NEWAM

New Wire Additive Manufacturing

Newsletter (3rd quarter, 2022)

Cranfield University

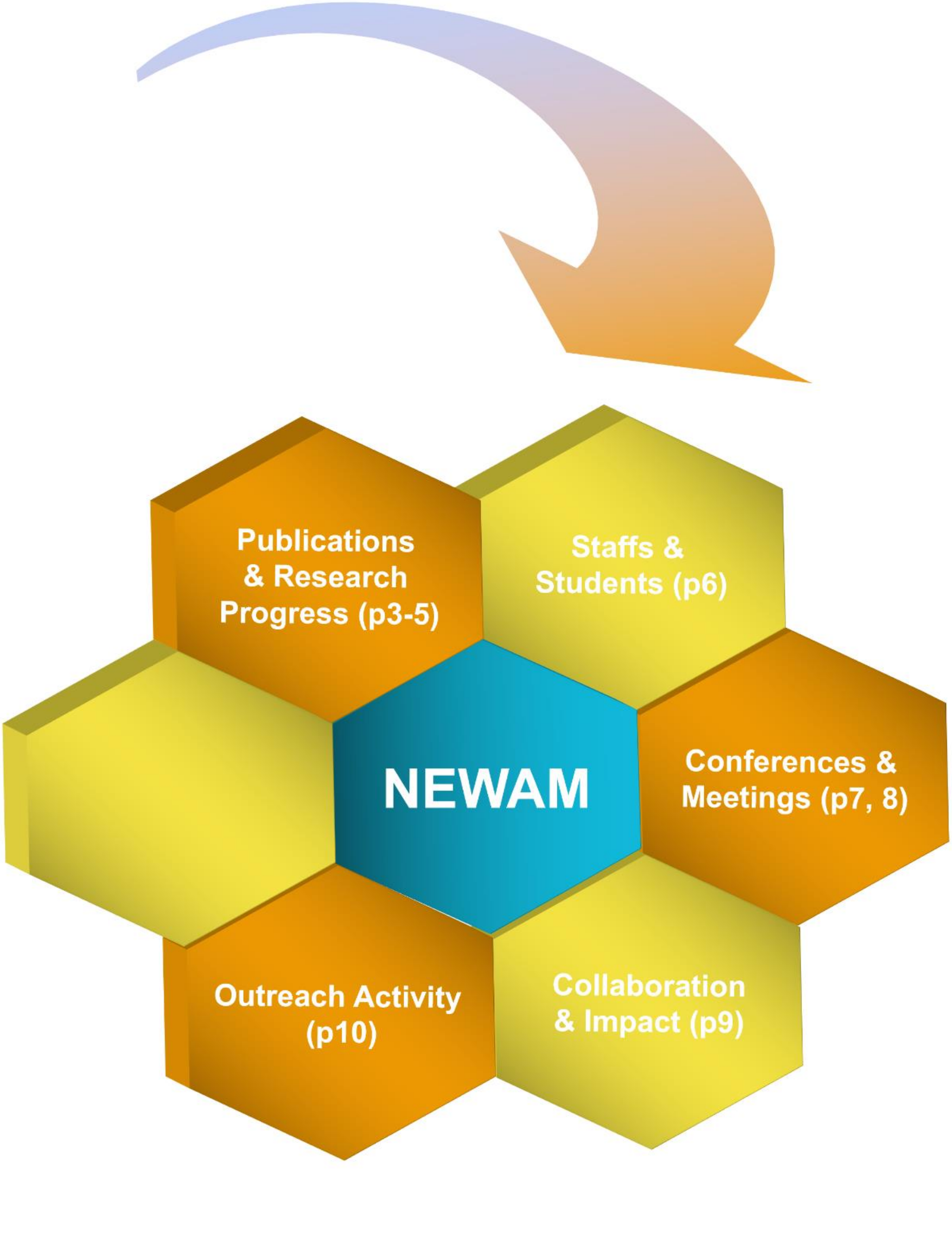
MANCHESTER 1824

University of Strathclyde

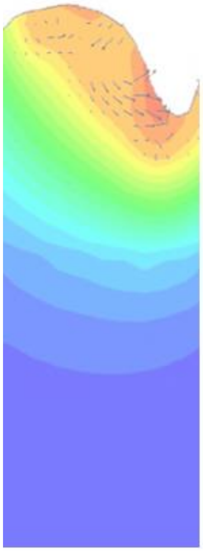
Coventry University

Compiled by NEWAM dissemination committee and released on 3 October 2022

Your NEWAM in July – September 2022

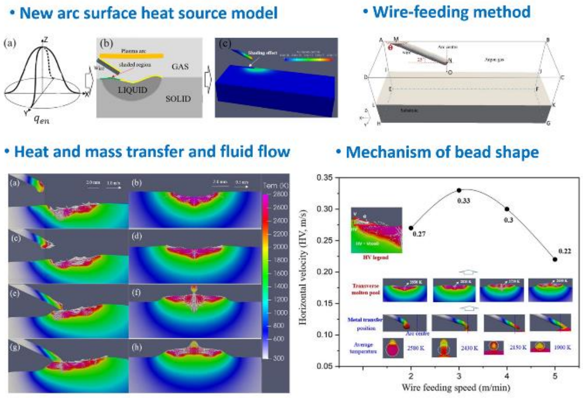


Publications & Research Progress



Cranfield process modelling team's new paper on CFD modelling of wire melting

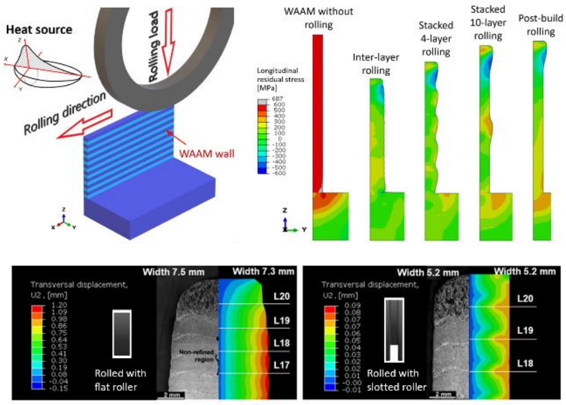
- This paper reports the development of a novel three-dimensional wire-feeding model for heat and mass transfer, fluid flow, and bead shape in the wire-arc DED process. This model is the foundation of the entire modelling framework developed for different types of wire-arc DED processes, including the MES DED process.
- The wire melting and metal transfer dynamics, the flow dynamics in the melt pool, and the mechanism of bead shape when the WFS increased from 1 to 5 m/min have been investigated and clarified. The developed model and findings can be served as a basis or reference for deep insight into the wire-arc DED process.



Xin Chen, Chong Wang, Jialuo Ding, Phillippe Bridgeman, and Stewart Williams. "A three-dimensional wire-feeding model for heat and metal transfer, fluid flow, and bead shape in wire plasma arc additive manufacturing." Journal of Manufacturing Processes 83 (2022): 300-312.

