

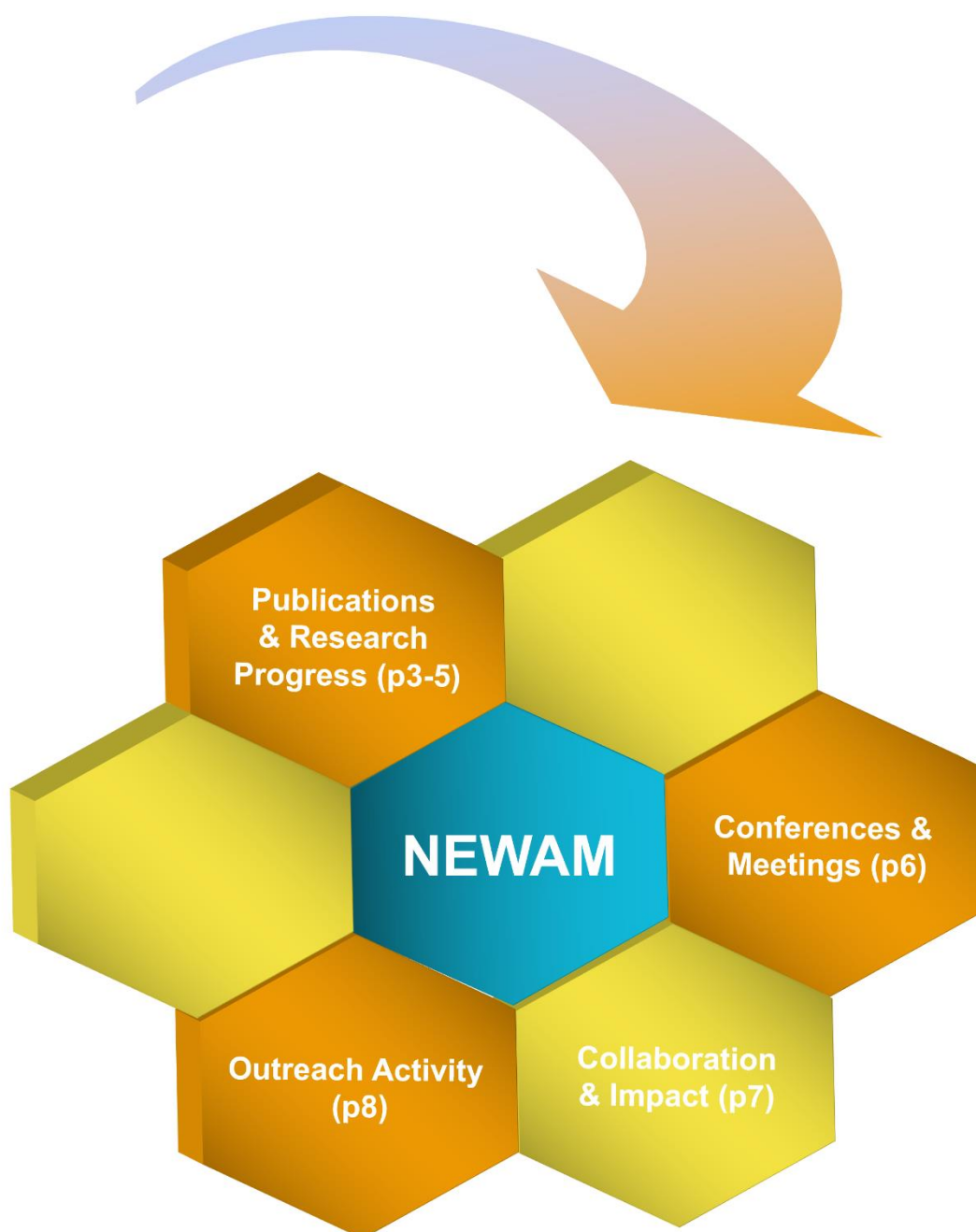
New Wire Additive Manufacturing

Newsletter (1st quarter, 2023)



Compiled by NEWAM dissemination committee and released on 1 April 2023

Your NEWAM in January – March 2023





New Wire Additive Manufacturing

Publications & Research Progress

Cranfield process team published a paper on hybrid manufacture of aluminium components

This paper aims to assess the possibility of including a substrate in a component by investigating the mechanical performances of the interface between a wrought plate and WAAM deposit. Four substrates alloys and AA2319 WAAM alloy were investigated. Inter-layer rolling and heat treatment, process steps known for improving the properties of WAAM deposit, were implemented. The WAAM deposit hardness was lower than that of the substrate in the as-deposited condition. Although the interface had no impact when using the same alloy for both substrate and wire, the weakest point of the combination was at the interface in dissimilar alloy combination. Heat treatment reduced the properties difference between the substrate and WAAM deposit. Inter-pass rolling strengthened the WAAM deposit without impacting the substrate and eliminated the micro crack that occasionally formed in the fusion zone in the as-deposited condition.

