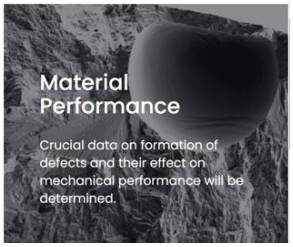
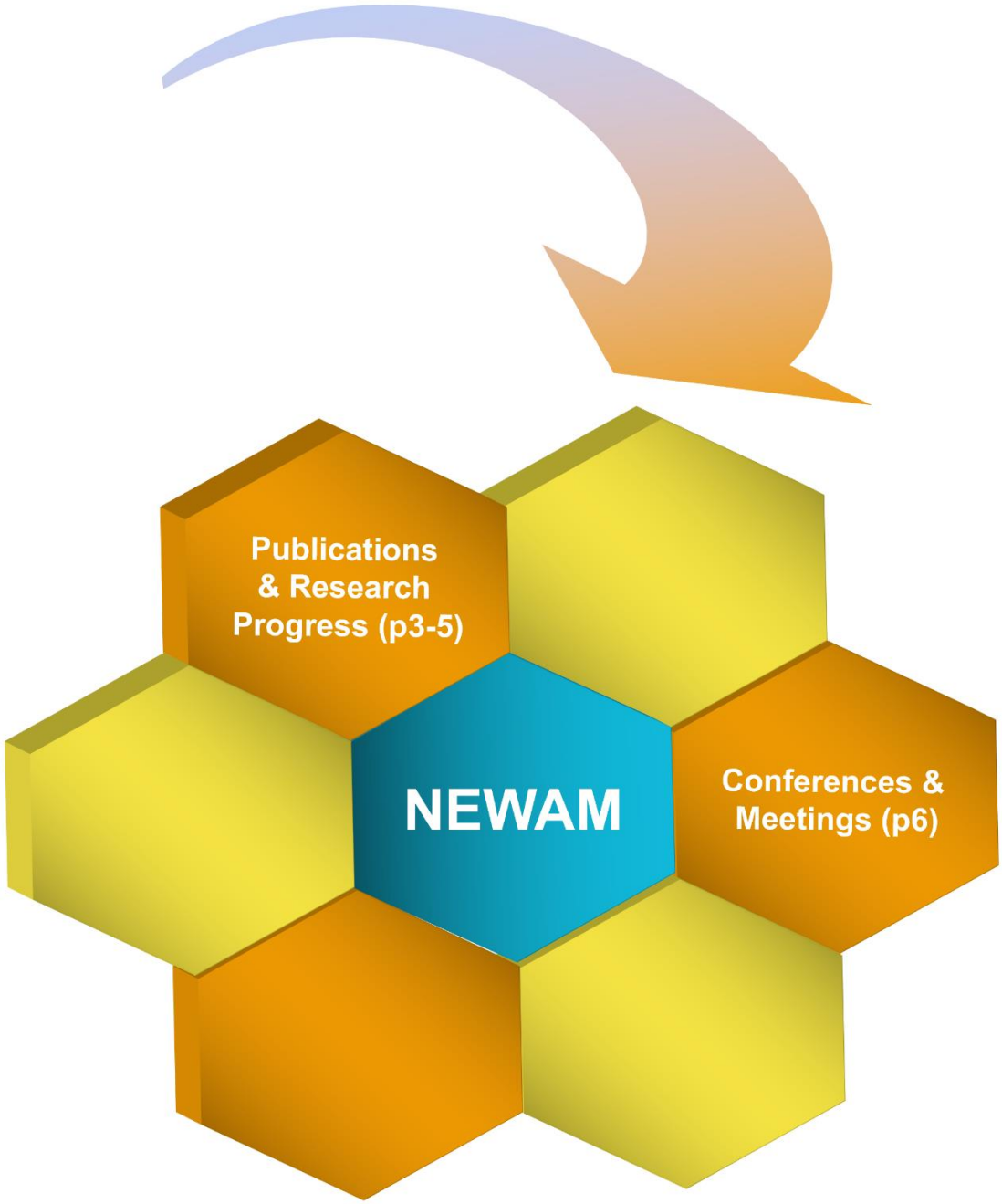
New Wire Additive Manufacturing

