Experimental report

29/10/2018

Proposal:	**1-02-222**	**Council:**	4/2017
Title:	Material anisotropy in additive manufactured nickel-based superalloy and its effect on macroscale behaviour		
Research area:	Engineering		

This proposal is a new proposal

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Samples: Inconel 718

Instrument	Requested days	Allocated days	From	To
SALSA	7	4	16/04/2018	20/04/2018

Abstract:

This experiment will investigate the relationship between microstructure and macro-scale mechanical properties of an additive-manufactured nickel-based superalloy. We will use SALSA to observe neutron scattering from single crystallites close to the crack tip in differently-oriented fracture specimens of additively-manufactured material. Digital image correlation will be used to track these crystallites as the specimens are loaded, and to measure total strain at the surface of the specimens. Using these measurements of elastic and total strain we will determine how the fracture process interacts with the inhomogeneous grain structure of this material.

Material anisotropy in additively manufactured nickel-based superalloy and its effect on macroscale behaviour

Report for experiment number 181-1-02-222

Experimental team: Harry E. Coules, Cui E. Seow, Molly Probert

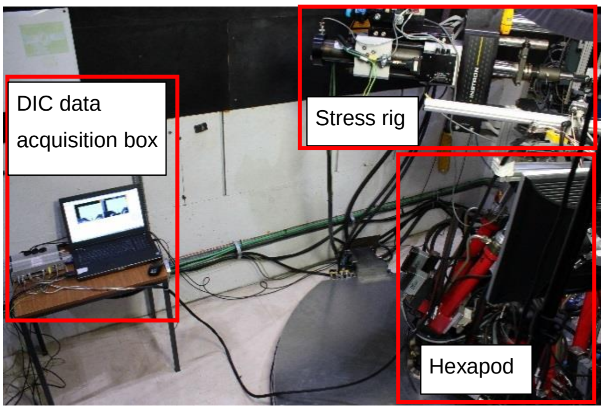
1 Scientific background

Wire and Arc Additive Manufacturing (WAAM) is a technique which uses a wire feedstock and a welding arc to simultaneously melt and deposit material in successive layers, into a desired 3D shape. The main advantages of WAAM are (i) high deposition rates [1], which enables large components to be built within reasonable lead times; and (ii) near net-shape geometry, which reduces machining operations and hence material wastage, in comparison to more traditional manufacturing processes of casting and forging. However, the process causes the part to undergo complex thermal cycling, which can lead to epitaxial grain growth and hence anisotropic material properties [2], [3]. At present it is unclear (i) to what extent macroscale properties are affected by microstructural anisotropy and (ii) if existing structural integrity assessment methods are suitable for the assessment of WAAM components. The aim of this experiment is to investigate how microstructural anisotropy affects the evolution of stress and strain during an elastic plastic fracture event. The material used in this experiment is nickel-base superalloy Inconel (IN) 718, manufactured using WAAM. The results will be compared against (i) detailed microstructural analysis of the deformed specimens, (ii) fracture toughness measurements, and (iii) surface strain distribution measured using Digital Image Correlation (DIC).

2 Methodology

Two compact tension (C(T)) specimens were extracted from a WAAM IN718 wall. They were notched and pre-cracked with different orientations with respect to the build direction of the wall, parallel and perpendicular, herein referred to as Crack PAR and PER respectively. In this experiment, they were both loaded to a maximum load-line displacement (LLD) of 4 mm, using the 50 kN Instron stress rig available on SALSA. The LLD was measured using a clip gauge. In parallel, two Digital Image Correlation (DIC) cameras were used to observe the surface (total) strain of the specimens. Photographs of the setup are shown in Figure 1.

(a)



(b)

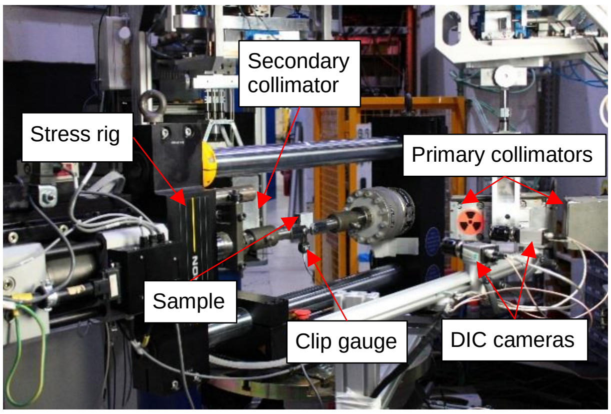


Figure 1: Photographs of experimental setup on SALSA showing in (a) the stress rig secured to the hexapod, and DIC data acquisition tools, and (b) the sample and clevis grips in the stress rig positioned between the collimators, DIC cameras mounted facing the surface of the sample, secured to the hexapod.

