, particularly powder manipulation, characterisation and small scale testing, especially of interfaces. He has published more than 90 papers, holds more than £20M in active grants and has collaborated with companies including SECO Tools, Shell, Element Six, Morgan Technical Ceramics and Camfridge.

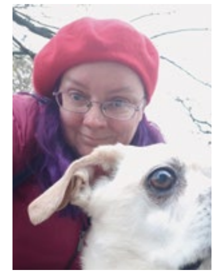
Professor Patrick Grant is Vesuvius Professor in the Department of Materials and Pro-Vice-Chancellor (Research) at Oxford University. He researches at the interface between manufacturing and novel materials, described in > 260 research papers and 8 patents. He commercialised his research work on spray formed 3D shapes in collaboration with Ford Motor Co., with licensed patents used in the production of components in Europe and the USA. Patrick is principal investigator of the £12.5M Faraday Institution (FI) grant *Next Generation Electrodes*, and work package leader for cell manufacture in FI project *Solid State Metal Batteries*. He is Co-I of EPSRC *Future Manufacturing Hub in Manufacture using Advanced Powder Processes*. Patrick served on the UK Fusion Advisory Board (2007-12), authored evidence paper New and Novel Materials for HMGs Foresight Future of Manufacturing report (2013). He is a member of Constellium's Scientific Council, a non-executive director of Oxford University Innovation, and was elected to the Royal Academy of Engineering in 2010.

Dr Kristian Groom, University of Sheffield. Kristian's research focuses on semiconductor optoelectronic component design and manufacture, with an interest in photonic integration and in the application of near- and mid-IR semiconductor lasers, superluminescent diodes, amplifiers, detectors and passive optical elements for application in high-value manufacturing. He is working on projects to develop capability for the heterogeneous integration of III-V semiconductor components and circuits upon a range of substrates to enable new sensor technologies, both through the EPSRC Heteroprint project and the EPSRC Future Photonics Hub. He is also pursuing research into the application of laser diode arrays for efficient high-speed additive manufacturing of both metallic and polymer parts.



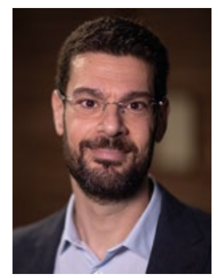
Professor Martin Jackson, University of Sheffield, P2.2 Theme Co-Lead for P2.2a FAST/SPS/HIP and P2.2b Fundamentals of Solid State Processing. Martin's research centres on the effect of solid state processes from upstream extraction technologies through to downstream finishing processes on microstructural evolution and mechanical properties in light alloys. A major research interest is to provide a step-change in the economics of titanium based alloys through the development of non-melt consolidation routes including FAST-*forge* and continuous rotary extrusion. Martin works closely with industry partners including VW, Rolls-Royce, Boeing and DSTL. He has more than 120 publications, was awarded a RAEng/EPSRC Fellowship in 2005 and the IOM3 Ti Prize in 2003.

Dr Chu Lun Alex Leung, University College London, Associate Professor in Advanced Manufacturing in the Department of Mechanical Engineering. He specialises in the application of synchrotron and laboratory X-ray imaging techniques to study AM processes and product performance. His research focuses on the development of intelligent advanced manufacturing using cutting-edge sensing technologies. In MAPP, he develops and applies multi-modal imaging and diffraction techniques for studying rapid solidification phenomena during AM, provides key insights into the fundamentals of AM, and generates data for validating existing and developing new process simulation models. He is the Chair of the MAPP training committee and advocates for developing a professional mentorship scheme for MAPP.



Dr Candice Majewski, University of Sheffield, P2.3b Future Manufacturing Platforms – High Speed Sintering & Polymer AM Theme Lead. Candice is a senior lecturer with over 20 years of experience in the field of AM. She manages the University's Advanced Polymer Sintering Laboratory and has built up a large network of academic and industrial collaborators, focusing much of her research towards improving powdered polymer AM materials and processes to increase their potential for widespread industrial usage. In 2011 she received the International Outstanding Young Researcher in Freeform and Additive Manufacturing Award. In 2022 she was shortlisted as one of five finalists in the 2022 TCT Women in 3D Printing Innovator Award, and placed within the 100 Highly Commended Finalists of the Top 50 Women in Engineering (WE50) 2022: Inventors and Innovators. She is an advocate for Equality, Diversity, Inclusion and Accessibility (EDIA), and has a role as Departmental Director of One University, where her remit includes EDIA, well-being, workplace culture and sustainability.

Dr Kamran Mumtaz, University of Sheffield. P2.3a Diode Area Melting Theme Lead. Kamran's research focuses on developing additive manufacturing methods and materials for metallic net shape component fabrication, specifically targeting the development of refined materials and new processes (i.e multi-laser Diode Area Melting) to deliver distinct capability advantages over conventional manufacturing techniques.



Professor George Panoutsos, University of Sheffield, X3 Theme Co-Lead. George's research is focused on the optimisation of manufacturing processes, systems design using computational intelligence and machine learning, as well as autonomous systems for manufacturing. A particular interest is metals design and processing with applications focusing on 'through-process modelling and optimisation' as well as 'prediction of mechanical properties' and 'real-time process monitoring' using data-driven methodologies.

Professor Philip Prangnell, University of Manchester. A leading expert on light metals and advanced manufacturing processes. His research activities are focused on studying advanced thermomechanical processing and joining techniques for light alloys (mainly aluminium and titanium). He works with major aerospace companies and their supply chain partners and has published extensively with more than 200 papers. He was co-director of the EPSRC LATEST2 programme grant in 'Light Alloys for Environmentally Sustainable Transport'. He is co-director of the Centre for Doctoral Training (CDT) in Metallic Materials with the University of Sheffield.