Newsletter (3rd quarter, 2023)

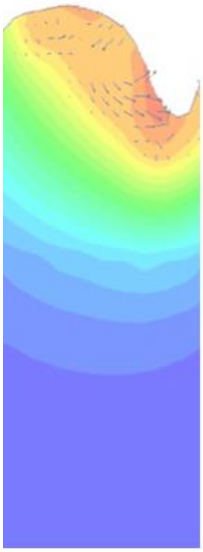


Compiled by NEWAM dissemination committee and released on 1 October 2023

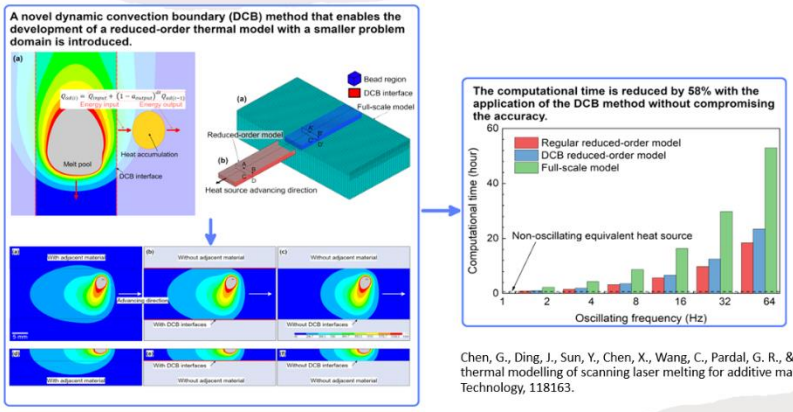
NEWAM in July – September 2023



Publications & Research Progress



Cranfield modelling team published a new paper on efficient thermal simulation of scanning laser (SL) process for additive manufacturing

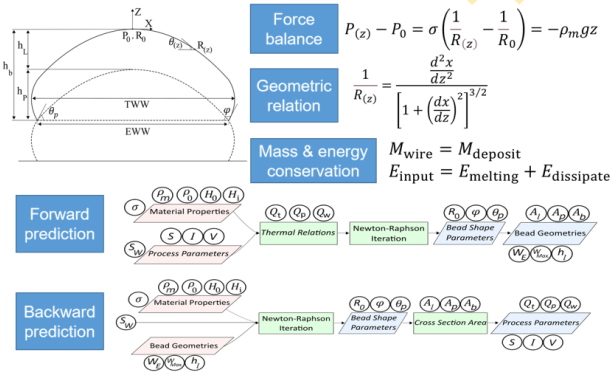


- A novel dynamic convection boundary (DCB) method is introduced, which enables the development of a reduced-order thermal model with a smaller problem domain.
- The computational time is reduced by 58% with the application of the DCB method with 99% accuracy.
- A bar-shaped non-oscillating equivalent heat source is introduced as a simplified substitution for the high-frequency oscillating SL heat source.
- The effects of the SL oscillation frequency on the melt pool geometry and thermal variables of the scanning laser process are investigated.

Chen, G., Ding, J., Sun, Y., Chen, X., Wang, C., Pardal, G. R., & Williams, S. (2023). Efficient reduced-order thermal modelling of scanning laser melting for additive manufacturing. Journal of Materials Processing Technology, 118163.

Cranfield modelling team's new paper on bidirectional analytical predictions of wire-DED bead geometries and process parameters

- Cranfield developed a thermo-capillary-gravity bidirectional analytical model based on the fundamental thermo-physical relations, enabling fast predictions of both w-DED bead geometries and process parameters. Using the forward algorithm, bead geometries can be predicted for given process parameters and material properties. In the reverse algorithm, the model outputs are process parameters, while the model inputs are the material properties and required bead geometries.
- This modelling approach is applicable to different w-DED processes, and it has been validated for the deposition of steel walls using plasma transferred arc and cold wire gas metal arc processes. It could be used as an efficient, reliable tool for w-DED process evaluation and design.