Eimer, E., Williams, S., Ding, J., Ganguly, S., & Chehab, B. (2023). Mechanical performances of the interface between the substrate and deposited material in aluminium wire Direct Energy Deposition. *Materials & Design*, 111594.

Mechanical performances of the interface between the substrate and deposited material in Aluminium Wire + Arc Additive Manufacturing

Background

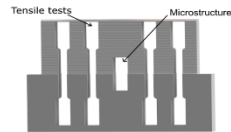
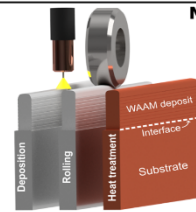
- Wire and Arc Additive Manufacture (WAAM) is a Direct Energy Deposition process suitable for building large and semi-complex near net shape components.
- In WAAM, a substrate is required to begin the deposition.
- Integrating the substrate into the built components leads to a reduction of material waste and deposition time, and enables the manufacture of hybrid components and functionally graded structures.
- The mechanical properties at the interface between the substrate and deposit should not be detrimental to the component performance.

Eimer E.^a, Williams, S.^a, Ding J.^a, Ganguly S.^a, Chehab B.^b
^a Cranfield University, ^b Constellium Technology Centre
 Funding:
 • C-TEC, Constellium Technology Center
 • Engineering Physical Sciences Research Council New Wire Additive Manufacturing (NEWAM) research programme (grant number EP/R027218/1)



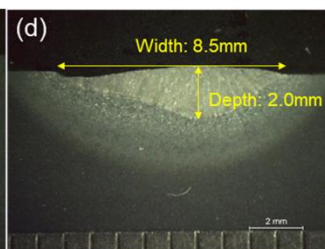
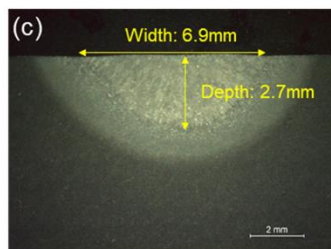
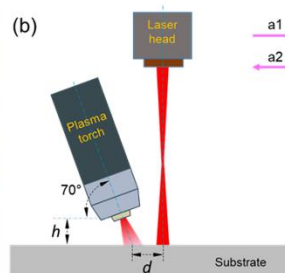
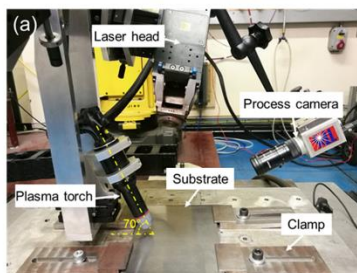
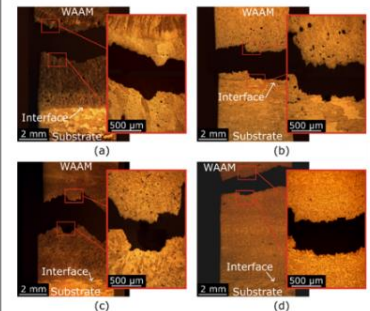
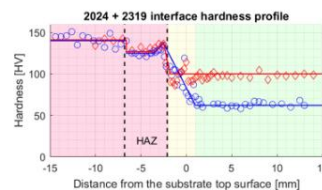
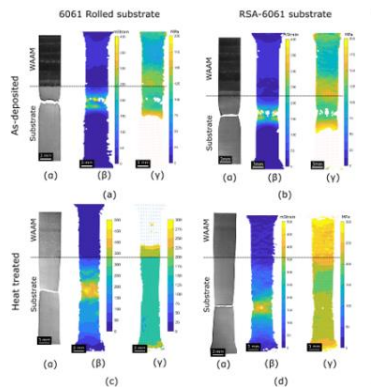
Methodology

- 1 wire (AA2319)
- 4 substrates (AA2219, AA2024, AA6061, RSA-6061)
- Conditions tested: with and without inter-layer rolling and before and after heat treatment



- ##### Outcomes
- Mechanical properties of the un-rolled and non-heat treated deposit are lower than the substrate.
 - Heat treatment increases and homogenises the properties at the interface, but compromises are required if the wire and substrate do not have the same chemical composition.
 - Interlayer rolling reduces the difference in mechanical properties between the substrate and WAAM deposit and reduces the formation of micro-cracks at the interface.