Professor Mark Rainforth, University of Sheffield. Mark's research interests are the high resolution characterisation of microstructures, in particular interfaces and surfaces. His research programmes are broadly based, covering metals, ceramics and coatings. He is a winner of the IOM3 Rosenhain and Verulam Medals and is a Fellow of the Royal Academy of Engineering. Mark has published more than 380 papers and is involved in >£40m of current grants. He co-directed the Mercury Centre with Prof. Iain Todd.

MAPP INVESTIGATORS

Professor Jon Willmott, University of Sheffield. Jon is a Professor of Metrology (measurement science) with a strong interest in developing novel instrumentation for additive manufacturing. He received his masters and PhD degrees in physics from the University of Southampton. After two years as a Post-Doctoral Research Associate in Liquid Crystal research at the University of Cambridge, he moved to the company Land Instruments International (now part of AMETEK Inc.) In industry, he designed thermal imaging cameras, radiation thermometers and other 'non-contact' scientific instruments. Following more than a decade in industry, he moved to the University of Sheffield in 2015 with an EPSRC Established Career Fellowship. He currently holds a Royal Society Industry Fellowship.

Professor Philip Withers, University of Manchester, Theme Lead for X2 Advanced Characterisation. Philip is the Regius Professor of Materials at Manchester and a major international figure in advanced characterisation. He is Chief Scientist at the Henry Royce Institute and a Director of the National Research Facility for Lab. X-ray CT. He has more than 500 publications in the field. Philip is a Fellow of the Royal Society and a Fellow of the Royal Academy of Engineering, the Chinese Academy of Engineering and the Indian National Science Academy.

MAPP PDRAs:

Dr Daliya Aflyatunova
Dr Ryan Brown
Dr Yun Deng
Dr Iuliia Elizarova
Dr Felicity Freeman
Dr Simon Graham
Dr Emad M. Grais
Dr Oliver Hatt
Dr Samy Hocine
Dr Wei Li
Dr Rohit Malik
Dr Mozhdeh Mehrabi
Dr Scott Notley
Dr Rob Snell
Dr Ben Thomas
Dr Rahul Unnikrishnan
Dr Siyang Wang
Dr Kai Zhang
Dr Xun Zhang
Dr Zihan Song

MAPP-aligned PDRAs

Dr Shishira Bhagavath
Dr Chizhou Fang
Dr Anqi Liang
Dr Oliver Levano Blanch
Dr Janith Petangoda
Dr Minh Phan
Dr Chatura Samarakoon
Dr Hamid Toshani
Dr Vasileios Tsoutsouras
Dr Nicholas Weston
Dr Zhuoqun Zhang

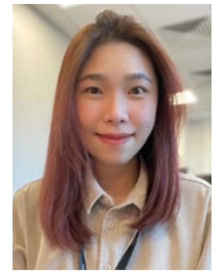
MAPP PhDs

Mohamed Atwya
Hugh Banes
Cameron Barrie
Alex Goodall
Guy Harding
Oliver Leete
Joseph Samuel
Henry Saunders
Alex Sloane

MAPP-aligned PhDs

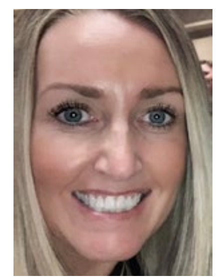
Hussam Abunar
Muhammad Aftab
Saad Syed Iqbal Ahmed
Talal M Al-Ghamdi
Abdullah Alharbi
Mohammed Alsaddah
Zaher Alsheri
Alkim Aydin
Josh Berry
Aisha Bhatt
Louise Chan
Harry Chapman
Lova Chechik
Max Chester Jude Emmanuel
Imogen Cowley
Xianqiang Fan
Lucy Farquhar
Cameron Favell Gallifant
Maureen Fitzpatrick
Matthew Gelmetti
Kubra Genc
Anna Getley
Adam Gothorp
Joe Hopkinson
Yinglun Hong
Caterina Iantaffi
Tianhui Jiang
Orestis Kaparounakis
Kwan Kim
Ruben Lambert-Garcia
Ming Li
Sam Lister
Elaine Livera
Francis Livera
George Maddison
Anran Mao
David McArthur
Karol Murgrabia
Kieran Nar
Ollie Osborn
Joe Palmer
James Pepper
Edward Rawson
David Rees
Nour Edinne Riahi
Tom Robb
Beatriz Fernandez Silva
Elena Ruckh
Sarath Veetil
Kai Wu
Zhen Xi
Jiaqi Xu
Yunqi Zhang
Miguel Zavala-Arredondo
Shitong Zhou

MAPP OPERATIONS TEAM



Eleona Chao, Project Manager and Communications Officer. Eleona has a Masters Degree in Advanced Engineering and Management from Sheffield Hallam University. She joined MAPP at the end of 2022 with over six years of industrial project management experience and acts as the central contact point for the academic partners in MAPP.

Dr Gavin Baxter, Senior Business Development Manager, Gavin joined MAPP in April 2021. He supports the development of large strategic research bids and research partnerships with a wide range of stakeholders including industry and sponsors. He has more than 24 years of industrial experience in advanced materials joining and powder-based processing research at Rolls-Royce plc with wide involvement and collaboration across both academic and industrial research teams, manufacturing processes and test facilities. Through pioneering research in a series of major industry-led collaborative partnerships, he has supervised more than 60 PhD students, five PDRAs and co-authored more than 60 academic papers on Advanced Materials Processes.