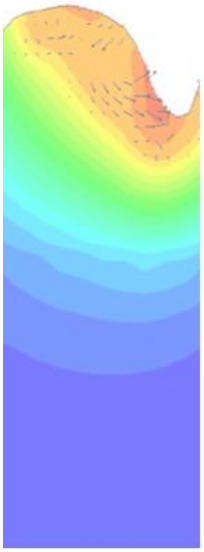


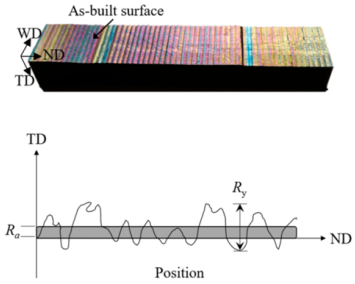
A.M. Haghighi, J. Ding, Y. Sun, C. Wang, S. Williams (2003). Thermo-Capillary-Gravity Bidirectional Modelling for Evaluation and Design of Wire-Based Directed Energy Deposition Additive Manufacturing. Journal of Manufacturing Processes.

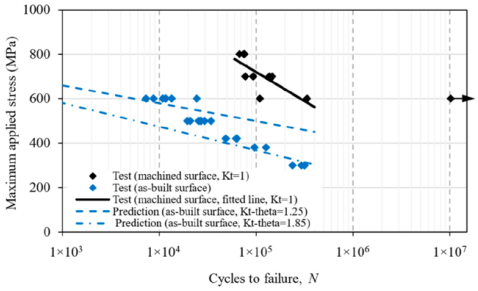
Cranfield process team published a new paper on high deposition rate WAAM

- Adding a non-energised wire to the gas metal arc (GMA) system makes it possible to overcome a process limitation and decouple the energy input from the material feed rate.
- Two novel process control methods were proposed, namely, arc power and travel speed control, which can keep the required geometry accuracy in WAAM through a broad range of thermal conditions.
- The reinforcement area of the bead is kept constant with accurate control over the height and width while still reducing the energy input to the substrate; decreasing penetration depth, remelting, and the heat-affected zone (HAZ); and reaching a dilution lower than 10%.
- This work also presents improved productivity compared to all the other single-arc energy-based processes with a demonstrator part built using the cold wire GMA process at a deposition rate of 9.57 kg/h.

Publications & Research Progress







Coventry team's new paper revealing surface waviness effect on fatigue life

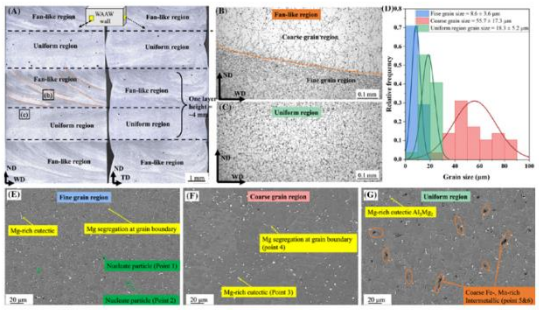
- The surface roughness or waviness of the as-deposited wall was fully characterised using formtracer. The local stress concentration caused by the surface waviness was quantified using finite element modelling.
- High cycle fatigue tests were conducted under 3-point bending loads. Based on the experimental results, two predictive methods were explored. By treating the troughs as small cracks, the fracture mechanics approach delivered good predictions at every applied stress level.
- This research demonstrated that the fracture mechanics approach can be a tool for decision making on the level of acceptable surface machining.

M. Shamir, X. Zhang, A.K. Syed, W. Sadler (2023). Predicting the Effect of Surface Waviness on Fatigue Life of a Wire+ Arc Additive Manufactured Ti-6Al-4V Alloy. Materials 16, no. 15: 5355.

