NEWAM

New Wire Additive Manufacturing

Newsletter (4th quarter, 2023)

Cranfield University

MANCHESTER 1824

University of Strathclyde

Coventry University

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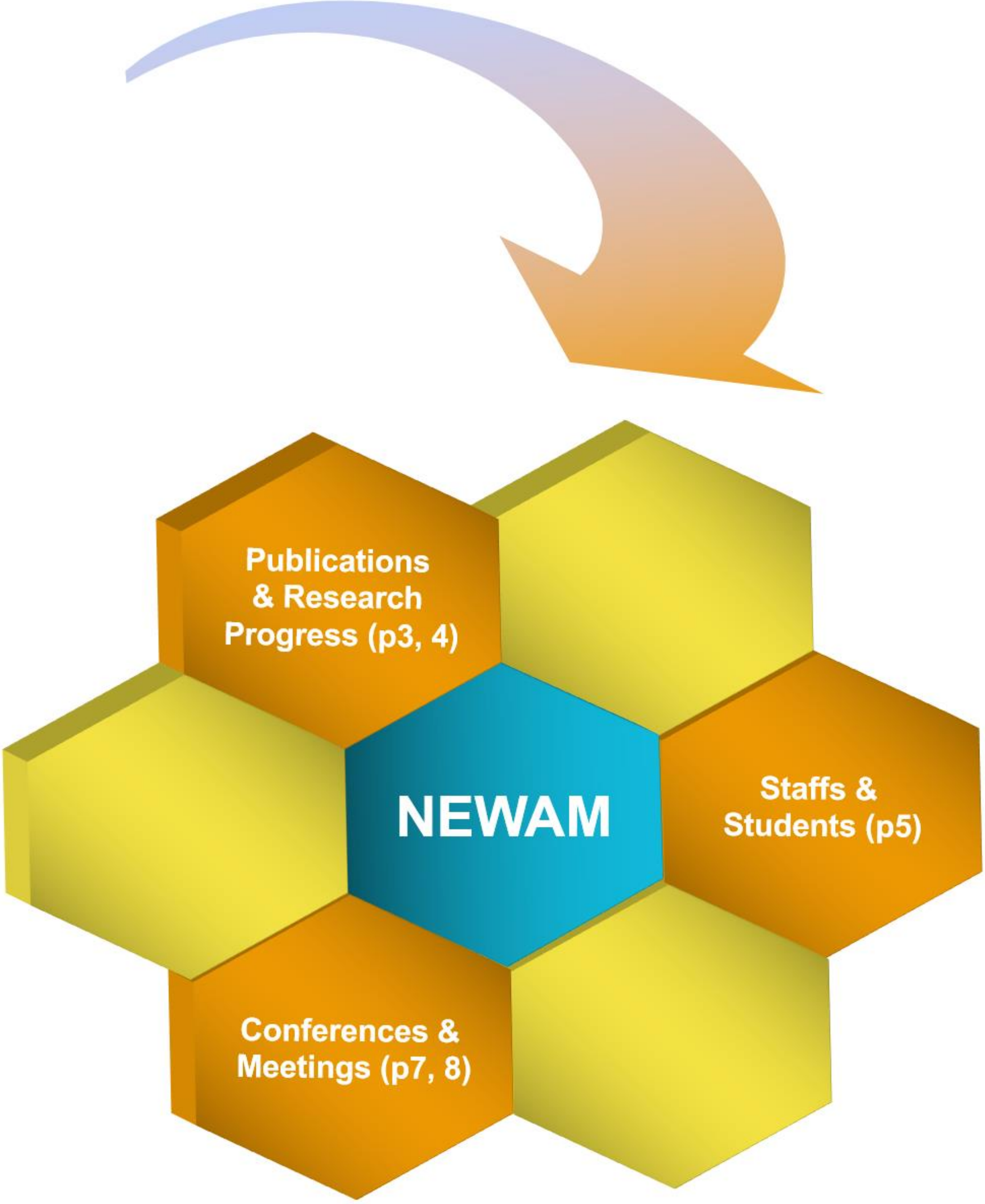
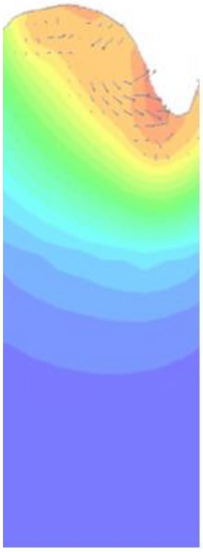
NEWAM in October – December 2023