Clare Faulkner, Project Administrator, Clare joined MAPP in April 2019. As well as providing executive support to Prof. Iain Todd and Dr Gavin Baxter, she led on project plans and reporting. Clare left MAPP in April 2023 and is now a Project Support Officer in the School of Biosciences at Sheffield University.

Sally Evans, Project Administrator. Sally joined MAPP in July 2022 and works alongside Clare Faulkner. As well as providing executive support to Prof. Iain Todd and Dr Gavin Baxter, she leads on events and Researchfish.

LIST OF PHD'S COMPLETED IN MAPP

Year	First Name	Last Name	University	Title of PhD	MAPP Theme	MAPP/ Aligned?
2018	**Alex**	**Leung**	University of Manchester	X-ray imaging of powder consolidation during laser additive manufacturing	X1	Aligned
2019	**Alaa MM**	**Almansoori**	University of Sheffield	Feasibility Study of Plasma Treatment of Clays and Polymers for Nanocomposite Manufacture by Laser Sintering	P2.3	Aligned
2019	**Lukas**	**Feiber**	University of Oxford	Hybrid additive manufacturing for the multi-phase fabrication and in-line characterization of functional devices (supercapacitors, electro-magnetism)	P2.2	Aligned
2019	**Luke**	**Fox**	University of Sheffield	Investigation into the Use of Polypropylene in High Speed Sintering	P2.3	Aligned
2019	**Sarah**	**Connolly**	University of Oxford	Manufacturing of Oxide Dispersion Strengthened (ODS) Steels for Nuclear Energy Applications	P2.2	Aligned
2020	**Zhen**	**Xi**	University of Sheffield	Deep Learning Systems with Linguistic Interpretability in Manufacturing Image Classifications	X3	Aligned
2021	**Beatriz**	**Fernandez Silva**	University of Sheffield	The Effect of Thermomechanical Processing on Texture, Macrozones and Cold Dwell Fatigue Performance in a Ti834 Compressor Disc Alloy	P2.2	Aligned
2021	**Cong (Harry)**	**Liu**	University of Sheffield	Selective laser melting of nickel superalloys for aerospace applications: defect analysis and material property optimisation	P2.1	Aligned
2021	**Emmanouil**	**Stavroulakis**	University of Manchester	Functionally graded components for nuclear applications	P2.2	Aligned
2021	**Leigh**	**Stanger**	University of Sheffield	Quantitative Thermography and Image Quality in Additive Manufacturing of Metal	P2.1	Aligned
2021	**Maha T**	**Omran**	University of Sheffield	3D printing polymer - ceramic composites for orbital floor reconstruction	P2.3	Aligned
2021	**Mozhdeh**	**Mehrabi**	University of Leeds	Analysis of bulk behaviour of particles based on their individual properties	X2	MAPP
2021	**Nick**	**Boone**	University of Sheffield	Near Infrared Thermal Imaging for Process Monitoring in Additive Manufacturing	P2.1	Aligned
2021	**Oliver**	**Levano**	University of Sheffield	Characterisation of FAST-DB - a Hybrid Solid-State Joining Process for Dissimilar Titanium Alloy Powder	P2.2	Aligned
2021	**Ryan**	**Brown**	University of Sheffield	Effect of crystallisation rate on the processability of polymer powders for High Speed Sintering	P2.3	Aligned
2021	**Simon**	**Graham**	University of Sheffield	The production of Ti-Fe alloys using solid-state, powder-based extraction and processing technologies	P2.2	Aligned
2022	**Alistair**	**Lyle**	University of Sheffield	Optimising the Laser Powder Bed Fusion Process for the Manufacture of a Nickel Superalloy	P2.1	Aligned
2022	**Dane**	**Buller**	University of Sheffield	Additive manufacturing of austenitic stainless steel 316L via laser powder bed fusion, hot isostatic pressing and additive friction stir manufacturing	P2.1	Aligned
2022	**Florian**	**Buschek**	University of Sheffield	Microstructural Control in Multi-Ti-Alloy Components using Laser Metal Deposition	P2.1	Aligned
2022	**James**	**Wingham**	University of Sheffield	Antimicrobial efficacy of laser sintered polyamide 12 / silver microcomposites	P2.3	Aligned
2022	**Kai**	**Wu**	University of Sheffield	Many-objective Optimisation Based on Decomposition Strategies	X3	Aligned
2022	**Kylee Yingwei**	**Wu**	University of Oxford	Additive manufacturing of graded and anisotropic materials for applications at microwave frequencies	P2.2	Aligned
2022	**Lorna**	**Sinclair**	UCL	In situ synchrotron imaging of additive manufacturing processes	X1	MAPP
2022	**Lova**	**Chechik**	University of Sheffield	Process Monitoring and Control during Additive Manufacturing	P2.1	Aligned
2022	**Sourabh**	**Paul**	University of Sheffield	Binder Jetting of Aqueous Polyvinyl Alcohol for Additive Manufacturing of Inconel 718	P2.3	Aligned
2022	**Tom**	**Robb**	University of Sheffield	Techniques for the characterisation of powder used in the repair of aerospace components	P2.1	Aligned
2022	**Zhouran**	**Zhang**	University of Oxford	Microstructure, mechanical properties and irradiation response of CrMnFeCoNi-(Y) high-entropy alloys	P2.2	Aligned
2023	**Abdullah**	**Alharbi**	University of Sheffield	Layered Extrusion of Metallic Alloys	P2.3	Aligned
2023	**Adam**	**Gothorp**	University of Sheffield	Applying Bayesian Statistical Methods to Optimise Processes Within Additive Manufacturing	P2.3	Aligned
2023	**Alex**	**Goodall**	University of Sheffield	Enabling 3D magnetic circuits by the additive manufacturing of soft magnetic material	P2.1	MAPP
2023	**Ben**	**Evans**	University of Oxford	Advanced manufacture and characterisation of think Tungsten coatings for nuclear fusion application	P2.2	Aligned
2023	**Cameron**	**Barrie**	University of Sheffield	Field-Assisted Sintering Technology Processing Route of Metal-Metal Composites	P2.2	MAPP
2023	**Elaine**	**Livera**	University of Sheffield	Microstructural Control in Inconel 718 Manufactured by Laser Powder Bed Fusion	P2.1	Aligned
2023	**George**	**Maddison**	University of Sheffield	In-Situ Monitoring and Control During Laser Powder Bed Fusion of Nickel Superalloys.	P2.1	Aligned
2023	**Halil Emre**	**Caglar**	University of Sheffield	Multi-laser hybrid powder bed fusion	P2.3	Aligned
2023	**James**	**Pepper**	University of Sheffield	Channeling Current in FAST Processed Titanium Alloys to Generate Uniquely Tailored Microstructures in a Single Step	P2.2	Aligned
2023	**Kubra**	**Genc**	University of Sheffield	Processing of NdFeB for Electric Motor Applications Using Selective Laser Melting	P2.3	Aligned
2023	**Max**	**Chester Jude Emmanuel**	Imperial College London	Study of Grain Boundary Character in WC-Co	P2.3	Aligned
2023	**Mohamed**	**Atwya**	University of Sheffield	Prior-guided Machine Learning for Monitoring Advanced Manufacturing Processes	X3	Aligned
2023	**Mohammed**	**Alsaddah**	University of Sheffield	Multi-laser powder bed fusion using 808nm sources	P2.3	Aligned
2023	**Muhammad**	**Aftab**	University of Sheffield	Development of Advanced Predictive Functional Control Strategies for SISO Dynamic Processes	X3	Aligned
2023	**Sarath Alayil**	**Veetil**	University of Sheffield	Diode Area Melting of Ti6Al4V: Probing the Multi-laser Interaction, Residual Stress Evolution, and Spattering Dynamics	P2.3	Aligned
2024	**Alisha**	**Bhatt**	UCL	Multi-scale additive manufactured embedded sensors for self cognitive metal parts	X1	Aligned
2024	**Caterina**	**Iantaffi**	UCL	Additive Manufacturing for Lunar In Situ Resource Utilisation	X1	Aligned
2024	**Xianqiang**	**Fan**	UCL	Magnetic Field Control of Melt Pool Flow and Keyhole Dynamics during Additive Manufacturing	X1	Aligned
2024	**Jiaqi**	**Xu**	University of Manchester	Towards HIPping of difficult to cast Ti alloys through time lapse 3D X-ray CT	X2	Aligned

