NEW WIRE ADDITIVE MANUFACTURING

EP/R027218/1

Annual Report

2022

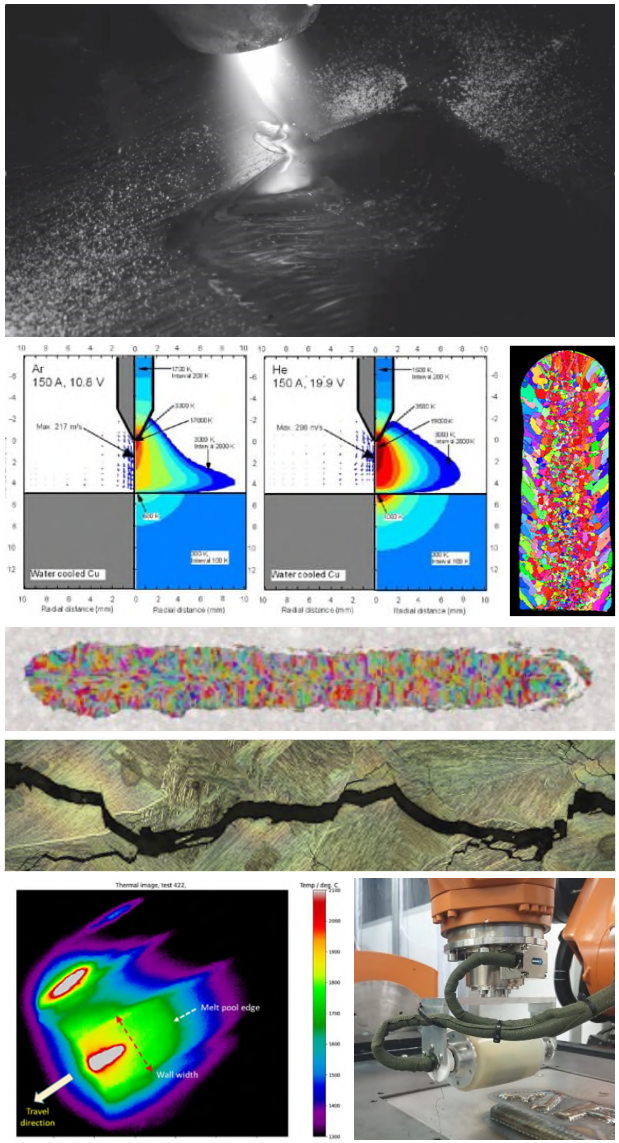
CONTENTS

Welcome to the 2022 annual report. there have been many exciting developments since our last report at the mid-term assessment. I am very pleased to say that we successfully passed through this assessment with both the international reviewer and strategic advisory group very satisfied with the progress we had made to date. We were commended not only on the quality of the research but also on other aspects such as:

- The level of collaboration and integration between the different research teams at the four universities;
- The management of the programme, in particular the use with the intermediate challenges to encourage the cross disciplinary interactions;
- Early achievement of some of the key performance indicators which will now be revised;
- The engagement that has been achieved with the public and school children despite the challenging conditions.

Of course, there were some recommendations where we can improve, and we will be implementing these over the remainder of the programme
There have been many notable technical highlights in recent times, and these can be seen in the following pages for the different research areas and I hope you enjoy reading about these.

Words **Prof Stewart Williams**



"Not off the shelf processes…"

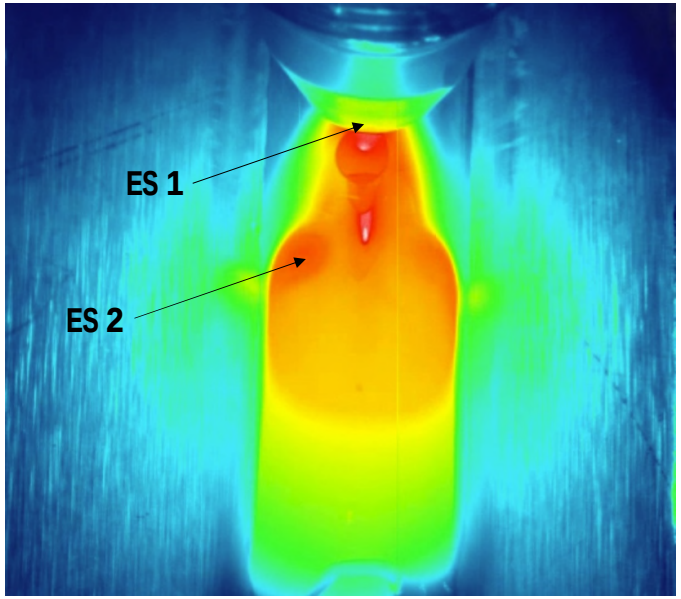
We are developing new better process for high deposition net-shape with tailored properties…"

"Optimised for Additive Manufacture not for welding or cladding…"

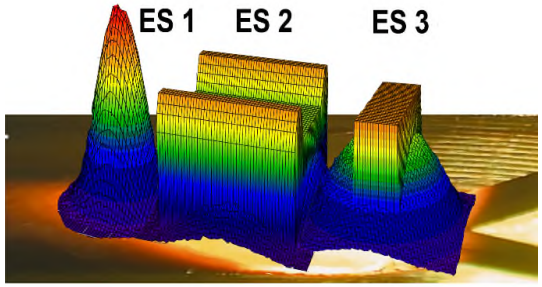
Words **Dr Wojciech Suder**

Multi Energy Source (MES)
In a standard AM technology, a single axis-symmetric heat source is used, such as a laser, electron beam or an arc-based welding process. In such processes any change of processing parameter induces a simultaneous change of microstructure, remelting into the underlying material and bead shape. In other words, with any standard process, it is impossible to decouple the thermal input and geometry of deposited beads.
In our MES process we utilize the benefits of laser and arc-based processes in one set-up to melt the feedstock efficiently and control the shape of laid material. This allow us to print precisely shaped material with the right microstructure at a high build rate and low cost.

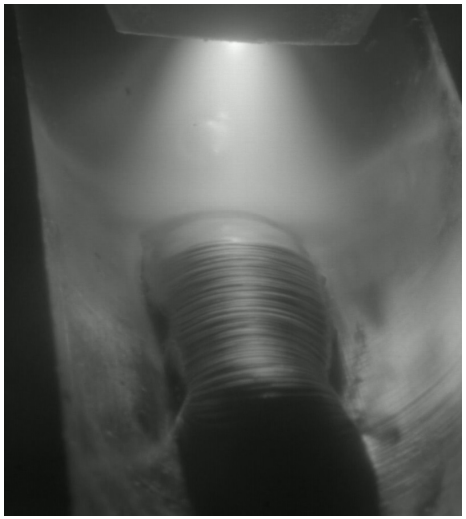
Dynamic beam shaping
A new way of adjusting the energy profile projected on the workpiece is needed to facilitate a full control of the printed geometry with net-shape. In this project a radically novel use of galvo-scanning laser optics has been developed, which enabled us to freely change the height, width and thermal cycle of deposited layers. The new process is coupled with the heat source designer, an analytical tool derived from numerical modelling data to support the process parameter selection.

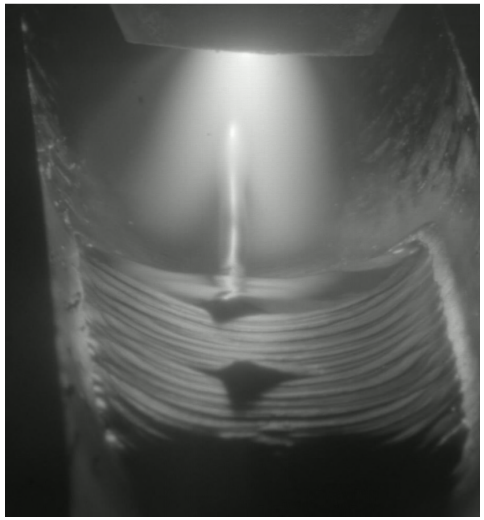


Temperature signature from MES Process

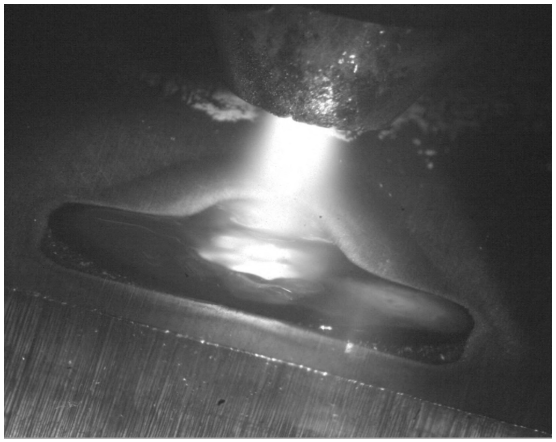


Schematic of Multi-Energy Source Process

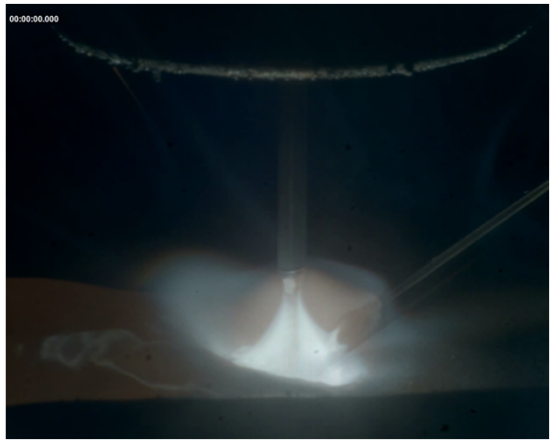




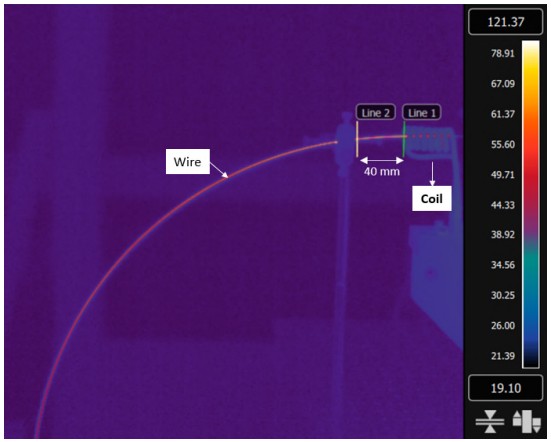
Bead shape control with dynamic beam shaping



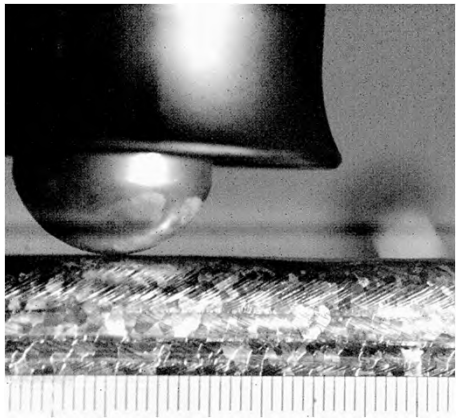
MES with dynamic beam shaping



CW – MIG



Thermal image of induction head wire

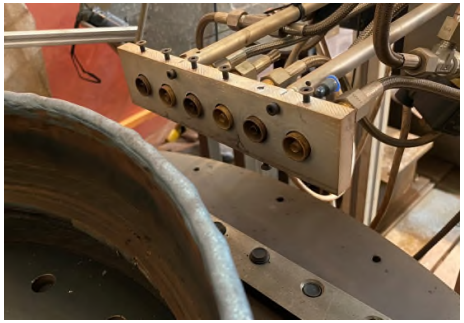


In-process robotic peening

Flexible bead shaping

Twin wire MES

Induction heating of feedstock wire



In-process cryogenic cooling

MES process development

The MES process, with a plasma arc utilized for feedstock melting and enhancement of laser absorption and a laser for control of meltpool shape and thermal cycle has been extensively tested. Now we have a full understanding of the process control have proven high deposition (up to 5 kg/h) and net shape (low surface waviness) for steel and titanium alloys. The next step is to build more complex parts. Good process tolerance to the wire positioning accuracy and independent control of deposition rate and thermal input makes it a perfect candidate for the next generation wire-based additive manufacture technology.