Cranfield highlight: Mechanical performances of the interface between the substrate and deposited material in aluminium wire Direct Energy Deposition



Laser beam size: 6mm

Laser beam size: 10mm

Cranfield process team's new paper on AM with combined energy sources

Cranfield's process development team recently published a paper on melt pool control in hybrid plasma arc-laser process. The study systematically investigates how the melt pool geometry is influenced by different process parameters in the hybrid process. The findings from this study provide a reference for melt pool control in wire-based hybrid arc-laser additive manufacturing.

Wang, C., Suder, W., Ding, J., & Williams, S. (2023). Parametric study of melt pool geometry in hybrid plasma arc-laser melting process for additive manufacturing application. *Welding in the World*, 1-12. <https://doi.org/10.1007/s40194-023-01476-9>



New Wire Additive Manufacturing

Publications & Research Progress



Coventry team published a new paper on fatigue behaviour of WAAM Ti64

- Strain-controlled fatigue testing allows a more rigorous and reproducible definition of failure than in load-controlled testing and provide insights into the applied elastic-plastic strain energy that is driving fatigue failure. Accurate local strain measurement within the gauge length allows to study the effect of plasticity, which is useful for predictive models, which cannot be determined in load-controlled fatigue testing for the stress-life fatigue property. Furthermore, applied loads in strain-controlled fatigue tests are fully reversed, with applied strain ratio $R_\epsilon = -1$ i.e., zero initial mean stress, to provide the baseline fatigue data from which the mean stress effect can be calculated, as in the variable amplitude load spectra in real world loading conditions. Additionally, because strain-life fatigue curves are based on the local strains, they are better suited to the predictive methods using the local stress or strain values, e.g., calculated by finite element analysis than using stress-life fatigue curves which are based on the nominal (applied) stresses.
- Therefore, this paper was focused on the strain-controlled fatigue behaviour, associated cyclic deformation and damage mechanisms of Ti64 deposited with oscillation build strategy developed for the WAAM process.



Strain controlled fatigue behaviour of a wire + arc additive manufactured Ti-6Al-4V

Abdul Khadar Syed ^{a,*}, Rob Plaskitt ^a, Michelle Hill ^b, Zsolt Pinter ^c, Jiahao Ding ^d, Robert Zhora ^e, Stewart Williams ^d, Xiang Zhang ^a

^a Faculty of Engineering, Environment and Computing, Coventry University, Coventry CV4 59B, UK

^b Hottinger Bruehl & Kjaer UK Ltd, UK

^c WAAMCO, UK

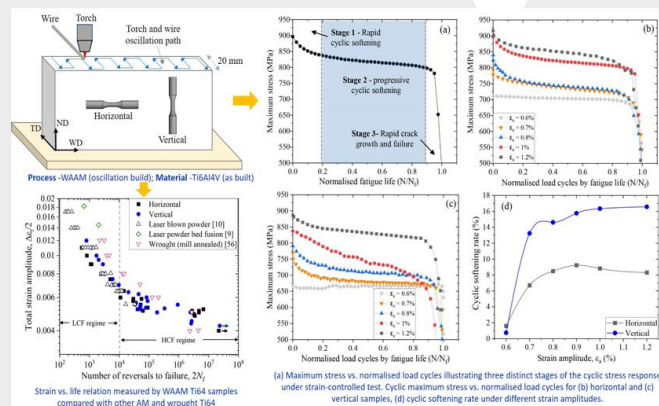
^d Institute for Engineering and Laser Processing, Coventry University, Coventry CV4 59B, UK

^e Swiss Federal Laboratories for Materials Science and Technology (Empa), 8600 Dübendorf, Switzerland

- To deliver this key material property, Coventry University teamed up with Hottinger Bruehl & Kjaer (HBK) UK Ltd (one of the NEWAM consortium industrial partner). HBK performed the strain-controlled fatigue testing on horizontal (α GB perpendicular to the loading) and vertical (α GB along the loading) orientation samples. All the tests were carried at room temperature. The experimental data was critically analysed, and the fracture surfaces were systematically studied at Coventry University to underpin the effect of sample orientation on strain-controlled fatigue performance.