Cranfield process modelling team's new paper on hybrid process of WAAM and rolling

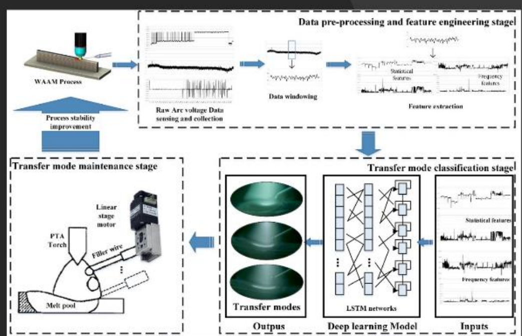
- An efficient coupled process model for a steel wall is developed to simulate the interaction between WAAM deposition and rolling. The predicted RS distributions and wall dimensions agree well with experimental results. Cyclic variation of longitudinal tensile RS occurs during WAAM deposition and inter-layer rolling in clamped condition. The influence depth of deposition and rolling is characterised by the number of the underlying layers that are plastically deformed after each process cycle. For the inter-layer rolling with a flat roller, the rolling has smaller influence depth than the deposition; consequently, the rolling does not eliminate but rather contains the regeneration of WAAM tensile RS after thermal cycles. Rolling with a slotted roller introduces more tensile plastic strain and thereby more effectively reduces the WAAM tensile RS and unclamping distortion.
- Compared to the inter-layer rolling, stacked-four-layer rolling has larger influence depth and hence achieves similar RS mitigation efficacy with fewer rolling operations, while post-build rolling has lower efficacy due to insufficient penetration. Therefore, stacked-layers rolling with slotted roller is recommended for an optimal hybrid process of WAAM and rolling.