High deposition rate

Multiple ways of achieving high rates of feedstock melting have been developed and tested independently. The most promising include a CW-MIG (Metal Inert Gas process with additional cold wire in one arc column), shaped wires or multiple wires. The CW-MIG process allows high deposition rate with low dilution into the underlying layer, and it has been delivering deposition rates exceeding 12 kg/h in a range of materials. A large 200kg demonstrator part has been built in low alloyed steel.
The multiple wire or shape wire solutions enhance the direct absorption of energy from the heat source leading to high deposition rate and low dilution. The most promising process will be installed on the MES system and used for building of demonstrator parts.

Efficient feedstock melting

Various techniques for improvement of the feedstock melting rate without the need for increasing the energy applied to the meltpool have been tested. A custom designed induction heating system has been proved to be an efficient feedstock melting enhancement process. Good control of temperature and high heating efficiency at high feed rates make this system very promising. Other solutions tested include, custom designed plasma torches and tailored heat sources for more efficient feedstock melting

In-process control
To facilitate the first-time right properties in different class of materials, such as steels, aluminium alloys, nickel alloys and titanium alloys, different approach to the control of microstructural development is needed. We have developed and tested new grain transformation theory in Ti6Al4V, which allowed us to formulate a simple empirical model for prediction of developed microstructure just based on mass and energy input.
In addition, various in-situ cold work processes have been developed for local property enhancement, similar to a locally applied forging. Also, for the heat management and potentially microstructure control we have successfully tested two different cryogenic cooling mediums with a positive outcome.

Research area leader:
Dr Wojciech Suder

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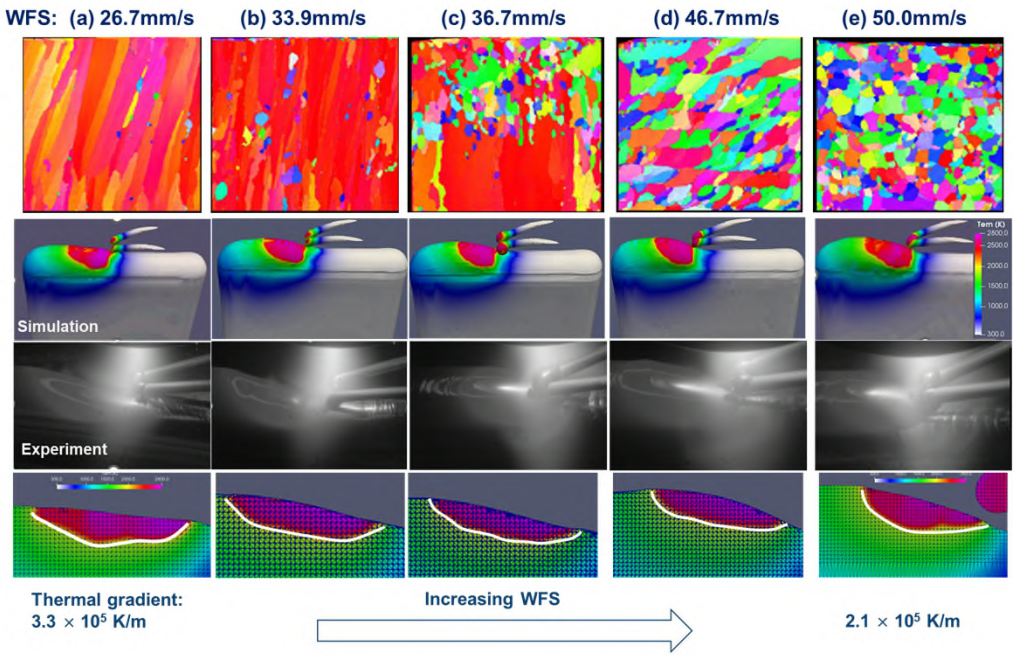
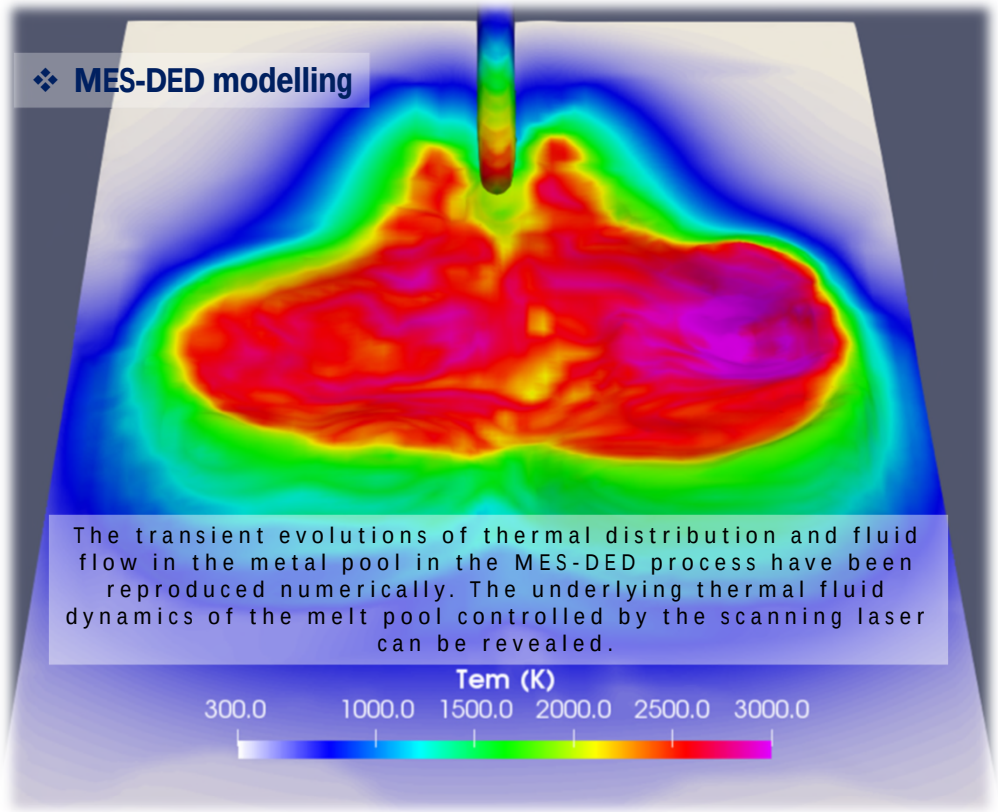


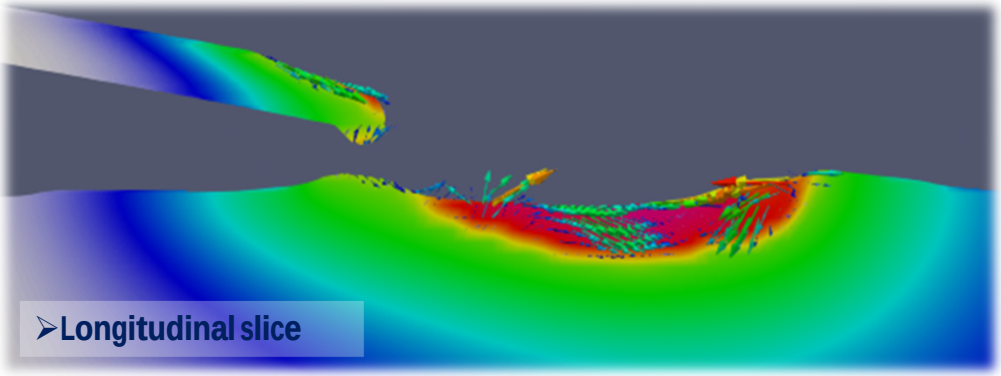
Detailed process model for studying microstructure transition

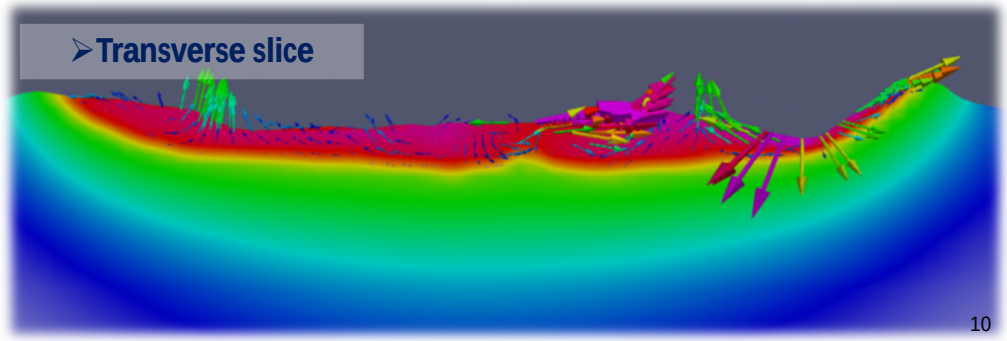
The EBSD results show that the CET (columnar-to-equiaxed transition) was achieved successfully in the WAAM process with increasing WFS from a low value to a high value.
The temperature distribution and melt pool shape with the five WFS considering the coupling effect of arc shading and metal transfer have been simulated and analysed. The calculated wire melting and metal transfer and melt pool cross-sections were consistent with the process images and measured bead cross-sections.
The simulation result showed that the steepness of the fusion line increased and the thermal gradient decreased with increasing WFS. Those variations of thermal conditions promote the CET process.
A novel CFD-CA coupling model has been developed to investigate the thermal behaviours of the melt pool and the evolution of microstructure to gain insight into the CET mechanism.

Study of configuration of wire

Wire feedstock is an essential factor in wire-based DED processes. Configuration of wire has been shown experimentally to significantly influence the process stability, deposition rate, and bead shape.
Based on our wire-feeding model, the effect of the filler wire shape (thin, thick, dual, round, flat) on the wire melting and melt pool dynamics was simulated and clarified numerically.
The effect of wire-feeding angle and direction on the process stability and bead shape was simulated. The best range of angle for the plasma-DED process and the mechanism of bead shape influenced significantly by the direction were proposed.
The effect of the dual-wire feeding configuration on the wire melting and metal transfer has been predicted, and the way to get the highest deposition rate was proposed numerically.