MAPP PROJECT RESEARCHERS 2016 TO 2024

Start Year	End Year	First Name	Last Name	University	MAPP Theme	MAPP/Aligned
2016	2024	**Ben**	**Thomas**	University of Sheffield	P2.1	MAPP & MMSC
2016	2022	**Jo**	**Sharp**	University of Sheffield	P2.1	Aligned & MAPP
2016	2019	**Sam**	**Tammas-Williams**	University of Sheffield	P2.1	Aligned & MAPP
2016	2020	**Everth**	**Hernandez-Nava**	University of Sheffield	P2.1	Aligned
2016	2019	**Phillip**	**Mahoney**	University of Sheffield	P2.1	Aligned
2016	2017	**Christopher**	**Smith**	University of Sheffield	P2.1	Aligned
2018	2022	**Nicholas**	**Weston**	University of Sheffield	P2.2	Aligned
2018	2021	**Wen**	**Cui**	University of Oxford	P2.2	MAPP
2018	2019	**Sandeep**	**Irukuvarghula**	University of Manchester	P2.2	MAPP
2018	2021	**Zicheng**	**Zhu**	University of Sheffield	P2.3	MAPP
2018	2023	**Iuliia**	**Elizarova**	Imperial College London	P2.3	MAPP
2018	2019	**Alex Chu Lun**	**Leung**	UCL	X1	MAPP
2018	2021	**Sam**	**Clark**	UCL	X1	MAPP
2018	2022	**Yunhui**	**Chen**	UCL	X1	MAPP
2018	2021	**Jabbar**	**Gardy**	University of Leeds	X2	MAPP
2018	2022	**Yi**	**He**	University of Leeds	X2	MAPP
2018	2021	**Timothy**	**Bigg**	University of Leeds	X2	MAPP
2018	2019	**Adrian Rubio**	**Solis**	University of Sheffield	X3	MAPP
2018	2020	**Ping**	**Li**	University of Sheffield	X3	MAPP
2019	2024	**Oliver**	**Hatt**	University of Sheffield	P2.1	MAPP
2019	2024	**Rahul**	**Unnikrishnan**	University of Manchester	P2.2	MAPP
2019	2020	**Alec**	**Shackleford**	University of Sheffield	P2.3	MAPP
2020	2023	**Felicity**	**Freeman**	University of Sheffield	P2.1	Aligned & MAPP
2020	2024	**Minh**	**Phan**	University of Sheffield	P2.1	Aligned
2020	2024	**Rob**	**Snell**	University of Sheffield	P2.1	MAPP
2020	2024	**Siyang**	**Wang**	Imperial College London	P2.3	MAPP
2020	2022	**Yuze**	**Huang**	UCL	X1	MAPP
2020	2023	**Bo**	**Luo**	University of Sheffield	X3	Aligned
2020	2024	**Scott**	**Notley**	University of Sheffield	X3	MAPP
2020	2022	**Daliya**	**Aflyatunova**	University of Sheffield	X3	MAPP
2020	2021	**Ashfaq**	**Khan**	University of Sheffield	P2.3	MAPP
2020	2022	**Samuel**	**McDonald**	University of Manchester	X2	MAPP
2021	2024	**Yun**	**Deng**	University of Oxford	P2.2	MAPP
2021	2024	**Ryan**	**Brown**	University of Sheffield	P2.3	MAPP
2021	2024	**Samy**	**Hocine**	UCL	X1	MAPP
2021	2023	**Xun**	**Zhang**	University of Manchester	X2	MAPP
2022	2024	**Oliver Levano**	**Blanch**	University of Sheffield	P2.2	Aligned
2022	2023	**Simon**	**Graham**	University of Sheffield	P2.2	MAPP
2022	2023	**Sheng**	**Cao**	University of Manchester	X2	Aligned
2022	2023	**Oriol Gavalda**	**Diaz**	Imperial College London	P2.3	Aligned
2022	2024	**Zhuoqun**	**Zhang**	University of Sheffield	P2.3	Aligned
2022	2024	**Kai**	**Zhang**	UCL	X1	MAPP
2022	2024	**Mozhdeh**	**Mehrabi**	University of Leeds	X2	MAPP
2022	2024	**Emad**	**Grais**	University of Sheffield	X3	MAPP
2022	2024	**Anqi**	**Liang**	University of Sheffield	P2.3	Aligned
2022	2024	**Erik**	**Poloni**	Imperial College London	P2.3	MAPP
2023	2024	**Elaine**	**Livera**	University of Sheffield	P2.1	Aligned
2023	2024	**Rohit**	**Malik**	Imperial College London	P2.3	MAPP
2023	2024	**Shishira**	**Bhagavath**	UCL	X1	Aligned
2023	2024	**Wei**	**Li**	UCL	X1	MAPP
2023	2024	**Zihan**	**Song**	University of Manchester	X2	MAPP
2023	2024	**Chatura**	**Samarakoon**	University of Cambridge	X3	Aligned
2023	2024	**Hamid**	**Toshani**	University of Cambridge	X3	Aligned
2023	2024	**Janith**	**Petangoda**	University of Cambridge	X3	Aligned
2023	2024	**Vasileios**	**Tsoutsouras**	University of Cambridge	X3	Aligned
2023	2024	**Tushar**	**Srivastava**	University of Leeds	X2	MAPP
2023	2024	**Xianqiang**	**Fan**	UCL	X1	Aligned
2023	2024	**Da**	**Guo**	UCL	X1	Aligned
2023	2024	**Ratul**	**Biswas**	UCL	X1	Aligned
2023	2024	**James**	**Pepper**	University of Sheffield	P2.2	MAPP
2024	2024	**Anatassia**	**Milleret**	UCL	X1	Aligned