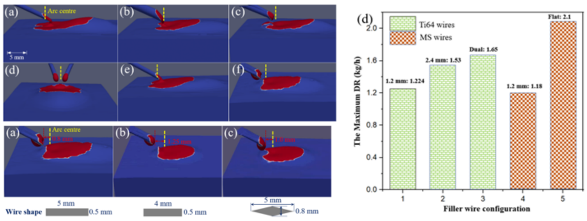


New Wire Additive Manufacturing

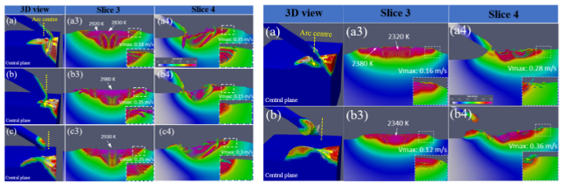
Publications & Research Progress



Cranfield process modelling team's new paper on thermal fluid dynamics of the effect of filler wire



Wire melting and deposition rate using different wire-feeding configurations

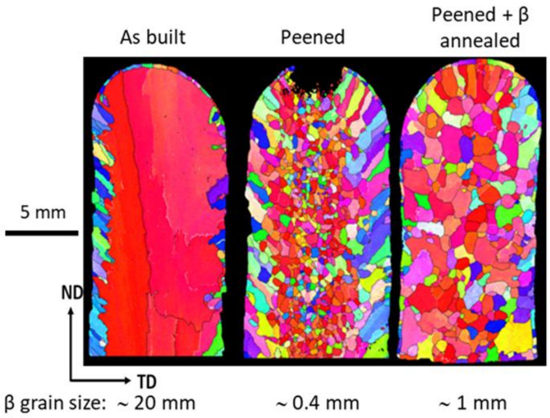


Temperature and fluid flow in the melt pool using five different wire feeding configurations

- In this paper, deposition rate (DR) and bead formation in plasma arc-based DED have been investigated by experiments and numerical simulations. The results demonstrate that the filler wire significantly affects the highest DR by altering wire melting and metal transfer behaviours through changes in arc energy absorption.
- The filler wire with a rhombus geometry which is closer to a Gaussian-like arc distribution than the flat wire was shown to get higher DR and more stable metal transfer. Furthermore, different filler wire configurations lead to distinct melt pool behaviours, including temperature distribution and flow velocity, due to various metal transfer behaviours and arc shading effects. This study sheds light on the fundamental physics underlying the impact of filler wire on wire melting and bead formation for the first time.

Chen X, Wang C, Ding J, Qu R, Wang Y, Pardal G, Williams S. Thermal fluid dynamics of the effect of filler wire on deposition rate and bead formation intending plasma arc-based DED. Journal of Manufacturing Processes. 2023 Dec 1;107:199-209.