Due to the coarse grain microstructure of WAAM IN718 material, not every part of the specimen contained grains which scattered off the {200} reflection in the crack transverse direction. Therefore, a preliminary scan was used to search for suitable scattering grains. A measurement grid about the crack tip, containing 380 points spaced 1 mm apart, was set up at three different through thickness directions (at the mid-plane and ± 5 mm). Fixed time measurements of 30 s were made, and the resulting intensity of each point was used to determine the points with scattering grains. Figure 2 shows plots of intensity (in terms of number of counts) in real space. Points with more than 180 counts were deemed to be suitable for the refined measurement grid. Reference measurements were taken before loading. Subsequently each specimen was loaded up in several loading steps and measurements were taken at 5 points during the loading regime (Figure 3a). During each loading step, list-mode measurements were also taken at one of the points in the refined grid. To avoid pseudo-strain effects due to large crystallites moving with respect to the gauge volume during loading, DIC was used to track the surface positions of the measurement points and the corresponding displacement after each loading step was applied. This method is described in more detail in the experimental report for INTER 364. All neutron measurements were made with an incoming neutron wavelength of 1.61 Å and a gauge volume of 2x2x2 mm^3.

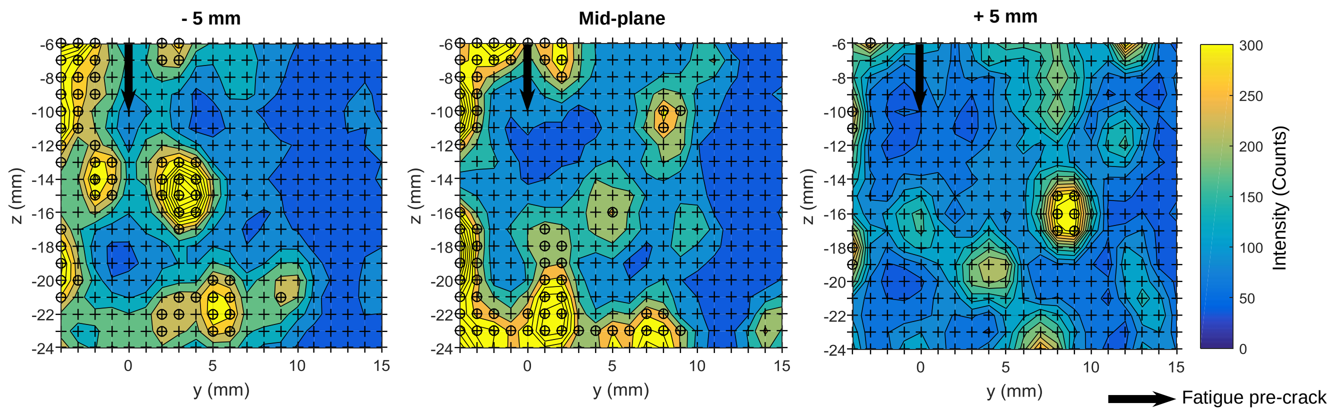


Figure 2: Plots of intensity in real space, with respect to hexapod coordinates, showing areas of grid with scattering grains in strain direction of interest, for specimen Crack PER. Circled points represent selected points for grid measurement.

3 Preliminary Results and Further Work

Load-displacement curves Figure 3a of both specimens are different, but this may be because the specimens had different initial crack lengths. These graphs will be normalised using measurements of fracture toughness for this material to get a better comparison between the two orientations.

DIC strain maps (Figure 3b) show that the crack tip plastic zone is different for the two specimens. This could be due to the specific microstructure at the crack tip. In the Crack PER specimen, the crack tip plastic zone is slightly asymmetrical. This indicates that there might be uneven load shedding between the grains at the crack tip.

Further to this, a crystal plasticity finite element model will be used to predict the strains in regions where measurements were not possible. This will give us more information about the strain field around the crack tip. A detailed microstructural analysis will also be used to correlate the effects of microstructure. We are working with the instrument scientists on the treatment of the list-mode scan data.

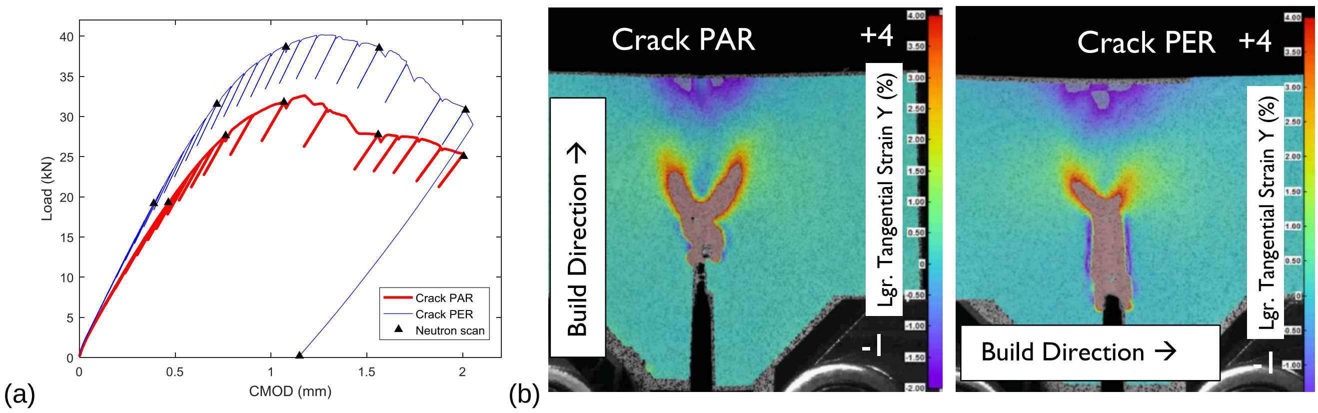


Figure 3: (a) Plot of load against CMOD for both specimens, showing where (in the loading regime) neutron scans were conducted. (b) Total surface strain maps of both specimens measured with DIC.