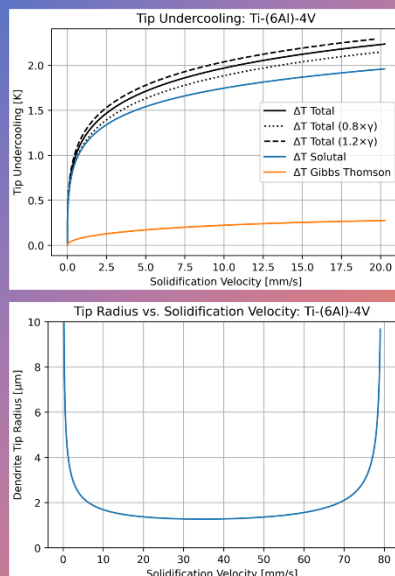
Coventry highlight: Strain controlled fatigue behaviour of a wire + arc additive manufactured Ti-6Al-4V

Between the two sample orientations, tensile and yield strengths are 5% higher in the direction normal to the material build direction (horizontal sample) owing to the columnar primary β grains with strong crystallographic texture along the α GB that is perpendicular to the loading axis. However, elongation is reduced by 60% in the horizontal samples due to preferential failure along the α GB of columnar β grain. Cyclic stress softening is observed in both sample orientations when the applied strain amplitude exceeds 0.6%. Because of higher ductility, the cyclic softening rate in vertical samples is approximately two times higher when strain amplitude is higher than 0.7%. As a result, horizontal samples show slightly higher peak stress by up to 4% compared to the vertical samples. In the low cycle fatigue regime ($2N_f < 104$ load reversals), the vertical samples' average life is about 2.5 times longer than that of the horizontal samples due to higher ductility in the former. In the high cycle fatigue regime ($2N_f > 104$), fatigue life property is almost isotropic.



Manchester material modelling team investigated the relative contributions to tip undercooling in Ti64

The KGT dendrite tip kinetics model developed by Danny Dreelan has been used to investigate the relative contributions tip undercooling in Ti-6Al-4V, by separating out the effects of solutal undercooling and curvature undercooling via the Gibbs Thomson effect. Complementary to this is the variation of dendrite tip radius with respect to solidification velocity shown left, with transitions to planar solidification being observed at low and high velocities. The inflection point occurs at a solidification velocity of 35 mm/s, meaning that beyond this, the Gibbs Thomson undercooling decreases. Since there is often uncertainty in values for the surface energy of the solidification front, variations of $\pm 20\%$ were also investigated in the tip undercooling plot above.



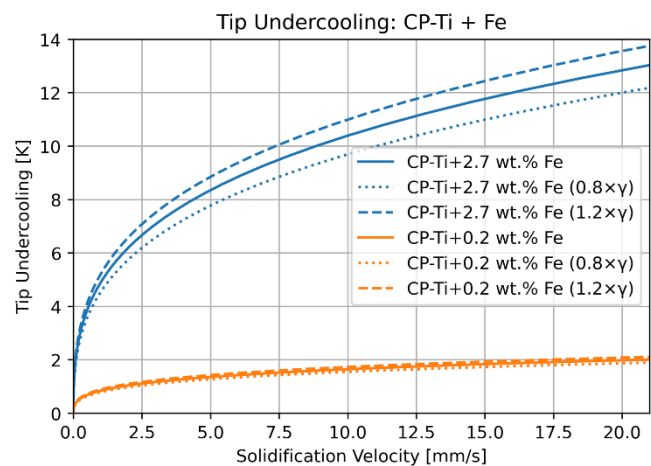


New Wire Additive Manufacturing

Publications & Research Progress

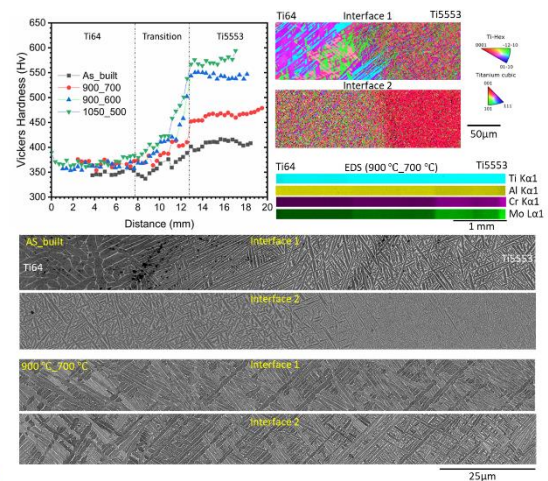
Manchester material modelling team's study on the effect of Fe content on tip undercooling in CP-Ti