Modelling of mechanical work for w-DEDAM process

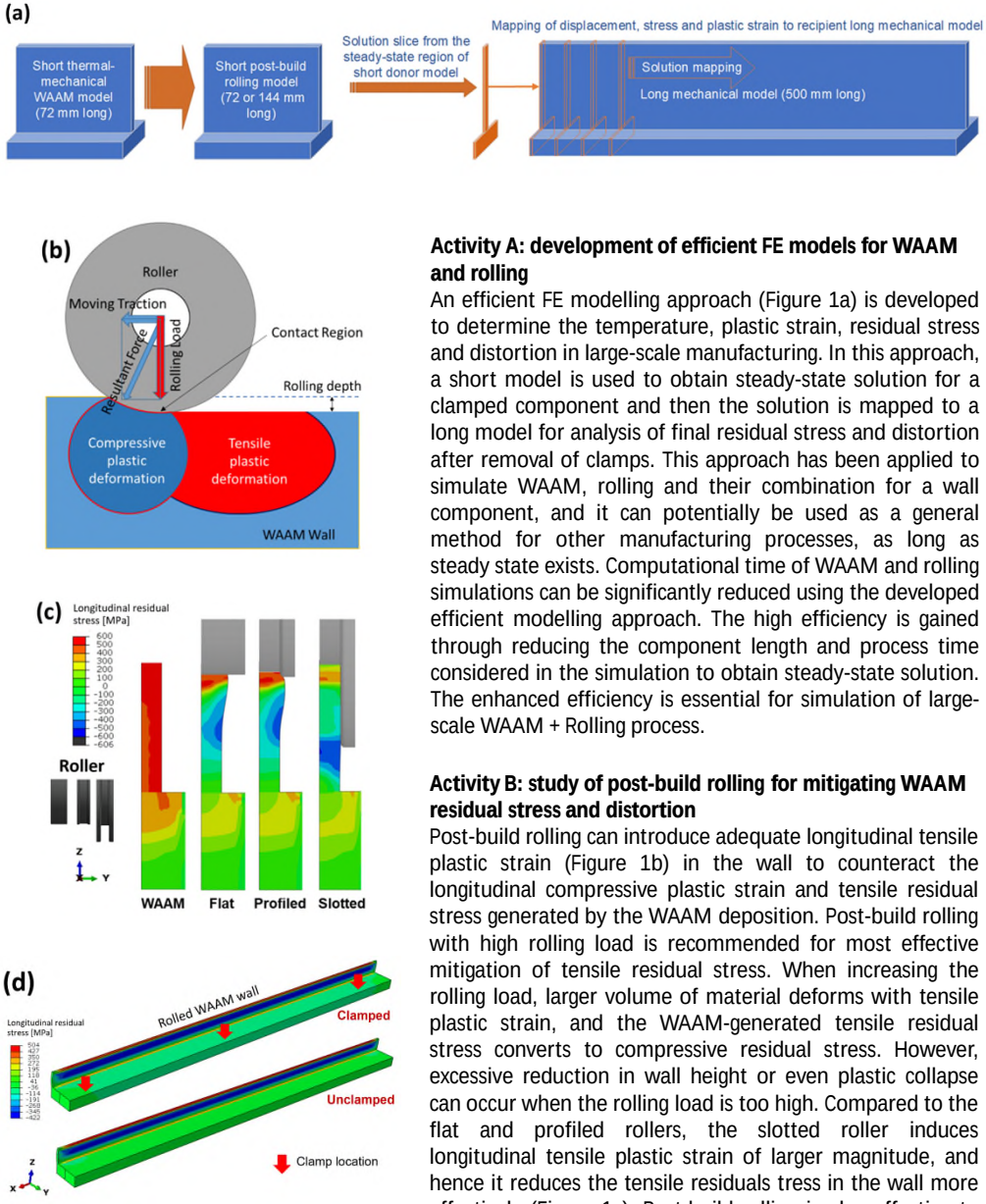


Figure 1: understanding and designing post-build rolling for wire arc additive manufacturing (WAAM)

Activity A: development of efficient FE models for WAAM and rolling

An efficient FE modelling approach (Figure 1a) is developed to determine the temperature, plastic strain, residual stress and distortion in large-scale manufacturing. In this approach, a short model is used to obtain steady-state solution for a clamped component and then the solution is mapped to a long model for analysis of final residual stress and distortion after removal of clamps. This approach has been applied to simulate WAAM, rolling and their combination for a wall component, and it can potentially be used as a general method for other manufacturing processes, as long as steady state exists. Computational time of WAAM and rolling simulations can be significantly reduced using the developed efficient modelling approach. The high efficiency is gained through reducing the component length and process time considered in the simulation to obtain steady-state solution. The enhanced efficiency is essential for simulation of large-scale WAAM + Rolling process.

Activity B: study of post-build rolling for mitigating WAAM residual stress and distortion

Post-build rolling can introduce adequate longitudinal tensile plastic strain (Figure 1b) in the wall to counteract the longitudinal compressive plastic strain and tensile residual stress generated by the WAAM deposition. Post-build rolling with high rolling load is recommended for most effective mitigation of tensile residual stress. When increasing the rolling load, larger volume of material deforms with tensile plastic strain, and the WAAM-generated tensile residual stress converts to compressive residual stress. However, excessive reduction in wall height or even plastic collapse can occur when the rolling load is too high. Compared to the flat and profiled rollers, the slotted roller induces longitudinal tensile plastic strain of larger magnitude, and hence it reduces the tensile residuals tress in the wall more effectively (Figure 1c). Post-build rolling is also effective to eliminate distortion in the WAAM component after removal of clamps (Figure 1d). This is because the WAAM residual stress in the clamped condition has been mitigated by rolling before unclamping (Figure 1c).

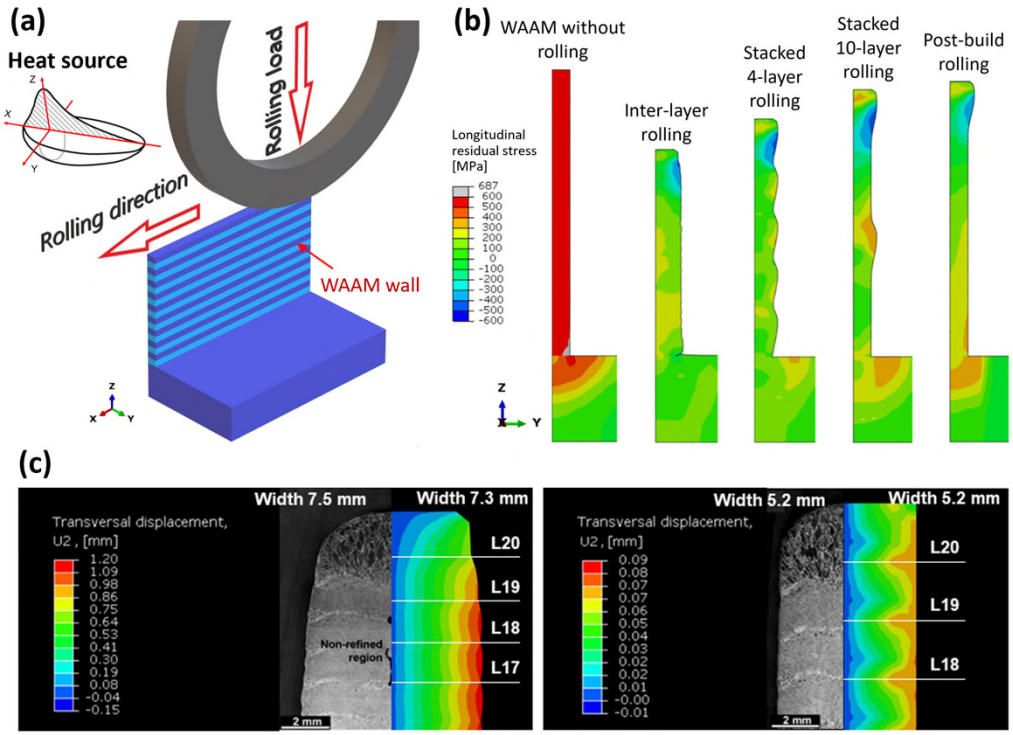


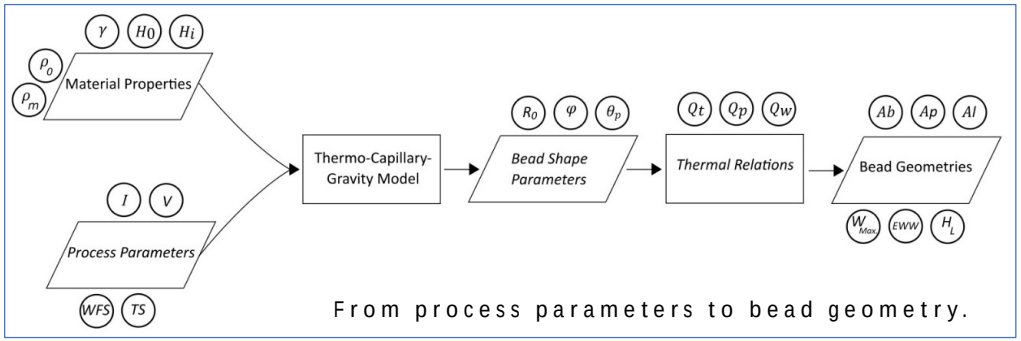
Figure 2: modelling and optimising hybrid process of wire arc additive manufacturing and high-pressure rolling

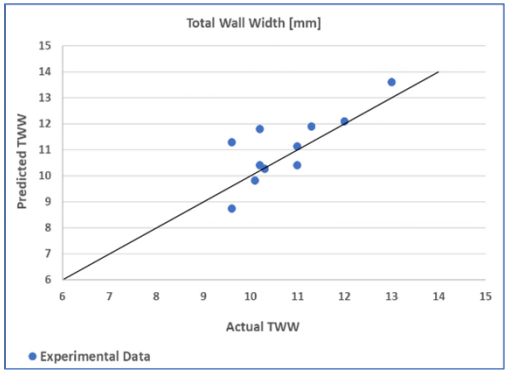
Activity C: investigation of the interaction between WAAM deposition and rolling

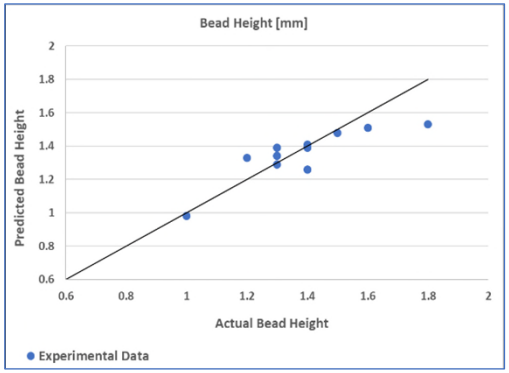
A coupled process model is developed for simulating the inter-layer rolling during WAAM deposition (Figure 2a). The predicted residual stress distribution (Figure 2b) and wall dimension (Figure 2c) agree well with experimental results. The process influence depth is manifested as the reaching depth of the plastic flow induced by the deposition or rolling of each layer. The greater the influence depth, the more extensive the effect of the process on the residual stress. The inter-layer rolling with the flat roller has smaller influence depth compared to the deposition. Therefore, the rolling mainly reduces the degree of the re-formation of the WAAM tensile residual stress during the consecutive deposition of layers. Thanks to the lateral restraint, the rolling with the slotted roller promotes more longitudinal tensile plastic deformation, despite its similar influence depth to the deposition. Consequently, the slotted roller reduces the WAAM tensile residual stress more significantly than the flat roller, and it also produces compressive residual stress more extensively.