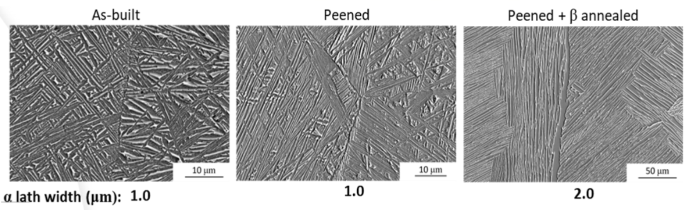
Coventry team's research highlight: Microstructure printing to achieve desired mechanical properties



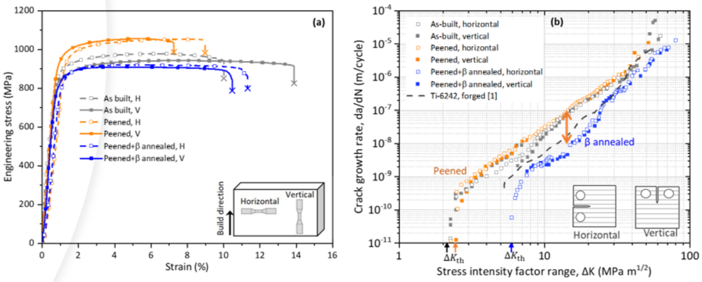
EBSD map shows the successful application of interlayer peening during material deposition to achieve desired grain refinement by refining the coarse columnar β-grain structure that is normally produced and greatly reduces the strength of β texture.

- Ti-6Al-2Sn-4Zr-2Mo (in wt%) (Ti6242) is a near-α titanium alloy with higher fracture toughness, high temperature stability and good creep resistance. It can be used for structures operating at elevated temperature up to 540°C. AM built titanium alloys known produce large columnar grains aligned along the build direction leading to anisotropic mechanical properties.
- In this study Coventry team have investigated the grain refinement by cold-working to produce specific microstructure that can deliver desired mechanical properties (e.g., higher resistance to crack growth) by combining in-process cold working with post process heat treatment. Ti6242 material was deposited using single bead deposition process and samples were tested in three conditions: as-built, peened, and peened+β annealed.

- Peening followed by β annealing (heating rate 0.1°C/sec, held at 1050°C for 30 min, followed by a cooling rate of 0.1°C/sec) did not alter the refined primary β grains and resulted in large single variant lamellar α+β colonies. The slower cooling rate from above the β transus temperature resulted in α growing into the opposite grains leading to coarser and large colonies.
- After peening, more isotropic tensile properties were found with increased strengths with some sacrifice on ductility. Overall, β annealing did not sacrifice any strength and ductility compared to the as-built condition. Fatigue crack growth testing shows: (a) the as-built and peened conditions had higher crack growth rate compared to conventionally built forged microstructure. (b) Peening + β annealing processing reduced crack growth rate significantly, by order of one magnitude.
- Crack path analysis has revealed that both the as-built and peened samples showed relative straight crack path with little crack deflection. The β annealed samples showed greater crack path deflection, and bifurcation, due to the presence of coarse lamellar single α variant colony microstructure. This can change the mode-I cracking mode to a mixed mode-I and II; the latter will reduce the crack growth driving force, thereby reducing the crack growth rates.

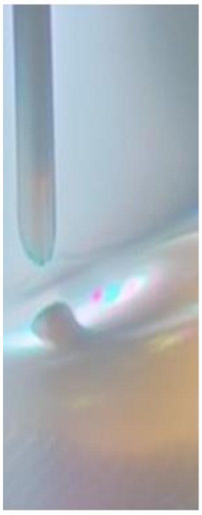


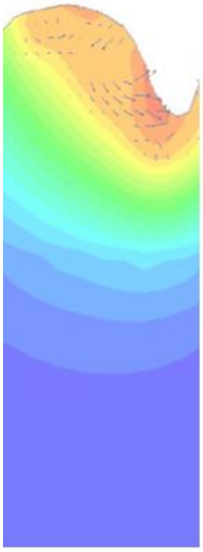
SEM images show that both the as-built and peened conditions have a transformation microstructure consisting of the Widmanstätten and colony morphology.



(a) Tensile properties for three build conditions. (b) Measured crack growth rate (da/dN) versus applied stress intensity factor range (ΔK) and comparison with conventionally built forged material. [Ref 1. W Shen et al., Mechanics of Materials, 36 (1–2), 2004, 117-140].