Valeriy Gornyakov, Yongle Sun, Jialuo Ding, and Stewart Williams. "Modelling and optimising hybrid process of wire arc additive manufacturing and high-pressure rolling." Materials & Design (2022): 111121.

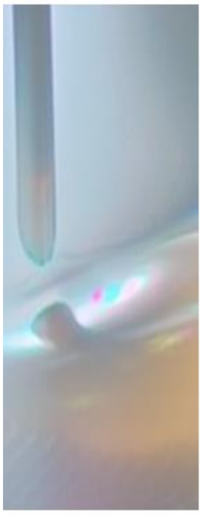
Cranfield process modelling team's new paper on machine learning model for droplet transfer control

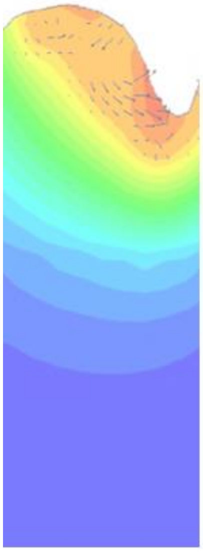
- The process stability is highly dependent on how the supply wire is added into the melt pool, which is known as droplet transfer mode. To keep a stable WAAM deposition process, it is essential to maintain the transfer mode in a suitable stable status.
- In this paper, a deep learning-based technology is proposed for the control of the droplet transfer mode based on the data collected from the WAAM process. A long short term memory neural network (LSTM-NN) is applied as the core transfer mode classification model. A time-series data, arc voltage, is collected and statistical and frequency features are extracted. Then, the distance between the melted wire and the melt pool is adjusted based on the determined transfer mode to keep a suitable stability of the process. The proposed method obtained the highest accuracy in determining the transfer mode which was over 91%.



Jian Qin, Yipeng Wang, Jialuo Ding, and Stewart Williams. "Optimal droplet transfer mode maintenance for wire+ arc additive manufacturing (WAAM) based on deep learning." Journal of Intelligent Manufacturing 33, no. 7 (2022): 2179-2191.

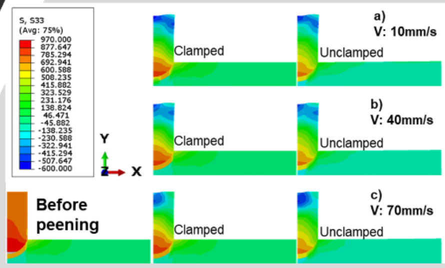
Publications & Research Progress

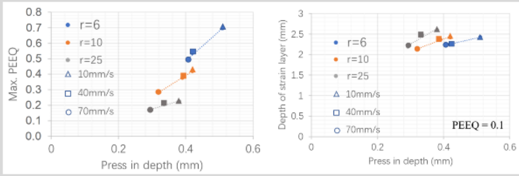




Cranfield process modelling team has initiated simulation of peening for WAAM

- Preliminary peening modelling results have been obtained to understand the effect of peening on WAAM residual stress and distortion, as well as the plastic strain distribution generated by peening. As a first attempt, the peening load is simplified as indentation displacement along the peening line, while the dynamic factors have not been considered. The results show the following trends:
  - ✓ Slower tool travel speed (V) produces larger peening coverage, which introduces higher plastic deformation and more significant residual stress
  - ✓ A larger radius (r) of peening head allows a more uniform distribution of the introduced plastic strain, while its effect on residual stress is complicated
  - ✓ Peening can introduce sufficient beneficial compressive residual stresses to counteract the tensile residual stresses due to WAAM deposition