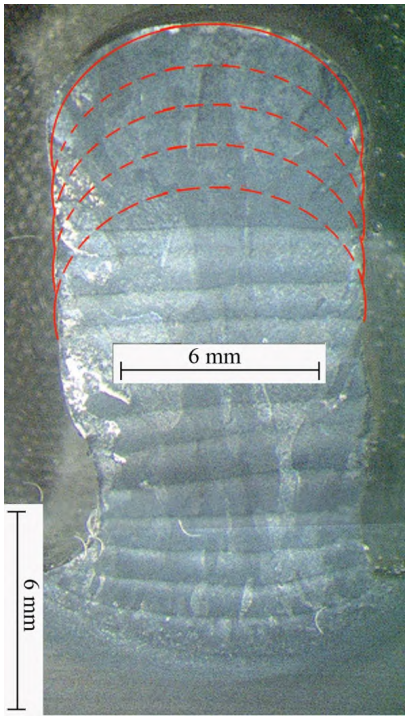
Activity D: optimisation of the hybrid process combining WAAM and rolling

Stacked-layers rolling can be used as an alternative to inter-layer rolling to reduce the manufacturing time (Figure 2b). The stacked-four-layer rolling process is implemented with fewer rolling operations than the inter-layer rolling. Fortunately, it has larger influence depth than the deposition and thereby leads to longitudinal residual stress distributions similar to those produced by the inter-layer rolling. The stacked-layers rolling with slotted roller is highly effective and has additional benefits such as marginal change of wall dimensions and low surface roughness, and hence it is potentially optimal for the hybrid process. Post-build rolling has relatively large influence depth, but it is not as effective as the inter-layer and stacked-layers rolling to reduce the residual stress in the whole WAAM wall studied here, since the penetration is insufficient for a tall wall. Nevertheless, it could be efficiently applied to lower height WAAM components.









Bi-directional analytical model for efficient bead geometry prediction

Controlling the bead geometry with accurate process parameters is critical to achieve good deposition quality of w-DEDAM. A thermo-capillary-gravity bi-directional model has been developed based on thermo-physical relations for efficient prediction of bead geometries of w-DED). In the forward algorithm, the bead geometry can be predicted by taking the process parameters and material properties as input; while in the reversed algorithm the process parameters can be obtained as output to achieve the required bead geometry.

This bi-directional model has been validated by the w-DEDAM process with different energy sources, such as PTA, cw-Mig and laser. Different materials were used, including mild steel, 316 stainless steel, and Ti64. All validation experiments achieved good accuracy, with most errors below 10% for both forward and backward predictions.

Compared to numerical models based on FE or CFD, this model is more efficient and can provide prediction results in seconds. Compared to pure data-driven models, this model is more reliable and does not require large number of experimental trials to provide the data needed for model training. Furthermore, since it is based on well-defined physical relationships, the model can be easily transferred to predict different processes and materials. This work is being extended to include more complicated build strategies and the effect of thermal mass variations due to local geometries.

Research area leader:
Dr Jialuo Ding

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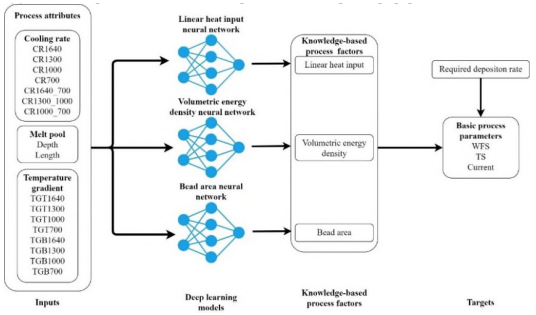
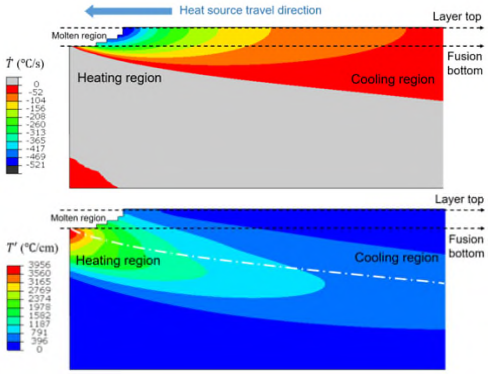
Knowledge-based bi-directional model

A knowledge-based model has been developed which combines both physics-based model and data-driven model. The target of this model is to provide bi-directional predictions with more complicated data, such as thermal information. A 'knowledge-based process factor' layer is added which converts the basic process parameters to process fundamental parameters based on the physical relationships and process knowledge. Artificial neural network (ANN) was used with training data sets obtain from both experimental trials as well as numerical simulations.



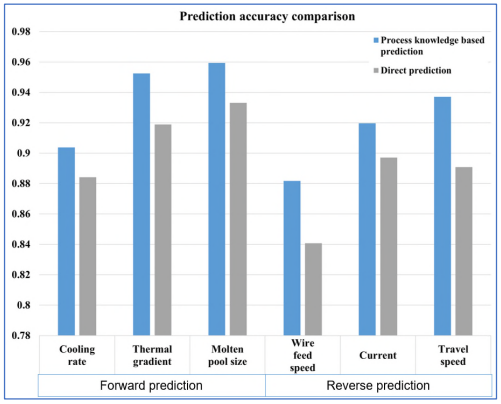


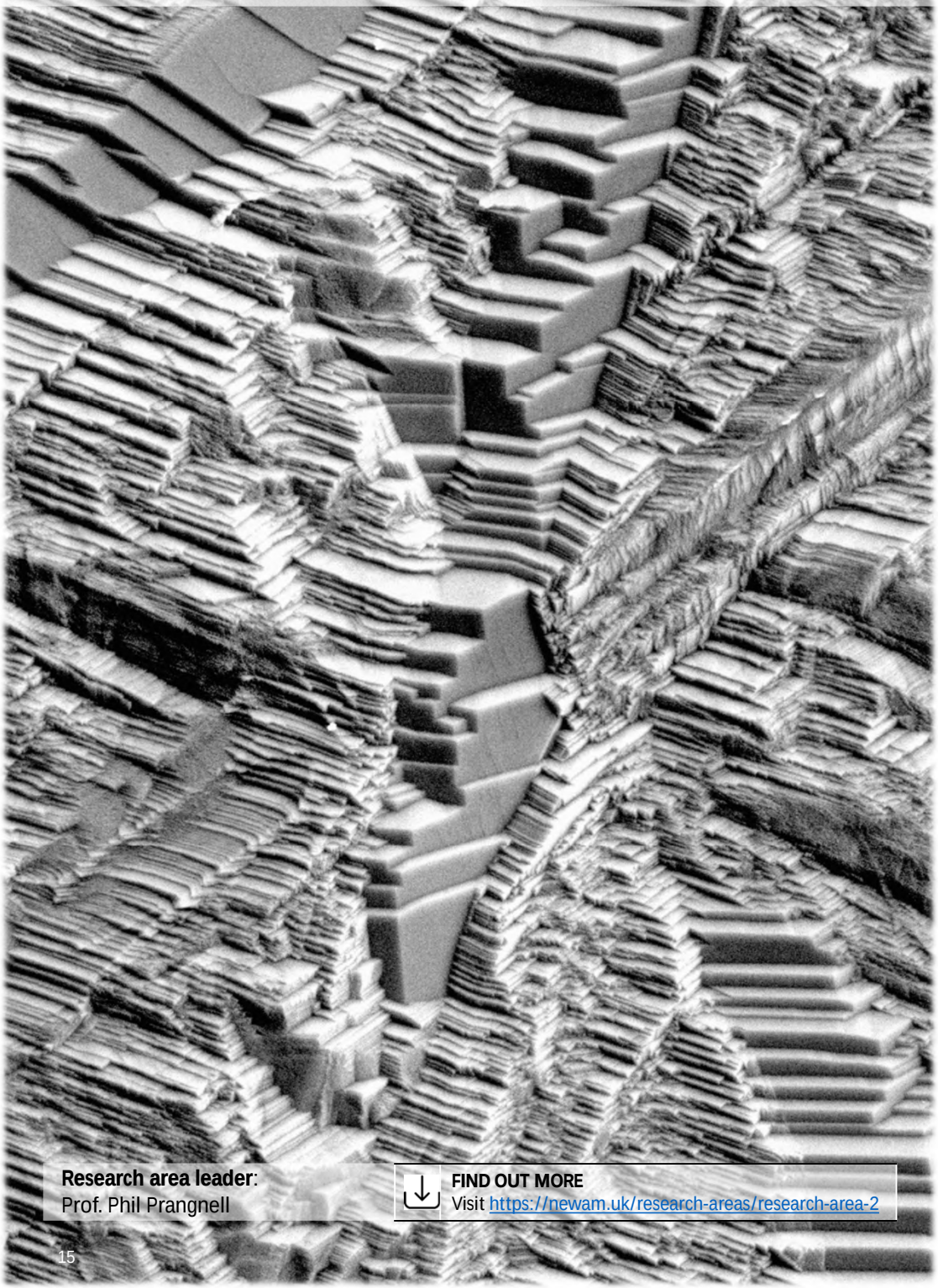
Use FE thermal predictions for model training

Thermal information is very important for microstructures and material performances of the deposited materials. Computational models are widely used for the predictions of the thermal field for AM process. However, they cannot provide a reversed prediction to suggest process parameters for the required thermal fields. In this study, a steady-state thermal FE model was used to provide training data sets of thermal process attributes, including cooing rate, temperature gradient and melt pool size.

Good accuracy was achieved for both forward and backward predictions

Overall, this model achieved good prediction accuracy. Especially, the added layer which contains process knowledge, was proved to improve the accuracy of the predictions significantly. This model achieved reliable performance with a high accuracy of above 90% for forward predictions and above 88% for backward predictions. The framework of this model can be extended as a key element of the MES designer.