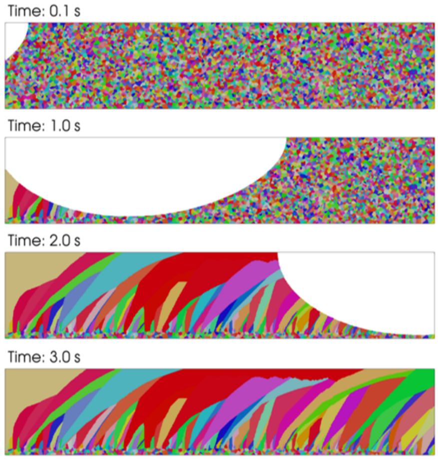
Publications & Research Progress



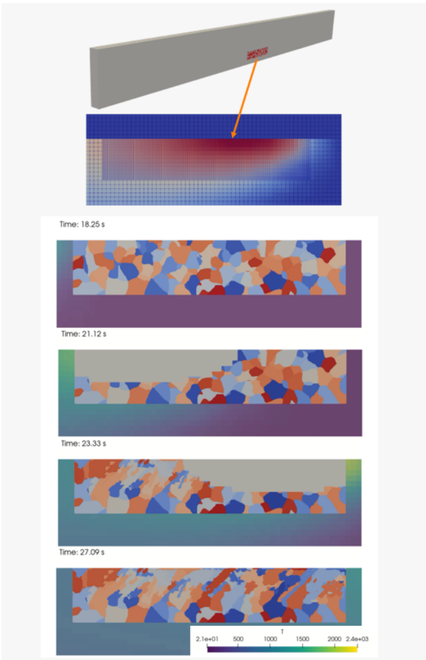


Manchester microstructure modelling team's research progress in HEDSATS & CA Coupling – Columnar grain growth towards melt boundary normal

- Since coupling the HEDSATS (High energy density semi-analytical thermal solutions) library [1] of Tom Flint to the Cellular Automata (CA) based solidification model of Dr. Danny Dreelan, higher resolution simulations have been used to demonstrate the mechanisms of columnar grain growth during AM.
- The double-ellipsoid heat source from HEDSATS was used with a voltage of 80 V and current of 10 A, travelling at 3.33 mm/s over a stainless steel substrate at 300 K. The shape of the double-ellipsoidal melt pool is adjusted by the width, depth, trailing distance and leading distance. These parameters could be extracted from more computationally expensive CFD/FEM models or inferred from imaging of experiment to provide a much cheaper and computationally efficient thermal model, which is particularly important when extending simulations to multiple layers.
- As can be seen, growth of the columnar grains at the base of the melt pool is near vertical, as is the normal direction to the melt pool boundary. Moving towards the back of the melt pool, the inclination of the boundary normal gradually decreases, until it virtually becomes aligned to the travel direction of the heat source. This change in melt pool normal causes a change in the growth direction of the columnar grains, and thus causes abrupt changes in the shape and tilting of the upper regions of each grain. The images on the right show IPF colouring with the build direction as the reference direction.



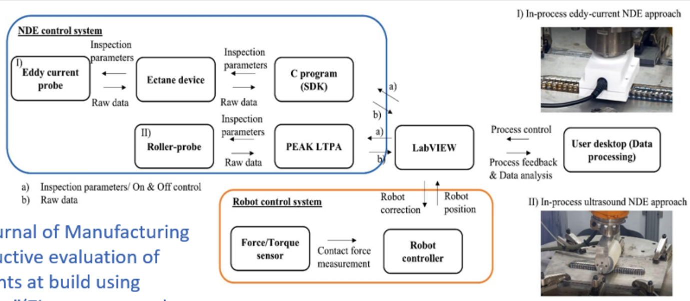
[1] Flint, T. F., & Smith, M. C. (2019). HEDSATS: High energy density semi-analytical thermal solutions. SoftwareX, 10, 100243.