Coventry team's new paper on fatigue crack growth behavior of WAAM deposited aluminum alloy Al–Mg–0.3Sc

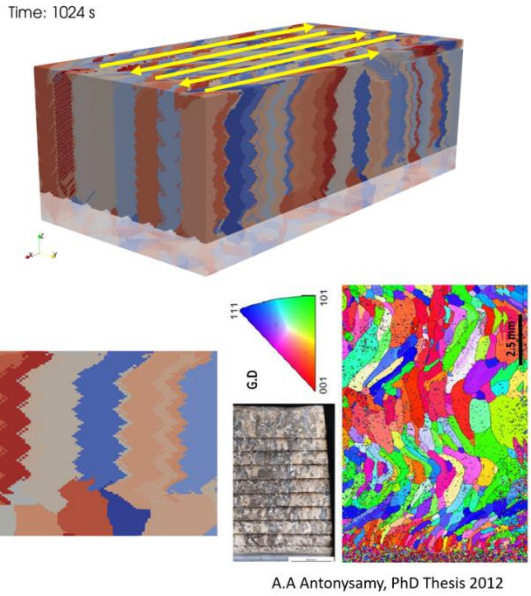
Ye, J., Syed, A. K., Zhang, X., Eimer, E., & Williams, S. (2023). Fatigue crack growth behavior in an aluminum alloy Al–Mg–0.3 Sc produced by wire based directed energy deposition process. Fatigue & Fracture of Engineering Materials & Structures.

- The material was deposited using Cold Metal Transfer-Advanced (CMT-Adv) process and a single bead deposition strategy. A detailed microstructure analysis along the build direction mainly shows two distinct regions, namely, the fan-like region and the uniform region. Furthermore, fan-like region consisting of alternative layers of coarse and fine grain microstructure bands which is the result of pulsated deposition during CMT process.
- Fatigue crack growth tests were conducted with two different crack orientations at cyclic load ratios of 0.1 and 0.5. At the lower load ratio, the horizontal crack showed a faster growth rate owing to the smaller grains and coarser second phase particles that the crack tip had encountered when it propagated along the material build direction.
- The anisotropy in crack growth rate was mainly caused by the grain size effect. When the applied stress intensity factor range exceeded the value of 10 MPa $m^{1/2}$, an isotropic crack growth rate between the two crack orientations was measured. This is due to the microstructural influence being overcome by the governing parameter of fracture mechanics.
- At the higher load ratio of 0.5, crack growth rate is isotropic, and the threshold stress intensity factor range was much lower than that tested under load ratio 0.1. Finally, the modified Hartman–Schijve equation has been successfully employed to represent the crack growth rates in all three regions.



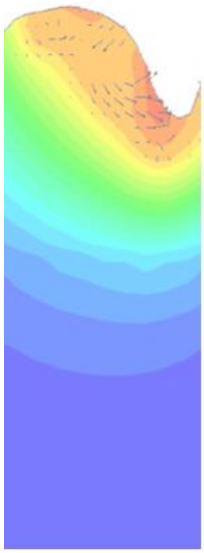
Manchester modelling team's multi-weave, multi-layer cellular automata grain structure predictions

- Recently the cellular automata (CA) based solidification of Dr. Daniel Dreelan has been adapted to employ analytical thermal solution for moving heat sources, to speed up computation sufficiently to allow grain structure predictions over multiple weaves and layers, with varying scan strategy.
- Initially the classical Rosenthal solution was employed, but was found to be an over-simplification, and the produced grain structure did not match experimental as closely as desired.



A.A Antonysamy, PhD Thesis 2012

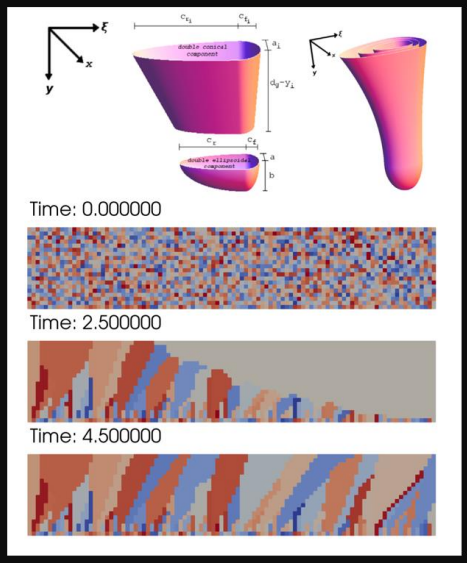
Publications & Research Progress



Manchester team is working on coupling of HEDSATS library to OpenFOAM Cellular Automata Model