Research area leader:
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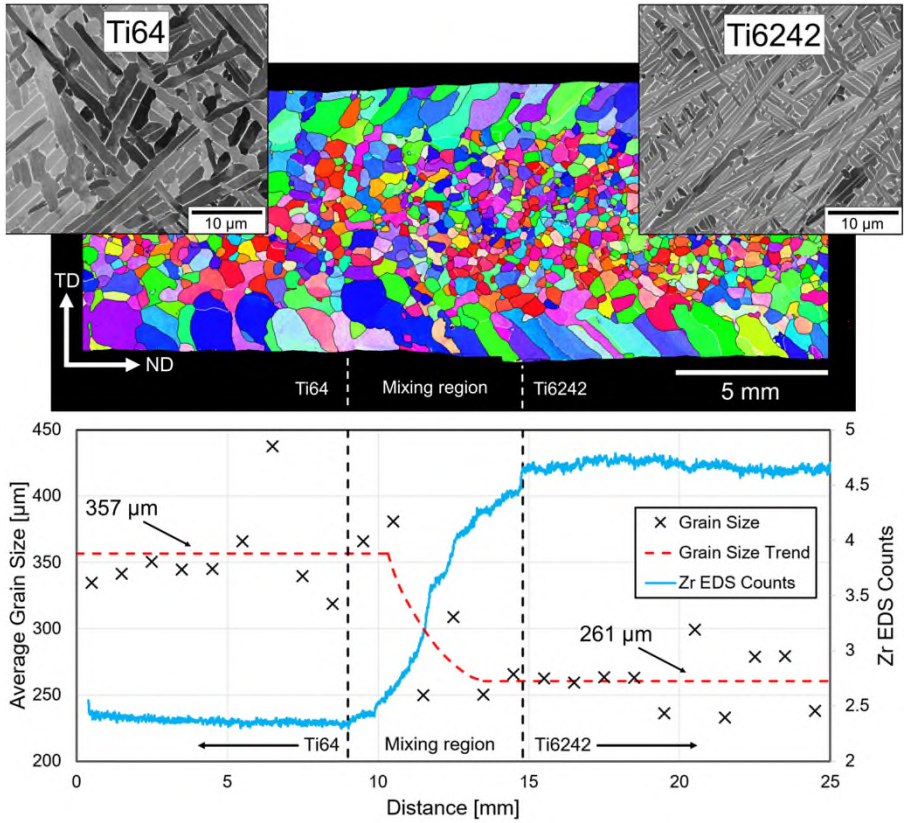
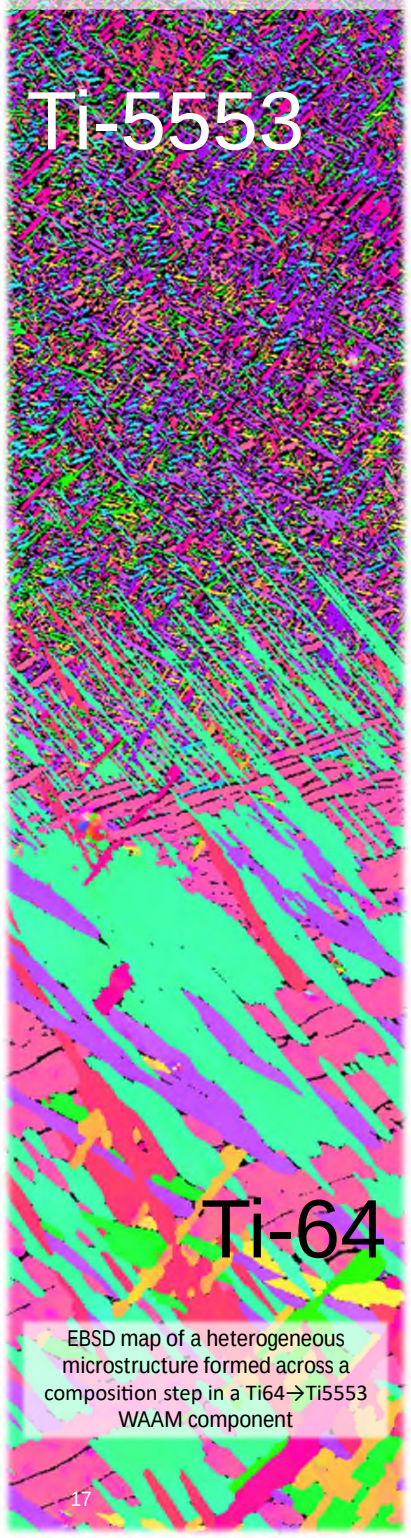


β-reconstruction EBSD map of the Ti64→Ti6242 WAAM build (top) and β-grain size plot (bottom)

Microstructure Refinement in WAAM by Intelligent Alloy Design

Thanks to the significant process innovations developed by the NEWAM consortium, **α+β titanium alloys, like Ti-6Al-4V (Ti64), can now be deposited using WAAM with refined β-grain structures.** This eliminates the mechanical anisotropy and associated risk produced by the coarse and columnar grain structures that afflicted AM components in the past. However, there are additional property improvements to be gained from an even more refined β-grain size. This is difficult to improve further only through better process control, but additional benefits can be achieved by metallurgically 'informed' alloy selection. For example, in a pioneering study, we have compared the microstructure refinement that can be achieved in the commonly studied alloy Ti64 to the higher-temperature alloy Ti6242 (Ti-6Al-2Sn-4Zr-2Mo-0.1Si) when deposited on top of each other by WAAM, under identical process conditions, to create a composite test part. **The Ti6242 section exhibited a 25% reduction in β-grain size when compared to the Ti64** (shown above) due to the addition of the slower diffusing element molybdenum in Ti6242, which also partitions more strongly during solidification than V and Al, as well as providing greater solute drag on β-grain growth. In addition, the transformation microstructure in Ti6242 was found to be refined by 25% when compared to Ti64. This study thus demonstrates the potential property benefits of selecting alloys more suited to the WAAM process, which is being pursued in the project to recommend improvements to alloy design for WAAM.

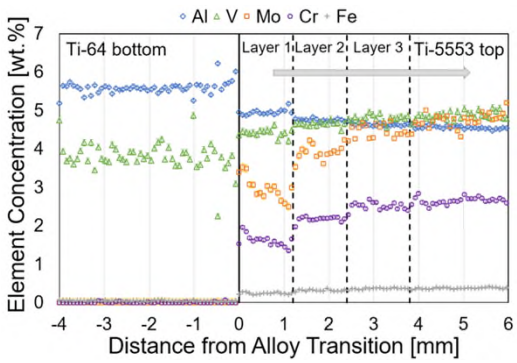


EBSD map of a heterogeneous microstructure formed across a composition step in a Ti64→Ti5553 WAAM component

Tailoring Properties in WAAM Components with Dissimilar Titanium Alloys

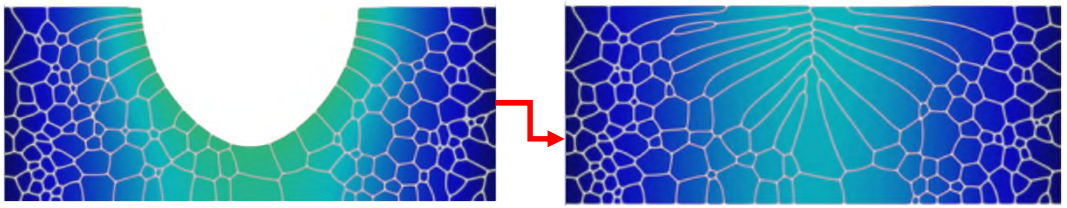
The focus of WAAM to date has been largely to manufacture monolithic components with properties that match those of standard forged aerospace parts, produced by conventional methods. **NEWAM has now begun to investigate exploiting AM deposition further** - to print property-tailored titanium components, where the wire feed is switched in-situ, to print specific alloys in different part locations. Ultimately, **this will allow more efficient components to be intelligently designed with site-specific properties**. In an initial study, the metastable β alloy Ti-5Al-5V-5Mo-3Cr was printed on top of Ti-6Al-4V with WAAM, to create a high strength → high damage tolerant property pairing. This research showed that, due to efficient melt pool mixing in WAAM, a stepped composition and microstructure gradient was produced between the two dissimilar alloys, that could be reliably controlled by altering the dilution ratio. **When combined with NEWAM process development led by key modelling techniques, transition gradients between regions with different properties can therefore be intelligently designed to achieve specific performance targets.**

The controlled stepped composition (below) and microstructure gradient (left) achieved in a Ti64→Ti5553 WAAM demonstrator

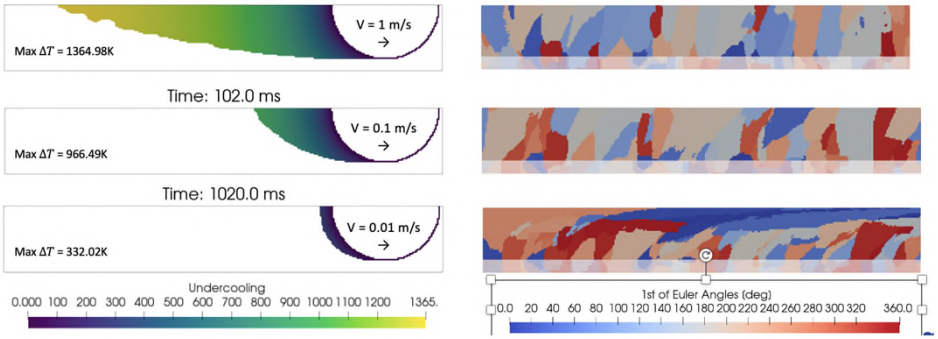


Multi-scale Materials Modelling

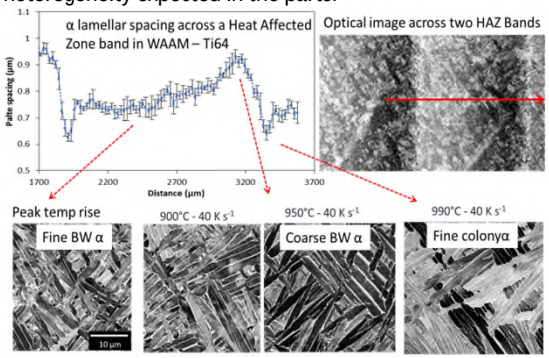
An array of modelling frameworks have been developed, across a range of fidelities, in the **NEWAM** programme. High fidelity Multi-Phase Multi-Component phase field frameworks that describe the microstructural evolution in terms of fundamental thermodynamics and physics, are being used to tease out the microstructural evolution driving forces related to the **WAAM** processes in a manner not possible with lower fidelity approaches.

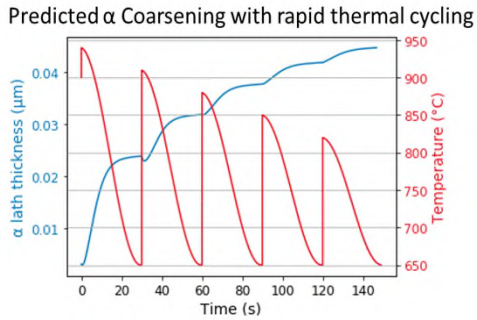


These high-fidelity approaches give us an incredible amount of detail. However, they are not suitable for use at length scales greater than a few mm³, due to their high computational expense. Cellular automata models, informed by the fine scale models, have therefore been deployed that couple to the processing models that are used to simulate the heat and mass transfer in the **WAAM** processes. **These cellular automata methods allow us to predict the solidification-grain structures that are expected to form over the entire component length scale**.