Manchester microstructure modelling team's research progress in Abaqus FEM Coupling – Single Bead WAAM

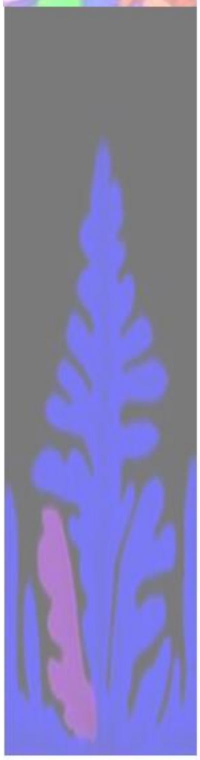
- A conversion script has been developed by Danny Dreelan in Python to facilitate the transfer for simulation data from Abaqus FEM models to OpenFOAM field files. Since Abaqus is a finite element model that stores data at nodes (i.e., at the corners of cells), and the CA model has been implemented using the OpenFOAM finite volume libraries that use data at cell centres, the data from the Abaqus model is interpolated onto a mesh generated separately in OpenFOAM using a developed interpolation scheme. This provides an extra advantage in that a specific region of the input data can be focused on to reduce the computational cost.
- The coupling scheme was applied to the single track WAAM Abaqus-based FEM simulations of Pradeeptta Kumar Taraphdar at Cranfield University, which have been well validated against thermocouple experiments. First, the entire length of the bead was simulated with a coarse mesh, but was later reduced to a small region in the middle of the build plate to reduce the computational cost.
- Below shows 2D slices at the centre of the bead track at times throughout the simulation that show the development of a generally columnar grain structure. The noncontinuity of grain may be related to the transverse growth of grain from the side of the bead, and will require further analysis. Future work will be to repeat the simulation for thermal data from simulations of multiple layers, so that the transient melting and solidification, and the consequential development of grain structure can be modelled and investigated.

Strathclyde team has published a new paper on in-process non-destructive evaluation



- The team published an article in the Journal of Manufacturing Processes, titled "In-process non-destructive evaluation of metal additive manufactured components at build using ultrasound and eddy-current approaches"(Zimermann et al., Journal of Manufacturing Processes 107 (2023): 549-558).
- In the article, the Strathclyde researchers have presented research from the multi-robot (RoboWAAM) cell, where the wire + arc additive manufacture is used to build components while novel in-process ultrasound and eddy-current approaches are deployed to inspect a component with artificially embedded reflectors. In fact, a combination of various NDT techniques, primarily ultrasound phase-array and eddy current testing, has been utilized for the in-process characterization of WAAM components.
- The outcome of this work demonstrates a promising ability to merge manufacturing and multiple NDE process into a single cell, hence, to achieve overall benefits of both surface and volumetric defect detections during the process of metal additive manufacturing.

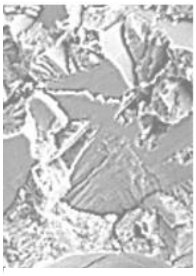
Staffs & Students

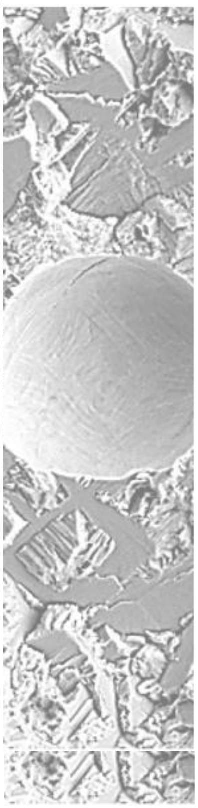


Strathclyde team welcomes a new PhD student

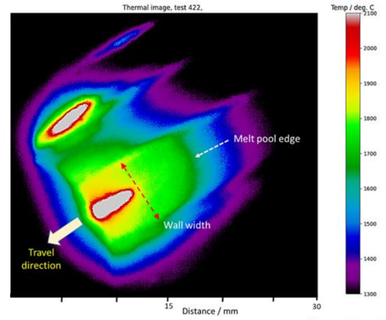
- The NEWAM team at University of Strathclyde is pleased to welcome Christopher Thompson, a new PhD student, who commenced his research in October 2023.
- Christopher brings a background in mechanical engineering.