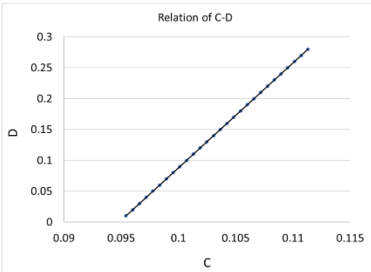




Cranfield process modelling team's research progress

- Energy transfer efficiency, η, is a parameter to specify the amount of heat transferred to the substrate or previously deposited layer from the energy source. The wire melting efficiency, η_w, is the ratio of the energy consumed for melting the wire to the energy absorbed by the wire, such as heat conduction, wire melting, and the associated energy loss (e.g., interaction between power source and material). Mostly this parameter contains small amount of heat which is less than about 11% ($\eta_w \cong 90\%$) for conduction and heat loss additional to the net heat consumed for melting the wire in wire-based processes.
- In previous research, transfer efficiency mostly has been considered as a constant or related to a specific process parameter. To the author's knowledge, there is not any specific method for determination of transfer and wire melting efficiency of w-DED process. In this study, a novel method to determine transfer efficiency and wire melting efficiency based on the thermo-capillary-gravity model and experimental results have been developed. For this purpose, by categorizing efficiency parameters of penetration area we have:

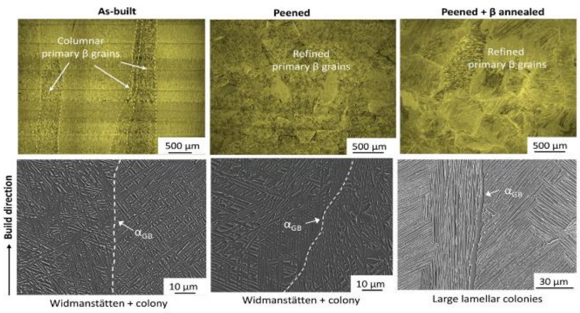
$$A_p = \frac{((C.I.V) - (D.(\pi.d^2.WFS.\rho_0.H_0)/4)))}{H_i.\rho_m.TS} \qquad C = \eta_m.\eta \qquad D = {}^{\eta_m}/_{\eta_w}$$



Relation of variables C and D in penetration area equation

Average transfer and wire melting efficiency for 5 cases of PTA process of ER90S-G wire

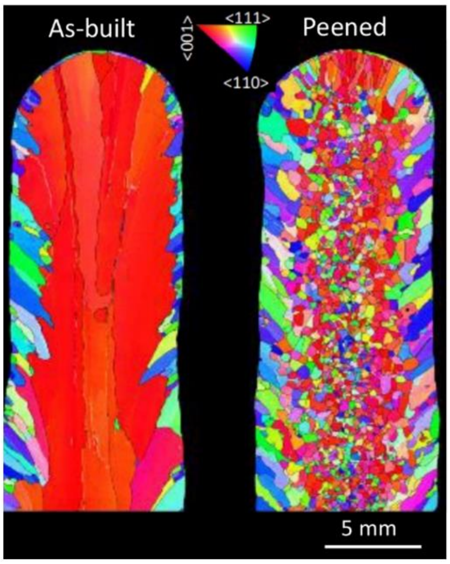
Std.	WFS $[mm/s]$	TS $[mm/s]$	I $[A]$	V $[v]$	C	D	η	η_w
1	23.3	1.5	170	23	0.11	0.18	0.62	93.45
2	25	2	173	23	0.11	0.19	0.63	93.45
3	25	2.2	179	24	0.11	0.18	0.62	95.24
4	25	2	206	26	0.09	0.17	0.57	94.34
5	23.3	2	238	29	0.10	0.17	0.58	96.15
							0.60	**94.53**



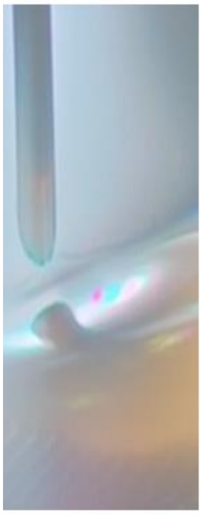
Coventry Team's research highlight: Microstructure printing to achieve desired mechanical properties (1)

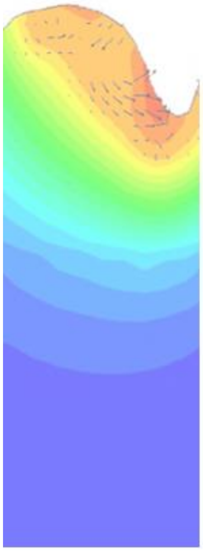
Ti-6Al-2Sn-4Zr-2Mo (in wt%) (Ti6242) is a near-α titanium alloy with higher fracture toughness, high temperature stability and good creep resistance. It can be used for structures operating at elevated temperature up to 540°C. AM built titanium alloys known produce large columnar grains aligned along the build direction leading to anisotropic mechanical properties.