ALIGNED PROJECTS

We are involved in a wide range of user-defined projects funded by industry, Innovate UK and agencies such as the Aerospace Technology Institute, which are focused on the translation and commercial application of advanced powder processes. In addition to these user-defined projects, we are also involved with a range of fundamental projects funded by research councils covering areas from new materials discovery to new manufacturing process development. Our aligned projects increase the breadth and reach of our research. These pages feature a selection of our aligned projects.

LIVE PROJECTS

AIRLIFT (Additive Industrialisation for Future Technology)

Funder: Innovate UK

Funded Value: £6,138,691

Funding period: December 2018 - November 2023

Organisations: GKN Aerospace Services Limited, Siemens Industrial Software, University of Sheffield, Cfms Services Limited.

ANTI INFECTIVES FOR ADDITIVE MANUFACTURING

Funder: EPSRC Impact Acceleration Account

Funded Value: £19,168

Funding period: August 2023 - March 2024

Organisations: University of Sheffield.

BIOINSPIRED COMPOSITE MATERIALS BASED ON SYNTHETIC MOTHER OF PEARL FOR SPACE APPLICATIONS (SYNACRE)

Funder: ESA

Funded Value: £220,000

Funding period: April 2022 - March 2024

Organisations: University College London.

DATA-DRIVEN, RELIABLE, AND EFFECTIVE ADDITIVE MANUFACTURING USING MULTI-BEAM TECHNOLOGIES (DREAM BEAM)

Funder: EPSRC

Funded Value: £399,163

Funding period: November 2022 - October 2025

Organisations: University College London, Renishaw Plc, European Space Agency (ESA), European Synchrotron Radiation Facility (ESRF), STFC Laboratories.

DIGITAL QUALIFICATION PLATFORM FOR ADVANCED ALLOY COMPONENTS

Funder: ATI

Funded Value: £13,992,261

Funding period: January 2023 - December 2026

Organisations: University of Sheffield, University of Manchester, Alloyed, Renishaw Plc, TWI, Boeing, CCFE/UKAEA.

DIODE AREA MELTING (A novel reconfigurable multi-laser approach for efficient additive manufacturing with enhanced thermal process control)

Funder: EPSRC

Funded Value: £629,879

Funding period: August 2022 - February 2025

Organisations: University of Sheffield, Carpenter Additive, Thinklaser, Renishaw Plc, Diamond Centre Wales.

LIVE PROJECTS

DOING MORE WITH LESS: A DIGITAL TWIN OF STATE-OF-THE-ART AND EMERGING HIGH VALUE MANUFACTURING ROUTES FOR HIGH INTEGRITY TITANIUM ALLOY COMPONENTS

Funder: EPSRC

Funded value: £2,608,542

Funding period: November 2020 - October 2024

Organisations: Aubert and Duval, Henry Royce Institute, High Value Manufacturing (HVM) Catapult, Rolls-Royce Plc, Timet UK Ltd, W. H. Tildesley Ltd, Wilde Analysis Ltd.