Using the same KGT dendrite tip kinetics model, the effect of low/impurity level, and higher levels of Fe in CP-Ti on tip undercooling was also investigated. Similar to before, a $\pm 20\%$ uncertainty in surface energy was also included. Interestingly, even the low level of 0.2wt.% Fe can have the same level of effect on tip undercooling as 4wt.% Al in Ti64, demonstrating both the weak partitioning effects of Al in the Ti64 system, as well as the significance of impurities in CP-Ti. Increasing the Fe content to 2.7wt.% in CP-Ti considerably increases tip undercooling to 13 K at a solidification velocity of 20 mm/s, which has been found by others (Welk, Frasser et al.) to induce a CET.



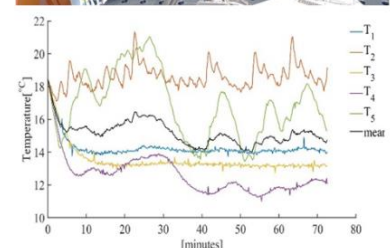
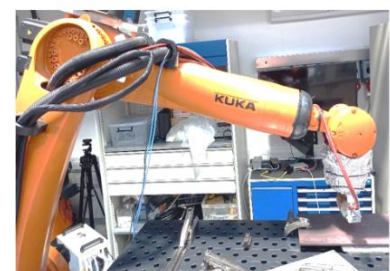
Manchester material development team's recent research on tailored mechanical property of WAAM-AAC (Ti64-Ti5553)

High deposition rate WAAM 3D printing provides design flexibility through layer-by-layer deposition to produce a cost-effective, near-net-shape product for the engineering components in the aerospace applications. By switching the compositionally different metal wire feed in 3D printing, 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 was performed at various temperatures to comprehend the mechanism of spatial hardness value. Microstructural characterization exploiting EBSD, EDS, BSE imaging suggests that spatially different hardness values result from a combined effect of α and β phase fraction, lamellar spacing/ α phase precipitation and solid solution strengthening mechanisms.



Strathclyde team developed a new Active Cooling System for High Temperature Roller Probe

- The phased array ultrasound (PAUT) roller probe has designed for the in-process inspections of additive manufacture (AM) components, where the transducer is deployed at elevated temperature of $> 350^\circ\text{C}$. However, the maximum operating temperature of commercial ultrasound transducers is 60°C .
- Hence, an active cooling system was designed which can maintain the temperature of ultrasonic transducer and the internal, complementary assembly of roller probe below 20°C during the inspection of a test sample heated to a temperature of 450°C . An optimized liquid pressure and temperature in the roller tire was achieved through a control flow rate and cooling cycles using an industrial chiller.



Temperature of the roller probe's internal assembly

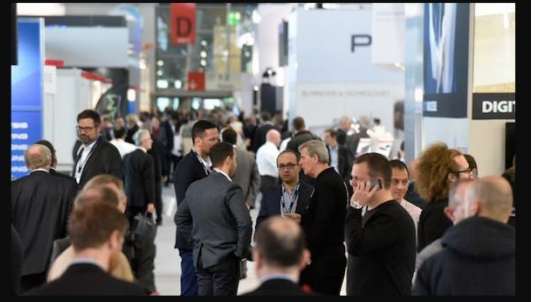


New Wire Additive Manufacturing

Conferences & Meetings

NEWAM will exhibit in TCT 2023

- We are glad to announce that the NEWAM research project will have a stand at the TCT 3Sixty 2023 which is considered the most influential 3D printing and additive manufacturing event in the UK.
- The two-day event, on the 7th and 8th June, will take place at the NEC (National Exhibition Centre) in Birmingham.
- You are invited to visit our stand, meet the NEWAM team and learn more about this exciting research project, including the new WAAM processes, new materials, customised tools for NDT, sensors for process monitoring, models for process and material development, etc.
- We look forward to meeting you there.
- For more details about this event, visit the website <https://tct3sixty.com/>.