In this study we 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.



Publications & Research Progress

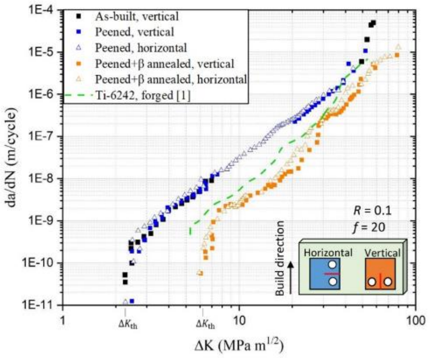


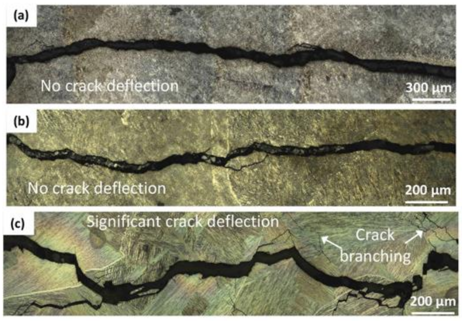


Coventry Team's research highlight: Microstructure printing to achieve desired mechanical properties (2)

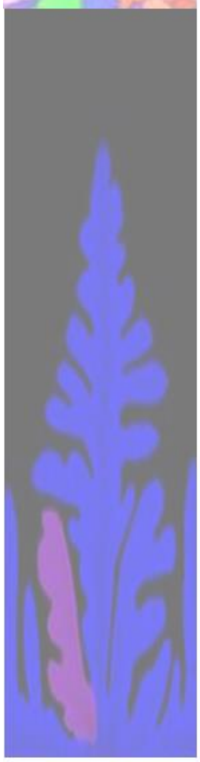
SEM images show that both the as-built and peened conditions have a transformation microstructure consisting of the Widmanstätten and colony morphology. Peening followed by β annealing (heating rate 0.1°C/sec, held at 1050°C for 30 min, followed by a cooling rate of 0.1°C/sec) did not alter the refined 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.

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. From this study we have demonstrated the use of WAAM process and post process to produce microstructure that can deliver desirable mechanical properties.





Staffs & Students



Charles MacLeod's promotion to professor at Strathclyde

- NEWAM Teams Lead at the Strathclyde University, Charles MacLeod has been promoted to Professor. Previously, he was working as a senior Lecturer at the Centre for Ultrasonics, the Strathclyde University.
- Prof. Charles MacLeod, of the Department of Electronic and Electrical Engineering and the Centre for Ultrasonic Engineering, was one of only eight recipients as part of the Royal Academy of Engineering's Research Chairs and Senior Research Fellowships programme, which was announced earlier this year
- Prof. Charles MacLeod is the Babcock International Group / Royal Academy of Engineering Chair in Sensor-Driven Automated Welding. He is director of the Sensor Enabled Automation & Robotics Control Hub (SEARCH), a £24M research innovation and technology transfer laboratory. Aligned to this, he is Course Director of the Autonomous Robotic Intelligent Systems (ARIS) MSc.