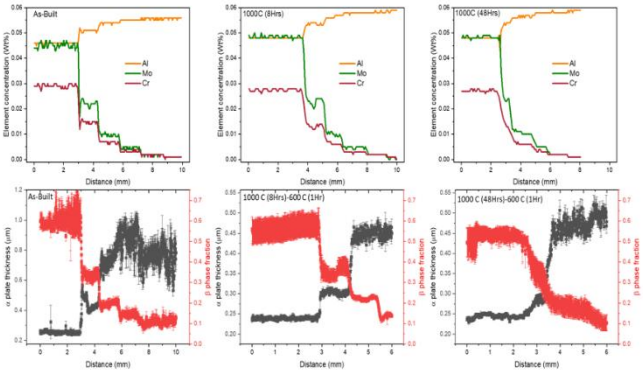
- The HEDSATS (High energy density semi-analytical thermal solutions) library [1] of Dr. Tom Flint has very recently been ported to OpenFOAM, and coupling to the CA solidification model has been implemented. HEDSATS is a mathematical simulation library designed for the modelling of the 3D transient heat equation due to the application of various distributed volumetric heat sources, representative of advanced manufacturing processes. The library constructs 3D solutions using one dimensional Green's functions, convoluted by the heat distribution in orthogonal domains.
- A key advantage of HEDSATS over the classical Rosenthal solution is that the size of the domain and boundary conditions are accounted for. The size and shape of the generated heat source can be tuned by the parameters shown on the diagram below, and can be matched to WAAM CFD simulations/observations.
- Preliminary results for single bead simulations using the double-ellipsoid HEDSATS heat source and CA model are shown below. The material simulated is a stainless steel, but Ti-alloys will become the focus going forward. The effect of melt pool size and shape on columnar grain morphologies for a single bead will be investigated, before extending the simulations to multiple layers.

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

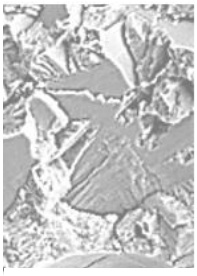


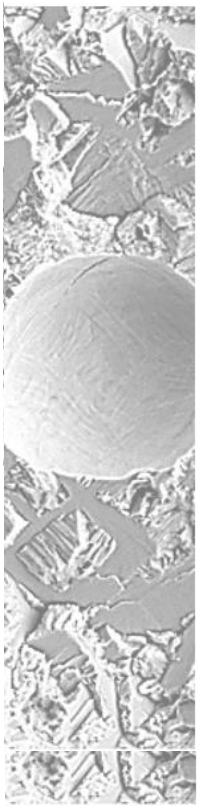
Manchester team is optimizing gradient microstructure of WAAM deposited AAC (Ti64-Ti5553)

- High deposition rate WAAM combines design flexibility through layer-by-layer deposition with the ability to produce cost-effective, near-net-shape engineering components in the aerospace applications. By intelligently switching the compositionally different metal wire feed in WAAM, we can produce compositionally gradient microstructure with tailored mechanical properties for the aerospace applications and eliminate the inefficient joint utilizing fastener and weld in the engineering design.
- In the present research, an alloy-alloy composite (ACC) of Ti-6Al-4V and Ti-5Al-5V-5Mo-3Cr was built using WAAM deposition, and post heat-treatment beta-annealing was executed at 1000 °C for different times. Using EDS, BSE imaging, and image processing, a smooth gradient of chemical compositions, β phase fraction, and lamellar spacing/alpha precipitation at 48 hours of β annealing was observed. This smooth gradient microstructure would provide a smooth transition of mechanical properties in heat-treated WAAM AAC Ti64-Ti5553.