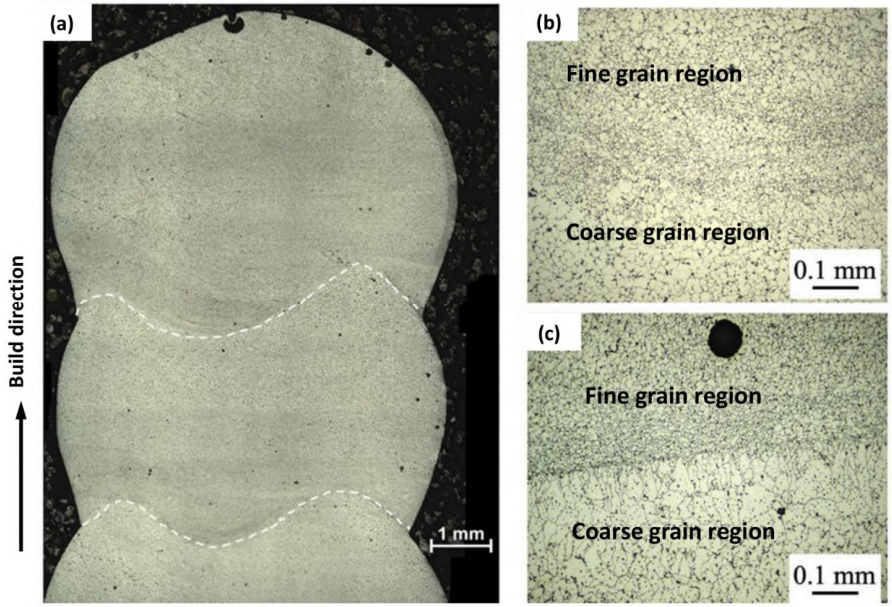
Furthermore, simpler fast mean-field descriptions of the solid-state β → α transitions in titanium alloys have been implemented; such as the KWN model, to describe the α lath spacing as a function of the complex cyclic thermal histories observed at any given point in a build. These mean field approaches are useful modelling tools for adapting processing parameters for controlling the thermal history of a build during building parts with complex geometries , as they are computationally cheap and provide rapid feedback on the scale and heterogeneity expected in the parts.



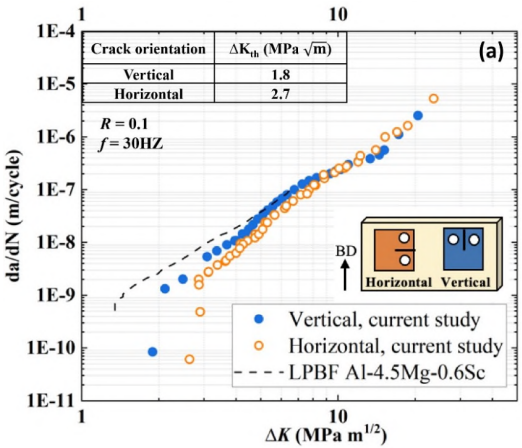


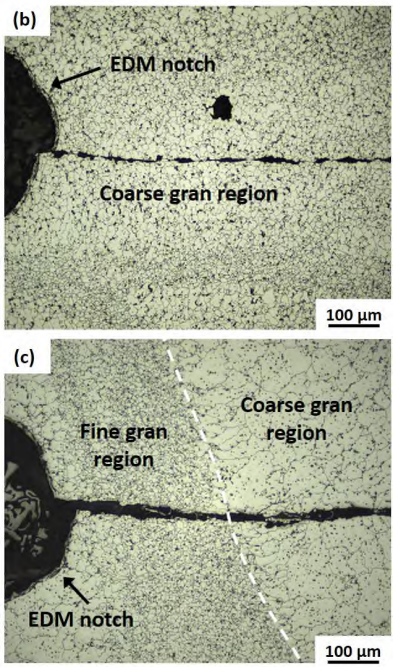
The modelling tools being developed in NEWAM will provide a means by which to quantitatively relate the processing conditions, alloy chemistry, and fundamental crystallographic information to the produced microstructures and, ultimately, the uniformity and material properties of the fabricated components.

WAAM of Al-Mg-Sc alloy for aerospace applications



Optical micrographs: (a) deposited layers, (b, c) microstructure heterogeneity manifested by alternating coarse and fine grains as a result of thermal cycles-





(a) Measured crack growth rate (d*a*/d*N*) versus applied stress intensity factor range (Δ*K*), and comparison with a laser powder bed fusion Al-Mg-Sc alloy. Crack path analysis showing (b) crack propagation through only coarser grain region (average grain size 40 µm) in horizontal crack samples and (c) crack going through regions of different grain sizes in vertical crack samples with grain sizes varying from 10 µm to 40 µm.

Fatigue crack growth testing was carried out on samples with crack either in *horizontal* or *vertical* orientation with respect to the material build direction. The horizontal crack samples showed lower crack growth rate compared to the vertical crack samples. Examination of the crack path revealed the horizontal crack propagating though a coarser grain region that resulted in crack path deviation at microscopic scale that led to lower crack growth rate (Fig. c). The vertical crack propagated through both fine and coarser grain regions, alternately, resulting in smoother crack path (little crack deviation), Fig. b; hence faster crack growth. Owing to its larger grain size, the WAAM alloy has lower crack growth rate than a similar alloy built by laser powder bed fusion (L-PBF) when the applied crack growth driving force ΔK is below 6 MPa $m^{1/2}$.

Representation of crack growth rate by the modified Hartman-Schijve equation

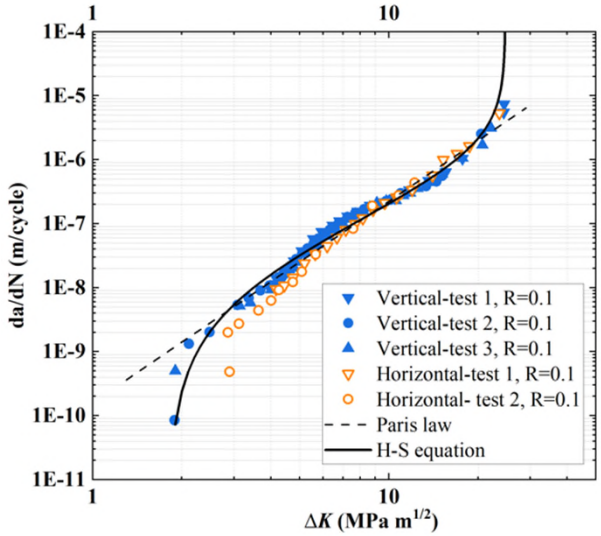
The Paris law was the first empirical relationship between the crack growth rate (d*a*/d*N*) and the stress intensity factor range (Δ*K*). However, it does not take account of the effect of the load ratio (or the mean load), nor the two extreme ends of the crack growth regions. New or modified equations have been developed over the past six decades to overcome these limitations. The Hartman-Schijve equation is one of them based on experimental testing of various aerospace aluminium alloys, eq (1).

$$\frac{da}{dN} = \frac{C(\Delta K - \Delta K_{th})^m}{(1-R)K_c - \Delta K}$$

where *C* and *m* are material constants, *R* the load ratio, ΔK_{th} the threshold stress intensity factor range, and *Kc* the fracture toughness. Later, a modified Hartman-Schijve equation was proposed, also referred as a variant of the NASGRO equation expressed by eq. (2)

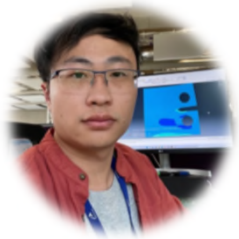
$$\frac{da}{dN} = D\left[\frac{\Delta K - \Delta K_{th}}{\sqrt{1 - K_{max}/A}}\right]^p$$

where *D* and *p* are material constants, *A* the cyclic fracture toughness, and ΔK_{th} the threshold stress intensity factor range



d*a*/d*N* vs. Δ*K*, and determination of the upper bound curve by modified Hartman-Schijve equation, eq. (2)

The modified Hartman-Schijve (H-S) equation can represent the experimental crack growth rates very well in all three regions, i.e., the near-threshold, the Paris law, and final fast crack growth. The generated curve represents the upper bound of the crack growth rate property that can provide a safe margin for damage tolerance design.

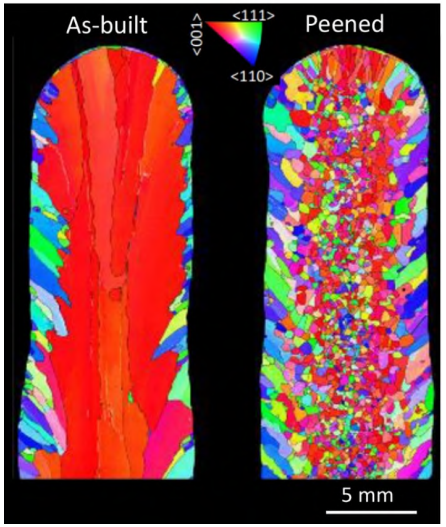


Jin Ye, PhD student, Coventry University

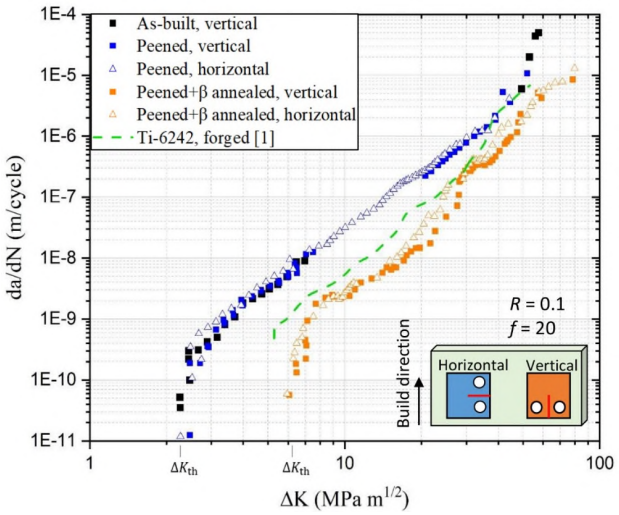
Microstructure printing to achieve desired mechanical properties

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. WAAM of Ti6242 results in solidification microstructures comprising large cm-scale, <001> fibre textured, columnar beta grains, which can cause mechanical property anisotropy and larger data scatter. In the NEWAM project 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. Samples were tested in three conditions: as-built, peened, and peened+β annealed.

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.



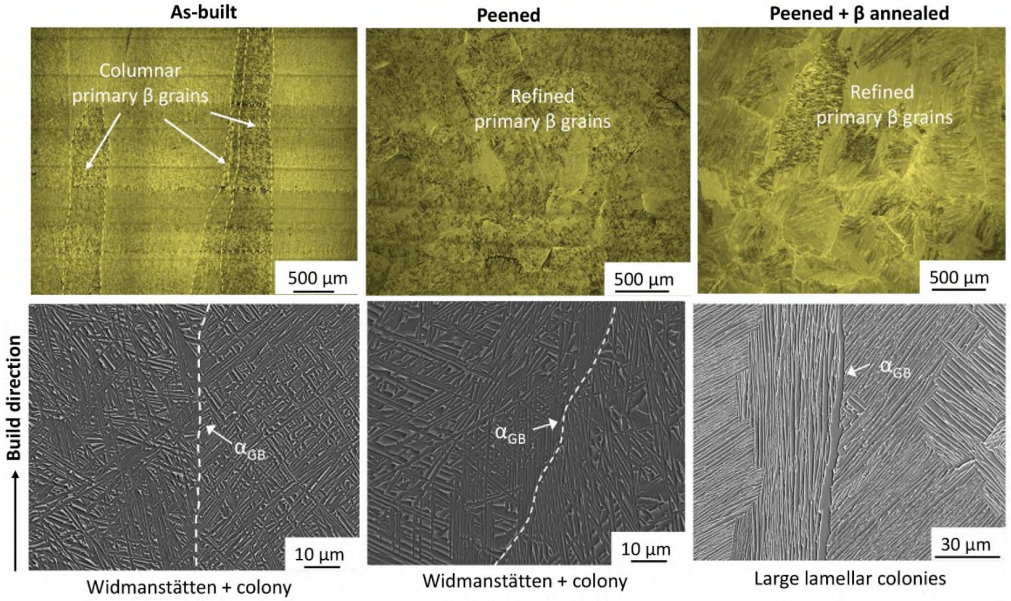
EBSD map showing grain refinement after peening an experimental build



Measured crack growth rate (d*a*/d*N*) versus applied stress intensity factor range (Δ*K*) and comparison with conventionally built forged material.