MANUFACTURING BY DESIGN

Funder: EPSRC

Funded Value: : £1,612,580

Funding period: March 2022 - March 2027

Organisations: University of Manchester, Jaguar Cars Ltd, The European Space Research and Tech Centre, TISICS Ltd, National Physical Laboratory NPL, University of Bristol, Renishaw Plc, National Composites Centre, Fraunhofer, Manufacturing Technology Centre, Britishvolt, Johnson Matthey Plc, Rolls-Royce plc,University of Sheffield, European Synch Radiation Facility – ESRF, EURATOM/CCFE.

MATERIALS MADE SMARTER

Funder: EPSRC

Funded Value: £4,049,023

Funding period: September 2021 - February 2025

Organisations: University of Sheffield, Constellium UK Ltd, Sheffield City Region, Knowledge Transfer Network KTN, National Composites Centre, Celsa Steel UK, Seco Tools, Manufacturing Technology Centre, ESI UK Ltd, STFC – Laboratories, Alloyed Limited, The Alan Turing Institute, Ferroday Ltd, Bikrkenhead, Advanced Manufacturing Research Centre, Tata Steel UK, Diamond Light Source, Rolls-Royce plc,Pro Steel Engineering, Materials Processing Institute (MPI), Thyssenkrupp Tallent Ltd.

NATIONAL RESEARCH FACILITY FOR LAB X-RAY CT

Funder: EPSRC

Funded Value: £10,097,652

Funding period: November 2020 - October 2025

Organisations: University of Manchester, Nordson (UK) Ltd.

Synchrotron-calibratEd lAser pRocessing teCHnologies (SEARCH)

Funder: Royal Academy of Engineering (Senior Fellowship)

Funded Value: £200,000

Funding period: March 2024 - February 2029

Organisations: University College London.

TAMMI (Transforming Additive Manufacturing via Multiscale *in-situ* Imaging)

Funder: Royal Academy of Engineering (Chair in Emerging Technology)

Value of award to the consortium: £2,687,000

Funding period: April 2019 - March 2029

Organisations: University College London.

COMPLETED PROJECTS

AMITIE [Additive Manufacturing Initiative for Transnational Innovation in Europe]

Funder: European Commission - Horizon 2020

Value of award to the consortium: £774,147

Funding period: March 2017 - 2021

Organisations: Imperial College London, University of Limoges, via the SPCTS laboratory, National Institute of Applied Sciences of Lyon, University of Valenciennes Haut Cambresis, University of Erlangen, Federal Institute for Material Research and Testing, University of Padova, Polytechnical Institute of Torino, Polytechnical University of Catalunia, Belgium Ceramic Research Center, Mohammadia Engineering College of Rabat in Morocco, 3DCeram, Saint-Gobain, Noraker, Anthogyr, Bosch, HC Starck, Desamanera.

COMBILASER [COMbination of non-contact, high speed monitoring and non-destructive techniques applicable to LASER Based Manufacturing through a self-learning system]

Funder: European Union's Horizon 2020 research and innovation programme

Project costs: EUR 3 439 420

Funded value: EUR 3 439 420

Funding period: January 2015 - December 2017

Organisations: HIDRIA AET, IK4 Lortek [LORTEK], Laser Zentrum Hannover [LZH], The Research Centre for Non Destructive Testing [RECENDT], The University of Sheffield, Laserline, Orkli S. Coop [ORKLI], Talleres Mecánicos Comas [TMCOMAS], Mondragon Assembly, 4D Ingenieurgesellschaft für Technische Dienstleistungen [4D], Cavitar Ltd. [CAVITAR] and SiEVA Development Centre [SIEVA].

DAM [Developing Design for Additive Manufacturing]

Funder: Innovate UK

Funded Value: £7,212,148

Funding period: December 2018 - November 2022

Organisations: GKN Aerospace Services Limited, University of Sheffield, Autodesk Limited.

DARE [Designing Alloys for Resource Efficiency]

Funder: EPSRC

Project costs: £4,033,113

Funded value: £3,226,490

Funding period: September 2014 – September 2019

Organisations: University of Sheffield, King's College London, University of Cambridge, Imperial College London, Magnesium Elektron Ltd, Siemens, Tata Steel, Firth Rixon, ArcelorMittal, Timet Ltd, Rolls-Royce PLC, Safran, Sheffield Forgemasters Engineering Ltd.

Development of MgWOxB Ceramic Neutron Shielding Material

Funder: UKAEA [UK Atomic Energy Authority]

Funded value: £20,000

Funding period: July 2021 - March 2022

Organisations: CASC Imperial.

COMPLETED PROJECTS

FACTUM

Funder: Innovate UK

Project costs: £1,427,215

Funded value: £725,001

Funding period: November 2013 - October 2016

Organisations: University of Sheffield, Farapack Polymers, Xaar, Unilever, Cobham, BAE Systems, Sebastian Conran Associates and Loughborough University.

FAST-STEP3 [Swarf Titanium to Engine Parts in 3 Steps]

Funder: Innovate UK

Funded value: £507,551

Funding period: March 2018 - 2021

Organisations: Participants include Force Technology Limited, Northern Automotive Alliance Limited, Transition International Limited, University of Sheffield and Victoria Drop Forgings Co. Limited.

Horizon [AM]

Funder: Aerospace Technology Institute and Innovate UK

Project costs: £13,304,769

Funded value: £7,042,370

Funding period: March 2015 – November 2017

Organisations: GKN Aerospace Services Ltd, Delcam Ltd, Renishaw PLC, University of Sheffield, University of Warwick.