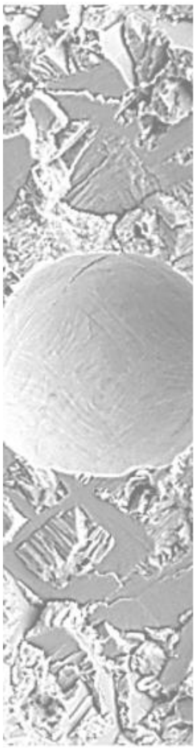
Dr. Tom Flint joined NEWAM: Research Fellow at The University Of Manchester

- Tom has recently joined the NEWAM team to take over leading the Materials Modelling Work Package.
- He is a Research Fellow, in the Department of Materials at The University of Manchester, specializing in developing high fidelity mathematical frameworks that describe microstructural evolution when multi-component substrates are subjected to high energy density sources of heat.
- Tom studied Physics at undergraduate level at Manchester, before obtaining a doctorate with a thesis on the development of analytical solutions for the temperature fields generated during arc and power beam welding applications.
- He will continue to develop microstructural modelling frameworks that will be used to predict how the substrate evolves due to the WAAM process.

Dr. Rastislav Zimermann has started new role as Research Associate at Strathclyde

- Rastislav Zimermann has joined the NEWAM team at the University of Strathclyde as a Research Associate
- He obtained his doctoral degree from the Strathclyde in June 2022, working on Automated Ultrasound In-process NDE of Wire + Arc Additive Manufacture.

Conferences & Meetings



Dr. Chong Wang and Dr. Romali Biswal attended the 75th IIW Annual Assembly and International Conference in July in Japan

Dr. Chong Wang and Dr. Romali Biswal from Cranfield University Process Development team (WP1), attended the IIW 2022 International Conference in July in Tokyo, Japan.

Dr. Wang presented his work sponsored by the NEWAM project entitled "Parametric study of melt pool geometry in hybrid plasma arc - laser melting process for additive manufacturing application". This work received lots of research interests from researchers around the world and has been nominated for publication in the special issue of the conference. Dr. Biswal's work was sponsored by the Multifun project and was titled "FeNi36 deposition using AM processes: In-situ alloying and pre-alloyed FeNi36". This work will be disseminated as a full-length journal paper.

Strathclyde Team's Presentations at BINDT 59th Annual Conference at Telford, 6-8 September

- NEWAM team member, Ehsan Mohseni presented his work of Automated In-process Inspection of Additive Manufactured Components by Different NDE Modalities
- NEWAM team member, Muhammad Khalid Rizwan presented his work of Investigating Ultrasound Wave Propagation through the Coupling Medium and non-flat Surface of Wire + Arc Additive Manufactured Components Inspected by a PAUT Roller-probe
- Ehsan Mohseni and Rastislav Zimermann have submitted abstracts to 13th The European Conference on Non-Destructive Testing (ECNDT).

NEWAM industry day 2022

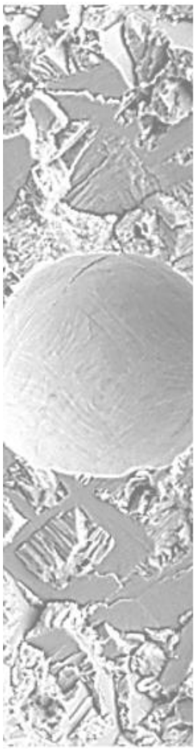
This was another successful NEWAM industry day with more than 50 national and international attendees, 20 of each from the industry.

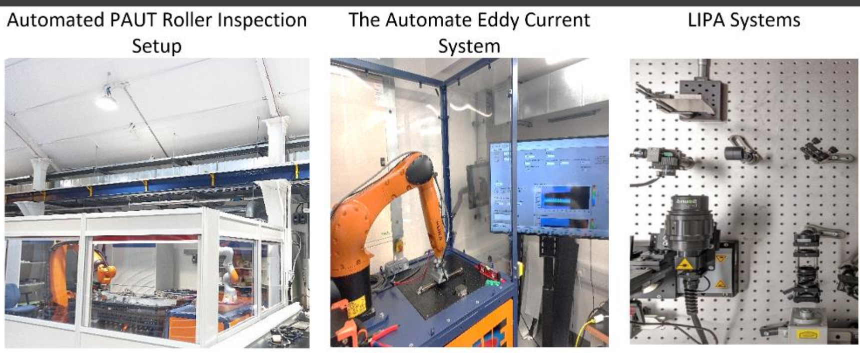
This time the event was in-person and offered the opportunity for the industrial partners to meet the team working on the NEWAM research programme.

There were very informative presentations given by the research area leaders, a poster session during lunch break and Prof. Stewart Williams talked about our next steps in AM and future proposals.