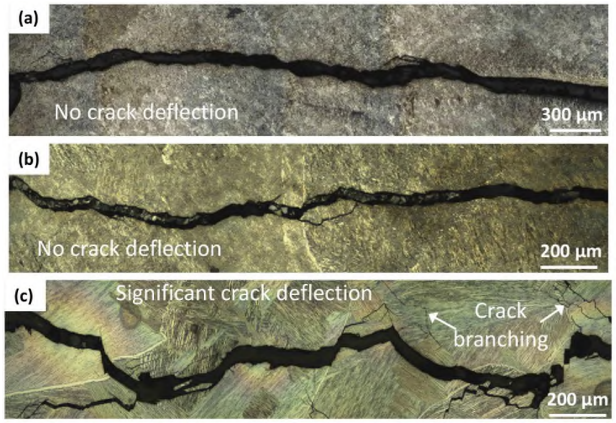
Fatigue crack growth testing shows: (a) the as-built and peened conditions had higher crack growth rate compared to conventionally built forged microstructure. (b) Peening + β annealing processing reduced crack growth rate significantly, by order of one magnitude.

Farhana Zakir,
PhD student,
Coventry University



Top: Optical micrographs of as-built, peened (refined primary β grains), and peened + β annealed microstructures. Bottom: SEM images showing the transformation microstructure in each condition.

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.



Optical micrographs of crack growth paths: (a) as-built, (b) peened, (c) peened + β annealed samples

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.

We have demonstrated the use of WAAM process and post process to produce microstructure that can deliver desirable mechanical properties.

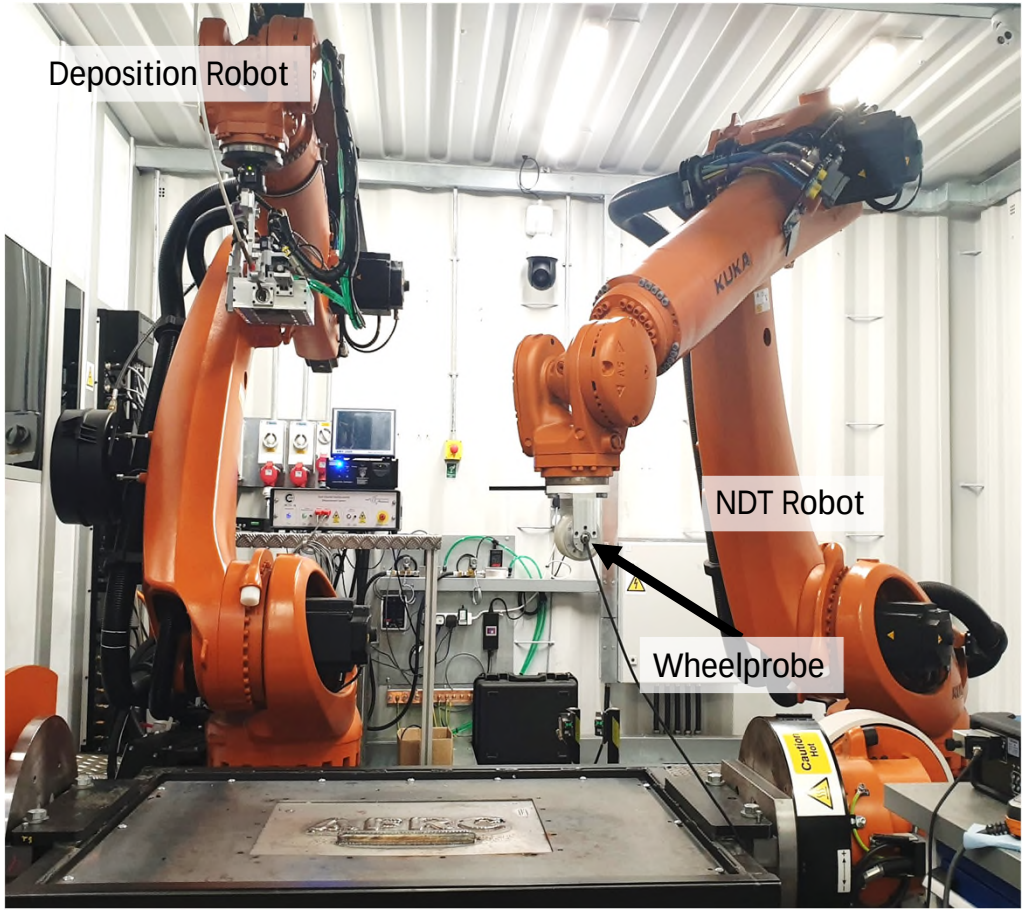
Research area leader:
Prof Xiang Zhang

FIND OUT MORE
Visit https://newam.uk/research-areas/research-area-3

Research area leader:
Prof Gareth Pierce

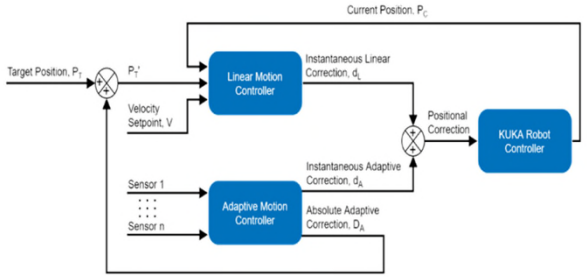
FIND OUT MORE
Visit https://newam.uk/research-areas/research-area-6

RoboWAAM cell with integrated NDT developed with Cranfield and WAAM3D



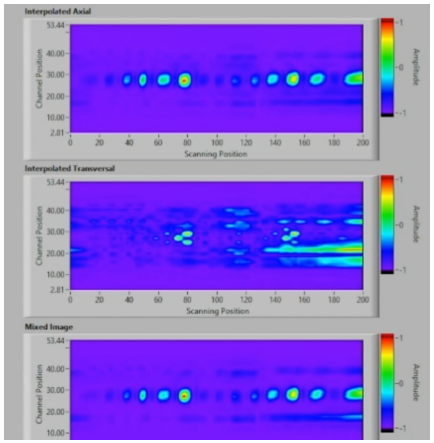
System Integration

Strathclyde's approach to system integration and robot control provides an integrated control interface to work with WAAM3D build software, allowing for a truly integrated solution for WAAM builds. Different NDT technologies can be used with this approach depending on the material, geometry and layer thickness.



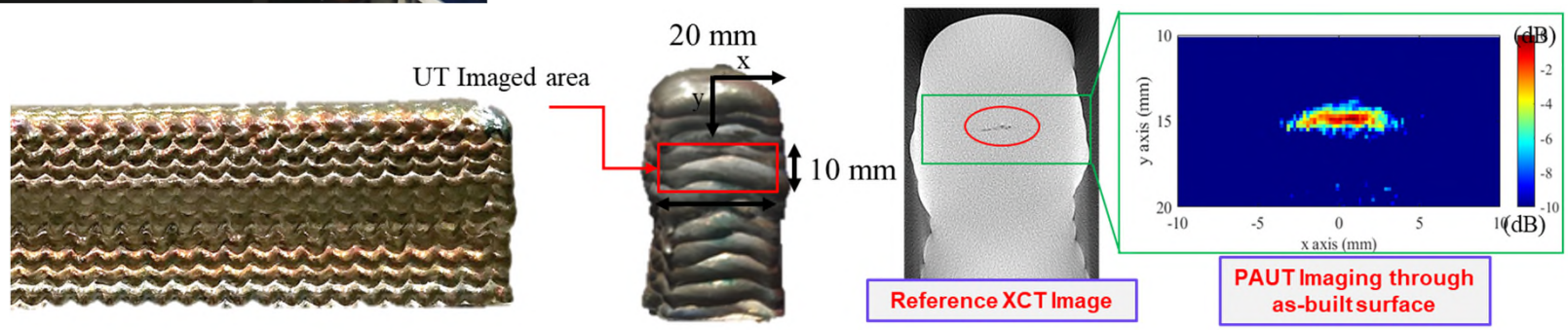
Eddy Current Inspection

An alternative NDT inspection capability using eddy current array imaging allows for near surface defect detection. The technique can be implemented in real time delivered from the NDT robot incorporated into the WAAM build cell.



Novel Ultrasonic (UT) Measurement

We developed a novel high temperature wheel probe allowing for advanced ultrasonic phased array (PAUT) volumetric imaging of WAAM components as they are built layer by layer. Our approach allows for compensation for surface curvature and temperature gradients in the material. Here we see PAUT imaging through the as-built surface of titanium component showing a volumetric build defect.

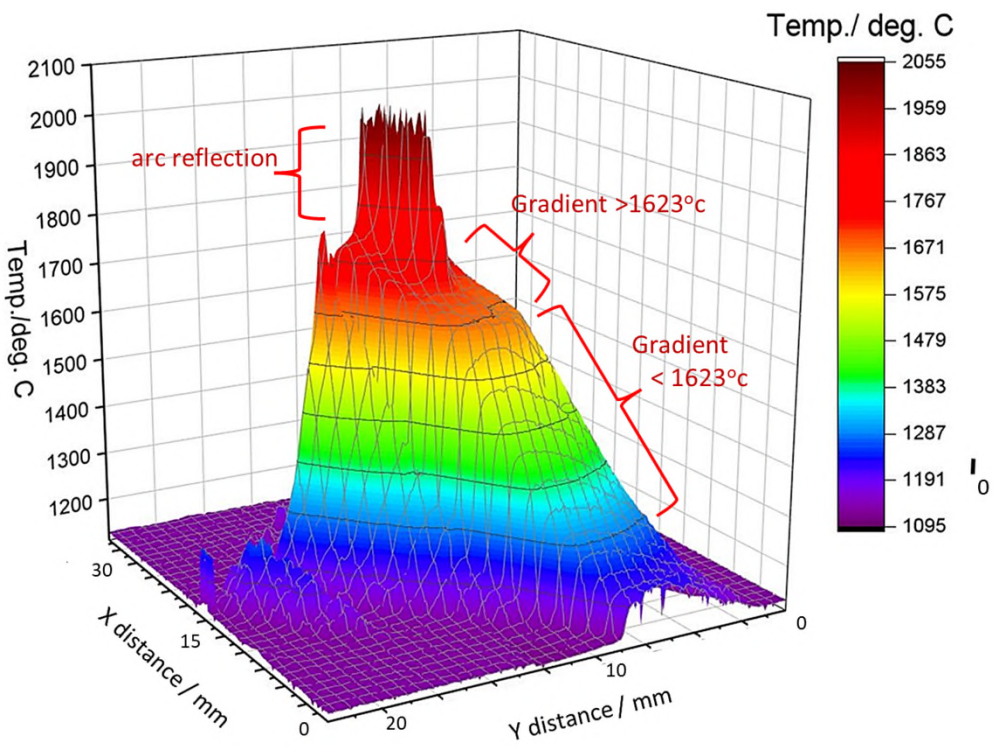


"Integrating in-process NDT into the WAAM process enables real time defect monitoring during build"