INTEGRADDE [Intelligent data-driven pipeline for the manufacturing of certified metal parts through Direct Energy Deposition]

Funder: Horizon 2020

Funded value: £672,915

Funding period: January 2019 - December 2022

Organisations: Limitstate Limited, University of Sheffield, ESI Software Germany GmbH, Atos Spain, Commissariat à l'énergie atomique et aux énergies alternatives, L'Institut de recherche technologique Jules Verne, MX3D, Loiretech Mauves, Fundingbox Accelerator SP Zoo, Imperial College of Science Technology and Medicine, Bureau Veritas Services, Indust Recherch Procedes Applicat Lase, Högskolan Väst, New Infrared Technologies S.L, GKN Aerospace Sweden, DIN - Deutsches Institut für Normung e.V., Arcelormittal Innovacion Investigacion E Inversion SL, Universidade de Coimbra, Datapixel SL, Corda - Orodjarna Proizvodnja Trgovina In Storitve Doo, Dgh Robotica Automatizacion Y Mantenimiento Industrial Sa, Panepistimio Patron, Brunel University London, Prima Industrie S.p.A., ESI Group.

JewelPrint [Innovative Jewellery Manufacturing Process using 3D Printing]

Funder: Innovate UK

Funded value: £401,528

Funding period: June 2019 - May 2020

Organisations: Diamond Centre Wales Ltd, University of Sheffield.

Large Volume, Multi-material High Speed Sintering Machine

Funder: EPSRC

Project costs: £1,115,283

Funded value: £892,226

Funding period: April 2015 – September 2017

Organisations: University of Sheffield.

COMPLETED PROJECTS

LATEST2 (Light Alloys Towards Environmentally Sustainable Transport)

Funder: EPSRC

Project costs: £7,202,651

Funded value: £5,762,121

Funding period: July 2010 - July 2016

Organisations: University of Manchester, Airbus Group Limited, Alcan, Alcoa, Bridgnorth Aluminium Ltd, Centre for Materials & Coastal Research, CSIRO, FEI Company, Innoval Technology Ltd, Jaguar Land Rover, Keronite International Ltd, Magnesium Elektron Ltd, Meridian, Business Development, NAMTEC, Norton Aluminium Ltd, Novelis, Rolls-Royce Plc, TWI Ltd.

LIVING MATERIALS

Funder: ONRG

Value of award to the consortium: £400,000

Funding period: July 2018 - January 2022

Organisations: Cidetec, Imperial College London.

MIAMI (Improving the productivity of industrial additive manufacturing)

Funder: University of Sheffield (Impact, Innovation and Knowledge Exchange funding)

Project costs: £552,732

Funded value: £200,000

Funding period: July 2017 – March 2020

Organisations: MAPP, Future Metrology Hub at the University of Huddersfield.

MIRIAM (Machine Intelligence for Radically Improved Additive Manufacturing)

Funder: Innovate UK

Funded value: £666,383

Funding period: October 2017 - March 2019

Organisations: Reliance Precision Ltd, University of Sheffield.

OPTICON (Optical Infrared Coordination Network for Astronomy)

Funder: European Union's Horizon 2020 research and innovation programme

Funded value: £166,605

Funding period: January 2017 - June 2021

Organisations: The Chancellor, Masters and Scholars of The University of Cambridge, Centre National de la Recherche Scientifique (CNRS),Istituto Nazionale di Astrofisica, Max-Planck-Gesellschaft zur Forderung der Wissenschaften EV, Science and Technology Facilities Council, European Southern Observatory - ESO European Organisation for Astronomical Research in the Southern Hemisphere, Agencia Estatal Consejo Superior Deinvestigaciones Cientificas, Universiteit Leiden, First Light Imaging SAS, Office National D'etudes et de Recherches Aerospatialess, Nederlandse Organisatie Voor Toegepast Natuurwetenschappelijk Onderzoek TNO, Instituto de Astrofisica de Canarias, Magyar Tudomanyos Akademia Csillagaszati es Foldtudomanyi Kutatokozpont (KONKOLY), Uniwersytet Warszawski, National Observatory of Athens, National University of Ireland, Galway, Kobenhavns Universitet, Universite de Liege, Universidade do Porto, Leibniz-Institut fur Astrophysik Potsdam (AIP), Politecnico di Milano, Nordic Optical Telescope Scientific Association, Department of Industry (AAO) Australia, Heriot-Watt University, The University Court of The University of St Andrews, Liverpool John Moores University, University of Durham, The University of Exeter, University of Bath, The Chancellor, Masters and Scholars of The University of Oxford, The University of Sheffield, Institut D'optique Theorique et Appliquee IOTA - Supoptique.

COMPLETED PROJECTS

REMASTER (Repair Methods for Aerospace Structures using Novel Processes)

Funder: Aerospace Technology Institute and Innovate UK

Project costs: £3,484,901

Funded value: £1,742,390

Funding Period: January 2016 – December 2018

Organisations: Rolls-Royce PLC, 3TRPD Ltd, University of Sheffield.

SHAPE (Self Healing Alloys for Precision Engineering)

Funder: Aerospace Technology Institute and Innovate UK

Project costs: £2,127,805

Funded value: £1,071,094

Funding period: September 2015 – August 2018

Organisations: Ilika Technologies Ltd, Reliance Precision Ltd, University of Sheffield.

TACDAM (Tailorable and Adaptive Connected Digital Additive Manufacturing)

Project funder: Innovate UK and EPSRC

Project costs: £1,482,626

Funded value: £1,071,094

Funding period: January 2017 - December 2018

Organisations: Hieta Technologies Ltd, Insphere Ltd, Metalysis Ltd, Renishaw PLC, McClaren Automotive Ltd, LSN Diffusion Ltd, University of Sheffield, University of Leicester, University of Exeter.