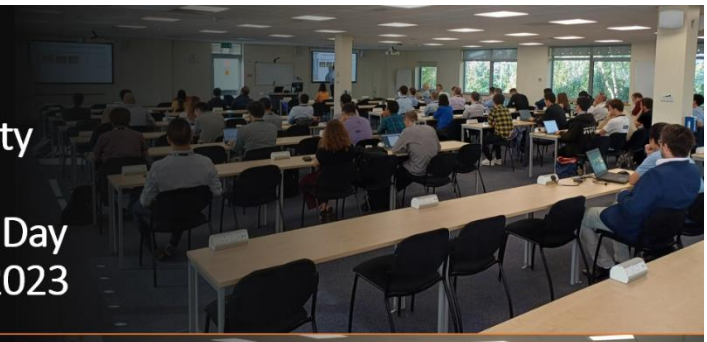


Conferences & Meetings





Cranfield University hosted the 6th NEWAM Industry Day on 5 September 2023



- More than 60 people attended the event, of which nearly half were guests from the industry.
- There were technical presentations covering the latest research outputs of the NEWAM project, a poster session, a lab tour at the Welding and Additive Manufacturing Centre at Cranfield, and a visit to WAAM3D, the spinoff company from Cranfield University.

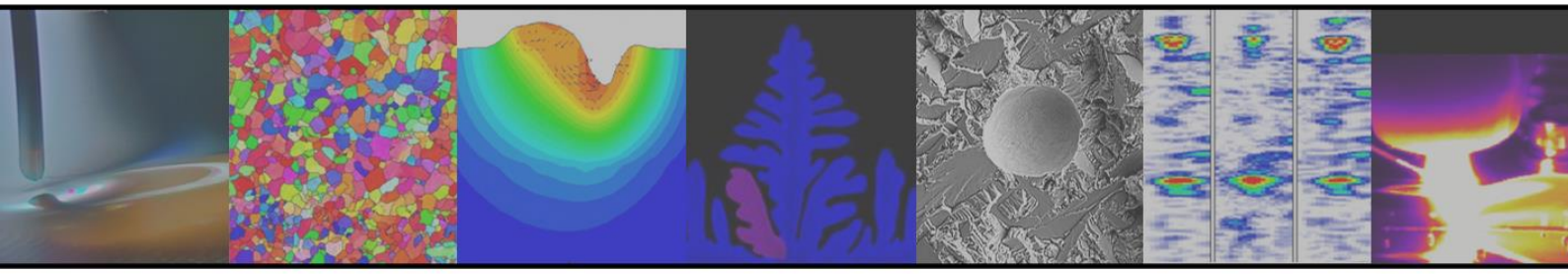
Cranfield lab visit on the NEWAM Industry Day

- At Cranfield, the visitors had the opportunity to see a selection of large-scale demonstrators built with different materials and various wire-based DED processes (Plasma transferred arc, CW-MIG, etc.). There were live demonstrations, too:
  - ✓ New wire-based DED processes for manufacturing with higher deposition rate: Multi-Energy Source (MES) and CW-Tandem MIG.
  - ✓ New end-effector with multiple sensors integrated with the WAAMControl software.
- We believe the NEWAM Industry Day was a successful event and look forward to meeting all again next year to celebrate the closure of the NEWAM research programme.

Strathclyde team presented at BINDT 60th Annual Conference at Northampton, 12-14 September

- NEWAM team Leader, Gareth Pierce presented "Considerations for process-to-part inspection for flexible manufacturing NDT".
- NEWAM team member, Muhammad Khalid Rizwan presented his work, "Optimization of transducer assembly for the phased-array ultrasound roller probe inspections of WAAM components".

New Wire Additive Manufacturing



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

Contact Information

Principal investigator: Prof. Stewart Williams (s.williams@cranfield.ac.uk)
Project manager: Dr. Sónia Meco (s.a.martinsmeco@cranfield.ac.uk)
Assistant Project Manager: Anne Fiorucci (a.fiorucci@cranfield.ac.uk)
Newsletter coordinator: Dr. Yongle Sun (Yongle.Sun@cranfield.ac.uk)