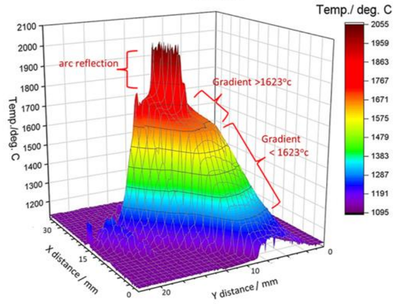
Conferences & Meetings





Invitation to Workshop on Future Qualification for AM Parts





Dear NEWAM community,

We would like to invite you, and/or your colleagues, to a workshop on **the future qualification of additively manufactured components**. The workshop will be held here at **Cranfield University on the 18th of January 2024**.

It is evident that qualification is a major barrier to the widespread adoption of AM technology in many industry sectors. Qualification procedures have generally been developed for bulk material, which is subsequently processed by subtractive manufacture. Therefore, specific material variants are qualified which is then applied to a broad range of parts without the need for a separate major qualification programme. In contrast, in additive manufacturing material is made locally using a variety of methods, so that each different process and system needs its own specific qualification. Furthermore, the properties of the material are affected by other factors such as local part geometry, feedstock condition, environmental conditions etc. The result is that qualification is highly specific to a particular material, process, system, and geometry. This means that every part made in a particular way requires its own qualification which is exceedingly expensive and time consuming. Furthermore, any improvements/changes in the process or the part results in the need for another qualification procedure. Clearly this is an unsustainable position if we want to exploit the full benefits of additive manufacturing.

Therefore, a new approach is required towards qualification, purposely targeting additive manufacturing. Our proposition is for a physics-based digital approach, which would be only dependent upon the material variant. The qualification would also be independent of the process, the system, or the part geometry. At Cranfield, with our partners, we have been working towards this for several years, now reaching a point where this radical new approach can be considered.

The purpose of the workshop therefore is to assess the current situation regarding AM qualification, discuss alternative scenarios, outline the potential for the physics-based approach, and detail industrial requirements and further technology developments that would be needed to make this viable. Finally, we will wrap up with some discussions about how to develop a full programme and acquire the funding required to make this happen.

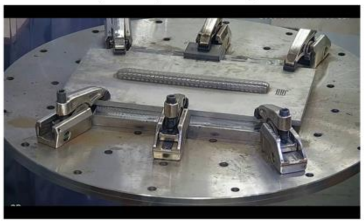
Your sincerely

Professor Stewart Williams

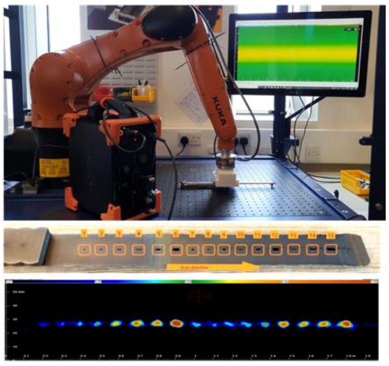
Director of Welding and Additive Manufacture Centre