The Effect Of Fibre Interface Chemistry And Thickness On CMC Mechanical And Environmental Performance

Funder: Rolls-Royce

Funded value: £100,000

Funding period: July 2021 - December 2022

Organisations: CASC Imperial.

TiPOW (Titanium Powder for Net-shape Component Manufacture)

Funder: Aerospace Technology Institute and Innovate UK

Project costs: £3,129,835

Funding period: March 2015 – February 2020

Organisations: GKN Aerospace Services Ltd, Metalysis Ltd, Phoenix Scientific Industries (PSI) Ltd, University of Leeds.

VULCAN

Funder: Innovate UK

Funded value: £267,650

Funding period: January 2020 - December 2021

Organisations: The University of Sheffield, Wayland Additive.

When the drugs don't work... Manufacturing our pathogen defenses

Project funder: EPSRC

Funded value: £149,031

Funding period: March 2018- March 2019

Organisations: University of Sheffield.

BACK COVER IMAGES

Powder Profile

An image captured using a FASTCAM Nova S12, a Cavilux Illumination Laser, and a 480nm light filter. This is an average pixel value plot over the course of 0.2seconds, with contrast normalised and equalised and false colour applied. The image depicts the powder flow from a DED Nozzle focusing into a powder "waist", which typically aligned with the laser focus, for powder capture efficiency.

The Complexity of an AM Surface

In the image, spacing out the laser tracks on the top surface created channels – the aim of our build! But so much more can be seen, such as the instability of the melt pool (how the track on the left is not a consistent width) and the partially sintered powder still clung to the surface.

Atomisation Melt RTC

Ti64 atomisation run conducted up at the RTC. Here we see the formation of a molten metal droplet ahead of the atomisation, a brief instance of apparent calm captured before the droplet is blasted into millions of powder particles.

Titanium Hourglass

A colour enhanced multi-focus image taken on a macro lens (courtesy of Dennis Premoli) depicts the heat tinted surface of a Ti-6Al-4V 80 mm diameter sample which failed during FAST processing and was exposed to oxygen.

MAPP
Manufacture using Advanced Powder Processes
EPSRC Future Manufacturing Hub

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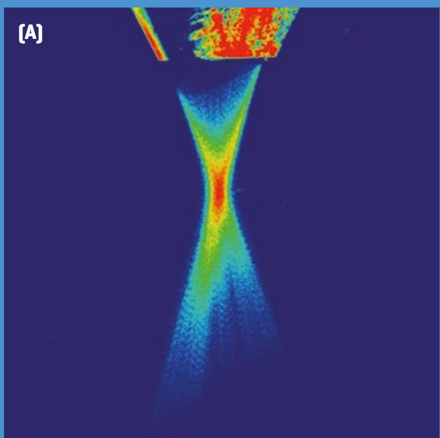
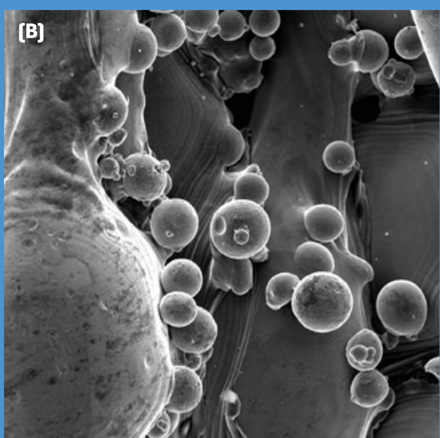
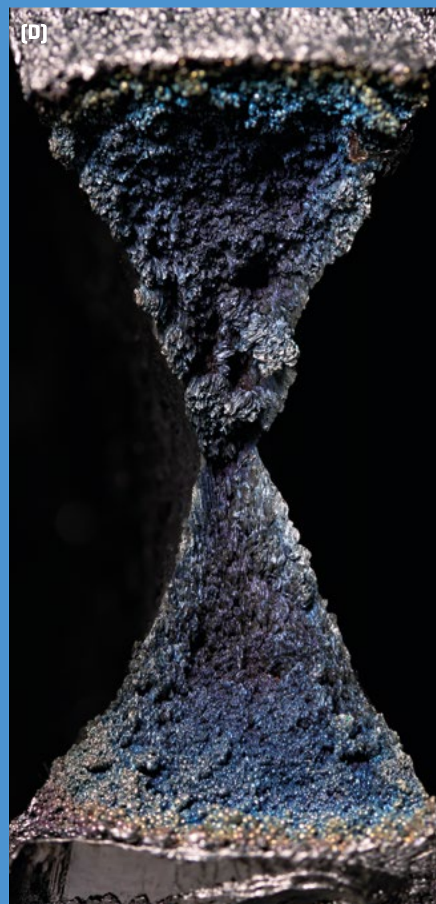
UKRI Engineering and Physical Sciences Research Council

TECHNICAL IMAGE

ARTISTIC IMAGE







(A) Powder Profile

First Prize technical image in MAPP October 2023 Image Competition was taken by Harry Chapman, University College London.

(B) The Complexity of an AM Surface

Runner Up technical image in MAPP October 2023 Image Competition was taken by Frances Livera, University of Sheffield.

(C) Atomisation Melt RTC

First Prize artistic image in MAPP October 2023 Image Competition was taken by Milo Maguire, University of Sheffield.

(D) Titanium Hourglass

Runner Up artistic image in MAPP October 2023 Image Competition was taken by James Pepper, University of Sheffield.

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