Words
Prof Gareth Pierce

Temperature – Rigid thermal camera

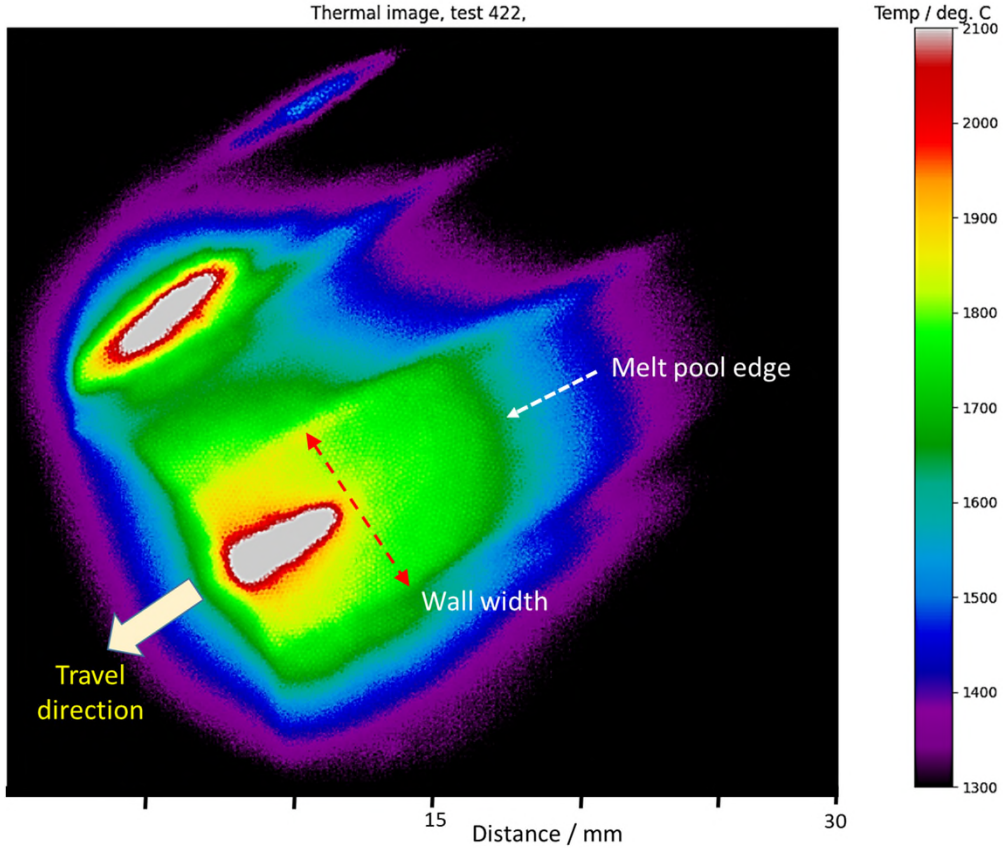
- Progress has been made measuring the thermal fields of WAM Ti64V melt pools.
- InGaAs & silicon cameras were used coupled to a rigid 6 mm diam. borescope operating in single wavelength mode.
- Measured thermal fields exhibit close correlation with thermal models and published material thermal properties.
- Images were recorded with a spatial resolution of < 100 µm.



Thermal image using borescope & InGaAs camera – Ti64V wall, 3D view

Temperature – Flexible thermal camera

- Progress has also been made measuring the thermal fields of melt pools using a **flexible multi-fibre bundle** with custom optics & low cost silicon camera operating in single wavelength mode.
- Allows optical head placement in locations with limited access e.g.. on robot end-effector. Bundle diameter is ~ 2mm.
- Measured thermal fields exhibit close correlation with thermal models and published material thermal properties.
- The fibre bundle type was selected to achieve a spatial resolution of < 200µm.



Thermal image using fibre bundle & silicon camera – Ti64V wall, plan view

Research area leader:
Prof Ralph Tatam

FIND OUT MORE
Visit https://newam.uk/research-areas/research-area-7

"We are now moving into a very exciting phase where we have some new innovative processes, extensive process and material modelling capability, a much higher level of understanding of how to achieve good properties and performance in materials, and the demonstration of the potential for the in-process NDT using a variety of techniques. To provide a focus for the remaining activities and to ensure that we will have a major impact of our research we have defined four demonstrators to be delivered before the end of the programme. These are based around the original challenges we identified and are as follows:"

D1	D2	D3	D4
In-process control of Ti64 microstructure with independent geometry and thermal control	AM with similar (or superior) durability or damage tolerance when compared to wrought materials	Q3 for high build rate with NDT	Multi-Energy Source AM with high build rate

"This has been a very challenging year of course but, as expected, the whole NEWAM team has risen to these challenges with great strides forward being made towards our programme's goals. Particular highlights for me include the validation of the multi-energy source concept, the first demonstration of robotic dry NDT for in-process inspection of AM components and real time shape measurement of deposited profiles.

Academically we have set the research team intermediate challenges to prove the much sought-after concept of integrated materials and process modelling, combined with innovative process development to obtain full control of material microstructure in as-deposited materials. Excellent progress is being made towards achieving this with all models developed and currently being validated. "

Words **Prof Stewart Williams**

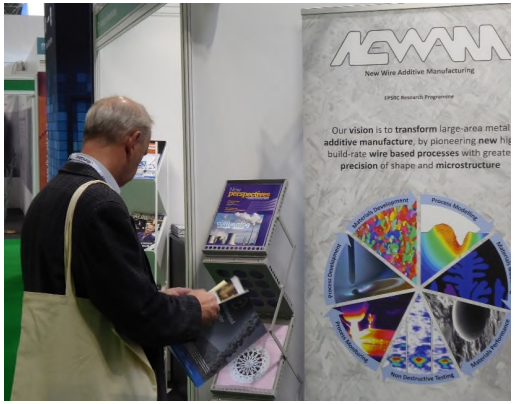
We are proud of our work and our achievements…

"We may achieve excellent results but if we don't share them with the others, they become meaningless"

Words **Dr Sónia Meco**

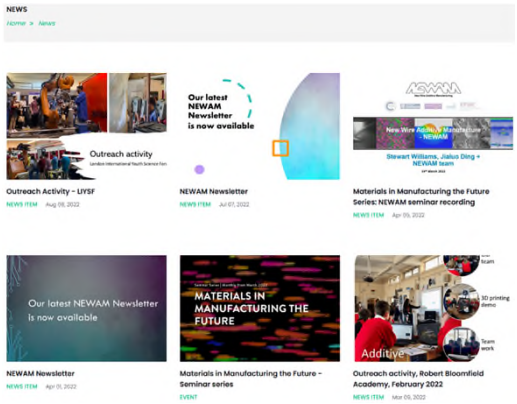
FIND OUT MORE
- https://newam.uk/news-events
- https://uk.linkedin.com/in/newam-epsrc-programme-grant-6617091a9

ENGAGEMENT WITH YOUNG GENERATIONS
This year we had the opportunity to interact with pupils aged 12-13 years old in a visit to a local school and also with teenagers from London International Youth Science Forum (LIYSF) coming from different parts of the globe with ages ranging between 16-21. During the talks and lab visit, the students learned about large scale Additive Manufacturing and the work that we do. No matter the age, they were all excited to talk to the researchers and PhD students, ask them questions about their work and their career choices.



EXHIBITING IN PUBLIC EVENTS
We have promoted the research programme in various public events: tradeshow events, shopping centre halls, TeenTech-Inspiring Tomorrow's Innovators, industrial conferences, etc. Since the beginning of the pandemic, our participation has significantly reduced but next year we are planning to exhibit our work at the TCT 3Sixty - 3D printing and additive manufacturing intelligence, in Birmingham. With more than 20k estimated visitors it is important to take this opportunity to disseminate the research outputs, such as the new processes, materials, tools, methods, and hopefully the portable wire-based arc and laser printers.

ONLINE PLATFORMS SPREADING THE WORD
We have been promoting the published papers, the outreach activities with schools, tradeshow events and conferences that we attend mainly via the NEWAM website, Linked-In and email.
The newsletter introduced last year is also an excellent tool to keep the industrial partners, and others, informed of the progress of the research programme, news about the team and outreach events. The newsletters are released every quarter via the online platforms above indicated aiming to reach a wide audience.



FIND OUT MORE
Visit https://newam.uk/team

Results from the anonymous team survey

"It is great experience to work as a member of the NEWAM team tackling the grand research challenges."

"A meeting or event for PhD students would be good to promote teamwork at that level."

"Perfect experiences in working in this research programme."

"Interesting and well-designed research program."

"Good connection between team members and other teams. Consortium meetings help to get updates, talking in-person and I think the results of this project would be a big step in upgrading direct energy deposition process in many aspects."

"I think the online bonding activities we had (during the pandemic) were great, and it is a shame that we cannot have them now, as some of the team members cannot attend all the consortium meetings and so are left out of the group."

"Fantastic"

"Not much interaction happens between most members in between the consortiums. Anyway, its not a big concern as the members are approachable through emails."

"It has been amazing to be part of the NEWAM research program, especially the integration with different people and institutions."

"A super project I work for. Excellent colleagues and everyone supports each other."

"There is always room for improvement that is why we hear our team!"

Words **Dr Sónia Meco**

Axe throwing game

Visit to the Transport Museum

More than words...
There has been many occasions for the team to get together and get to know each other. But... we can still do better. Next year more opportunities will come!

Consortium dinner

"Perhaps the most satisfying aspect of NEWAM so far is that four research teams, based at four Universities, are now fully integrated and working in a highly collaborative way. This is leading to the whole being much greater than the sum of the parts. I believe this is a major achievement which the whole team should be proud of."

Words **Prof Stewart Williams**

A N Jinoop
Abdul Khadar Syed
Alec Davis
Alireza M Haghighi
Amir Zadehkabir
Anne Fiorucci
Armando Caballero
Bilal Ahmed
Charles MacLeod
Chong Wang
Daniel Dreelan
David Rico Sierra
Ed Pickering
Ehsan Mohseni
Eloise Eimer
Euan Foster
Farhana Zakir
Gareth Pierce
Geo Davis
Goncalo Pardal
Guangyu Chen
James Wainwright
Jialuo Ding
Jian Qin
Jin Ye
Joao Bento
Jonathan Hallam
Jonathan Singh
Joseph Robson
June Wang
Katy Tant
Kevin Mullaney
Kuladeep Rajamudili
Martin McInnes
Momchil Vasilev
Muhammad Rizman
Nina Binaei
Nina Sweeney
Panos Kamintais
Phil Prangnell
Pradeeptta Taraphdar
Pratheek Shanthraj
Anthony Gachagan
Michael Fitzpatrick
Ralph Tatam
Randika Vithanage
Rastislav Zimermann
Robin James
Romali Biswal
Rongdong Qu
Rory Hulse
Sónia Meco
Stewart Williams
Sumana Sumana
Teti Stratoudaki
Thomas Flint
Veeramanikandan Selvakumar
Vijayavarman Chakkravarthy
Vivek Sahu
Wojciech Suder
Xiang Zhang
Xin Chen
Yashar Javadi
Yongle Sun