The feedback from the Strategic Advisory Group and other attendees was excellent which means that we are going in the right track 😊

Conferences & Meetings



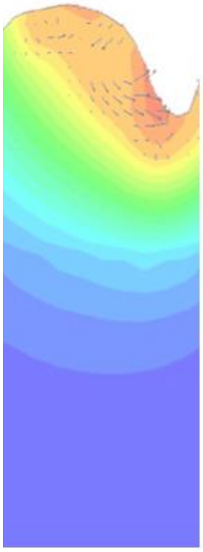


Sensor Enabled Automation Robotics & Control (SEARCH) Hub

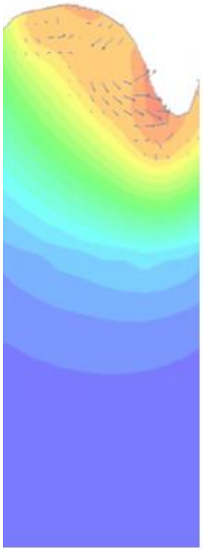
Strathclyde hosted the NEWAM Industry Day

- The team at Strathclyde hosted the NEWAM Industry Day 2022 on 20th September. Delegates form both the academia and industry participated in the event.
- Live demos and practical demonstrations of a wide range of NDT activities were given to the participants at the Sensor Enabled Automation Robotics & Control (SEARCH) Hub. SEARCH Lab exploits multiple NDT aspects of WAAM components, like the automated phased-array ultrasonic testing (PAUT) roller probe inspections, the automated Eddy Current Testing, and the Laser Induced Phased Arrays (LIPA).

Collaboration & Impact



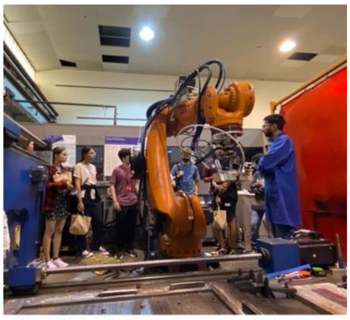
Outreach activity



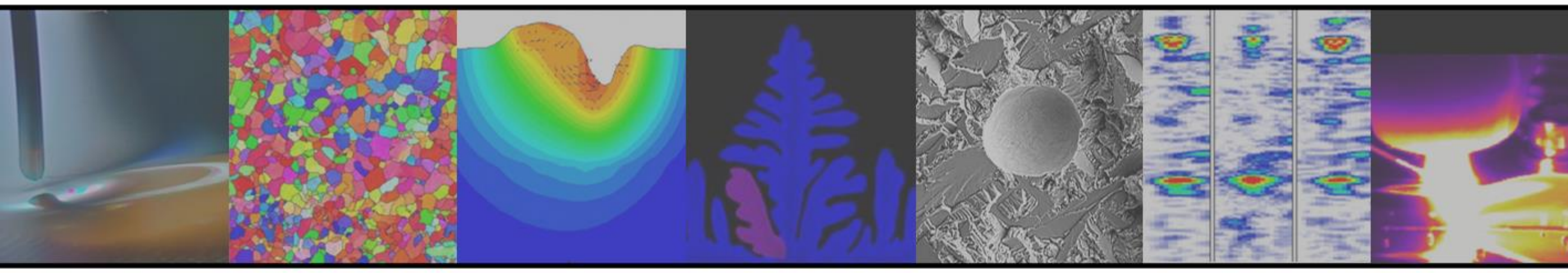
Outreach Activity - LIYSF

London International Youth Science Forum (LIYSF) came to visit Cranfield University last week and they stopped by to have a look at our Welding & Additive Manufacturing Centre lab. The attendees were aged 16-21 and came from many different countries (Estonia, Switzerland, Cyprus, Canada, Panama, Czech Republic, Malaysia, Spain, USA, Australia, Portugal, Brazil, Poland, Nigeria, Mexico, Germany and Sweden!). They had a glance at the 3D printing we do here and it is always wonderful to see young science enthusiasts showing an interest in what we do and asking questions.

It was the first post-pandemic visit in our lab welcoming young people, and we are very much looking forward to many more!



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

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