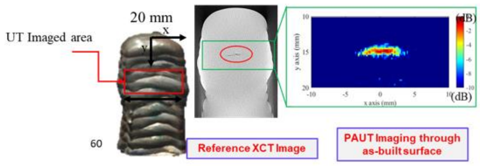
Cranfield University

Dry roller phased array USI



Contact based eddy current

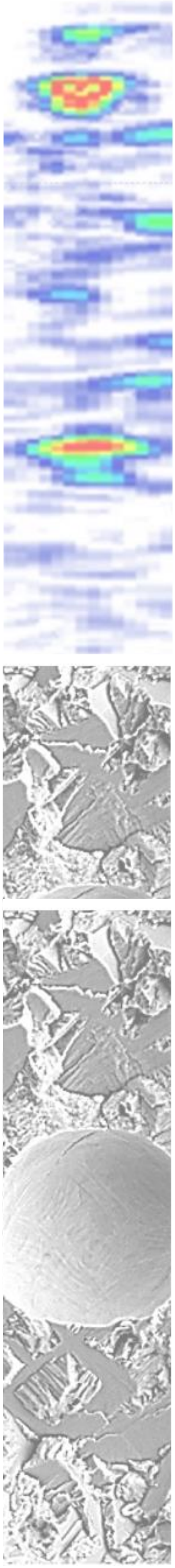




Cranfield team members attended Metal Additive Manufacturing Conference in Austria

- Dr. Eloise Eimer and Alireza M. Haghighi, representing WAMC, Cranfield University, attended the metal additive manufacturing conference (MAMC) in Vienna, Austria, on October 17-19, 2023.
- Alireza presented his thermo-capillary-gravity bidirectional model for rapid prediction of bead geometries and process parameters selection for wire-DED processes and the advantages of this approach to other techniques.
- Eloise's presentation focused on the aluminium research programme within the Cranfield Research Centre and the development of new alloys using in-situ alloying, inter-layer cold work and milling, and component manufacture.
- NEWAM results were also reported by Dr Marco Simonelli, assistant Professor at the University of Nottingham, during his keynote presentation on the metal AM research landscape in the UK.

Conferences & Meetings



Coventry team delivered a presentation at 13th international fatigue congress

- Coventry team presented a research paper at 13th international fatigue congress (Fatigue2022+1, Hiroshima, 6-10 Nov 2023).
  Conference Website: https://fatigue2022.org/Introduction.html
- The conference paper title is *"Effect of microstructural modification on fatigue crack growth behaviour in additively manufactured titanium alloys"*
- Authors: Xiang Zhang, Abdul Khadar Syed, Farhana Zakir

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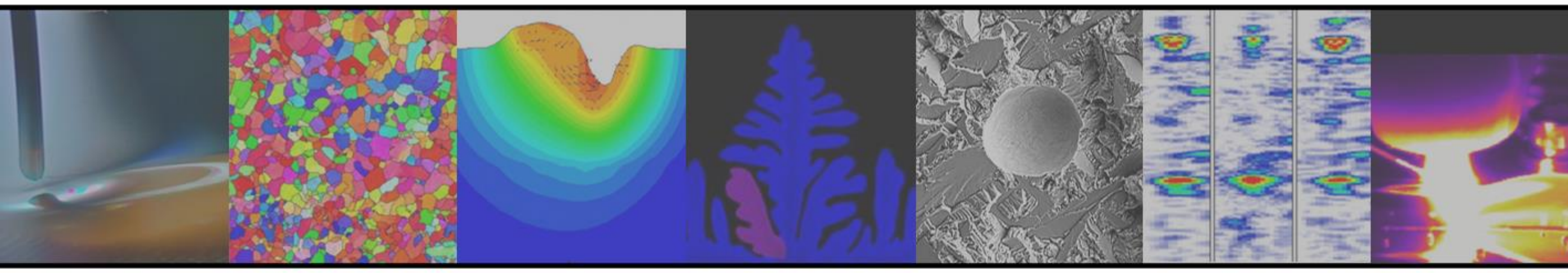

Further Reading

NEWAM website: https://newam.uk/
NEWAM LinkedIn: https://www.linkedin.com/in/newam-epsrc-programme-grant-6617091a9/
NEWAM ResearchGate: https://www.researchgate.net/project/New-Wire-Additive-Manufacturing-NEWAM

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