JUNE 2023

NEC, Birmingham, UK



Strathclyde team member, Dr. Rastislav Zimmermann, has submitted an abstract to the ICAM 2023 conference, entitled "Towards fully automated quality assured metal additive manufacturing", and another abstract to the ASNT 2023 Conference with the title of "Dry-coupled ultrasound phased array inspection of as-built complex geometry metal additive manufactured components"

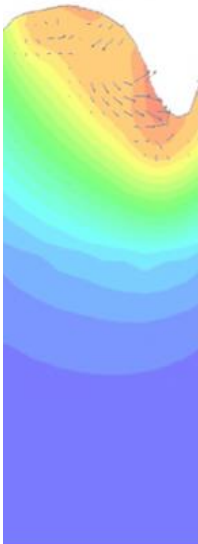


Cranfield team member, Dr. Yongle Sun, has been invited to deliver a presentation on physics-based process modelling for wire directed energy deposition in the symposium of Advances in Additive Manufacturing: Experiments and Modeling from Cutting-edge Fundamental and Applied Research, part of the 11th ICAMT congress 2023



New Wire Additive Manufacturing

Collaboration & Impact



Department for
Science, Innovation
& Technology



Professor Charles MacLeod in Strathclyde team has obtained funding as a part of Glasgow's Innovation Accelerator project. Approved by the UK Government Department for Science, Innovation and Technology (DSIT), the project has share of the Levelling Up funding for 11 ambitious local projects to further accelerate the Glasgow's booming innovation economy.

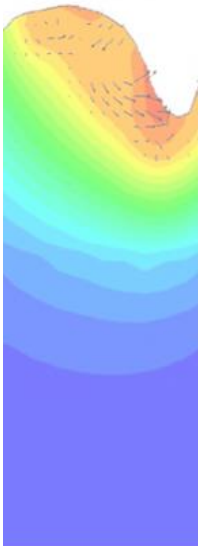


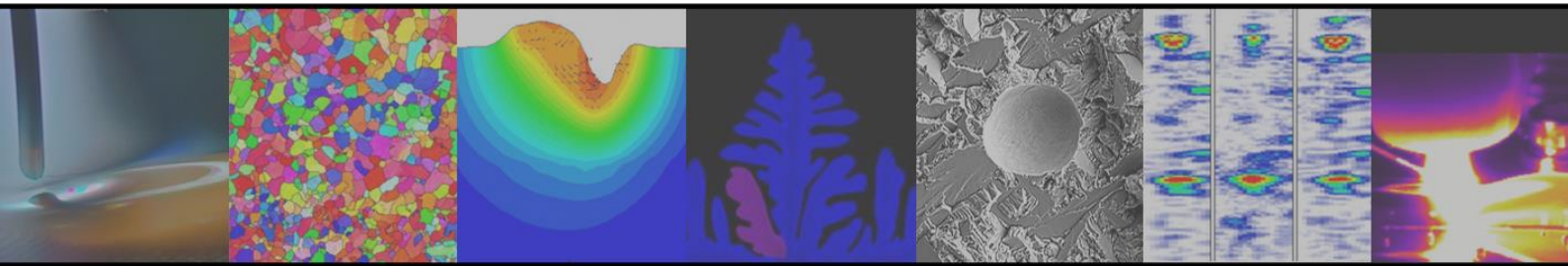
**Outreach
activity**



STEM Careers fair – Bedford Academy school

- We were invited to the STEM Careers Fair at Bedford Academy secondary school on 10th March to present what we do in our Welding and Additive Manufacturing Centre at Cranfield University. The students were very interested in knowing about the different routes to get into engineering, either through university or apprenticeship.
- We undeniably had a fantastic team of 2 PhD students, one apprentice and one Research Fellow helping out to put our amazing stand together: a chatty humanoid robot, our 3D printer to explain how Additive Manufacturing works, together with the thermal camera to show the heat source; a small robotic arm to replicate how robots in our lab work, but our VR Welding kit stole the show with load of students patiently waiting for their turn...
- School feedback: *"On behalf of staff and students at Bedford Academy, we just want to say a big thank you for supporting out STEM Festival last Friday. Student and staff feedback has been really positive and the afternoon wouldn't have been possible without your support! We look forward to inviting you to join us again next year!"*
- We are of course very much looking forward to doing this again next year!





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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