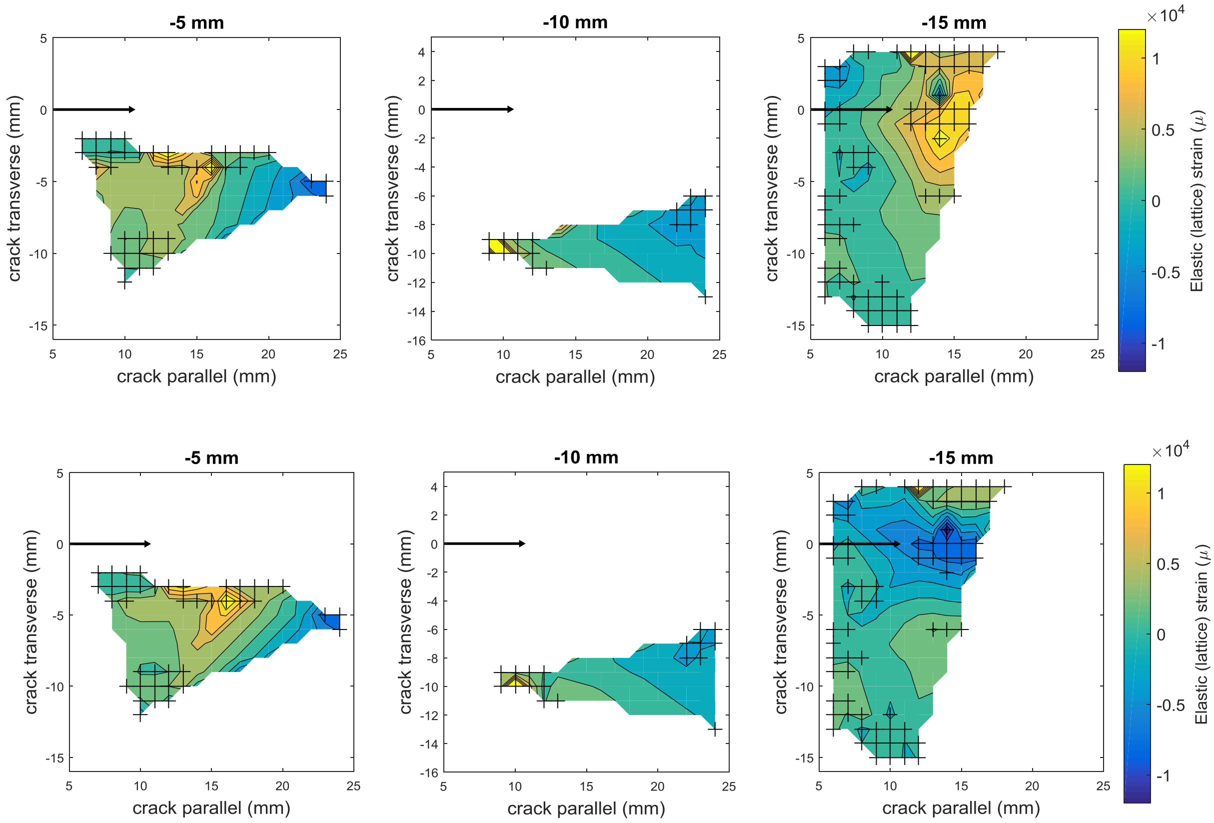


Figure 4: Elastic (lattice) strain maps for loading step 3 and 4 for Crack PAR specimen showing progression of crack through specimen.

[1] S. W. Williams, F. Martina, A. C. Addison, J. Ding, G. Pardal, and P. Colegrove, “Wire + arc additive manufacturing,” *Mater. Sci. Technol.*, vol. 32, no. 7, pp. 641–647, 2016.

[2] F. Martina, P. A. Colegrove, S. W. Williams, and J. Meyer, “Microstructure of Interpass Rolled Wire + Arc Additive Manufacturing Ti-6Al-4V Components,” *Metall. Mater. Trans. A Phys. Metall. Mater. Sci.*, vol. 46, no. 12, pp. 6103–6118, Dec. 2015.

[3] F. Wang, S. Williams, P. Colegrove, and A. A. Antonysamy, “Microstructure and mechanical properties of wire and arc additive manufactured Ti-6Al-4V,” *Metall. Mater. Trans. A*, vol. 44, no. 2, pp. 968–977, 2013.