Experimental report

24/08/2022

Proposal:	**1-04-191**	**Council:**	4/2020
Title:	Residual stress in dissimilar metal joints fabricated through both arc welding and powder metallurgy hotisostatic pressing		
Research area:	Engineering		

This proposal is a new proposal

Main proposer:	**lee AUCOTT**
Experimental team:	lee AUCOTT
Local contacts:	Thilo PIRLING

Samples: Welded steel pipe
HIPed steel pipe

Instrument	Requested days	Allocated days	From	To
SALSA	6	2	29/01/2021	03/02/2021

Abstract:

The United Kingdom Atomic Energy Authority (UKAEA) is carrying out research into nuclear fusion as a future source of clean energy. Fusion reactors are fabricated using an array of joining process. Future fusion reactors will require the joining of many dissimilar metals. Powder Metallurgy Hot Isostatic Pressing (PM-HIP) is an emerging technology capable of near net shape joining of dissimilar metals in a single process step. Unlike arc welding, PM-HIP is a solid-state process which consolidates powder through deformation and joins the powder particles via diffusion bonding. UKAEA are developing this process for fusion relevant steels. One of the key benefits this process theoretically offers is the removal of residual manufacturing stresses which are unavoidable in arc welding. Whilst this is theoretically sound, to the best of our knowledge, it is so far unproven in previous literature. Hence, the aim of this study is to measure and then compare residual stress in dissimilar metal (P91-SS316L) joints fabricated through both arc welding and a PM-HIP manufacture using neutron diffraction.

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Introduction

The aim of this experiment was to measure the residual stresses of two heterogenous P91-316LN joints using neutron diffraction. One was made via an arc welding process, and one was made with a Powder-Metallurgy Hot Isostatic Pressing (PM-HIPing) process. The residual stresses present in these joints will eventually be compared to confirm whether PM-HIPing produces a heterogenous joint with lower residual stress.

Samples

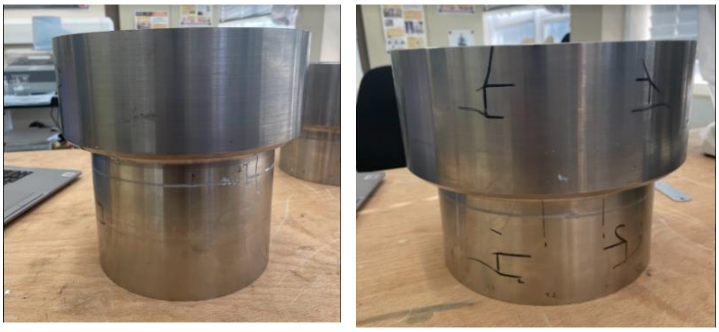

Figure 1: photos of arc-welded (left) and HIPed (right) pipe joint demonstrators

Experimental Approach

Several points across the joint were chosen to be analysed via neutron diffraction. The points furthest into the parent materials were chosen to characterise the residual stresses in the bulk material. The points at and immediately adjacent to the joint were chosen to capture any change in residual stress occurring through the joint. In this area, the analysed areas overlap to ensure a thorough analysis, as residual stresses in this area may have a larger spread due to changes in composition during the joint's fabrication.

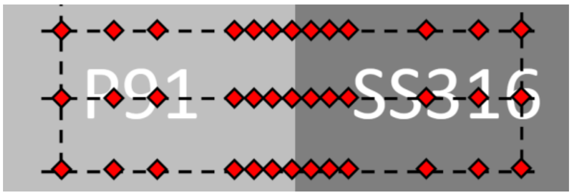

Figure 2 placement of interaction volumes analysed for residual stress

Data Processing

The data was received as a files accessible via visa.ill.fr, which contained raw diffraction data and summary of the conditions for all analysed volumes during the experiment. A local version of LAMP software was used to integrate the raw diffraction data into spectra, and to fit the spectra to a peak model using a least-squares approach. The following conditions applied:

1. Calibration file **SALSA_211_37323**
2. No background data fitted- flat background assumed
3. No fixed FWHM
4. Fitted to Psuedo-Voight Model

As diffraction data was fitted to peak models, diffraction data which fitted badly due to large spread or lack of data points were discarded from the completed data set. Diffraction data from interaction volumes that traversed the metal joint contained two peaks corresponding to the two different crystal types present in the sample (Austenitic and Martensitic). Here, each peak was fitted separately by selecting the x-translation range around each peak and fitting this data range to the pseudo-voight model. This tended to yield better fits than fitting two peaks simultaneously.

All peak data along with location of the analysed volume was compiled into an excel sheet. In the absence of a true zero-strain measurement (d0), the 2theta value for the interaction volumes furthest into the austenitic and martensitic parent materials were used as a proxy for d0. Here it was assumed that these areas in the sample would have the least residual stress. Using this, centroid/ 2theta values and the neutron wavelength, residual strains were approximated within each interaction volume and plotted as below.

Results and Analysis

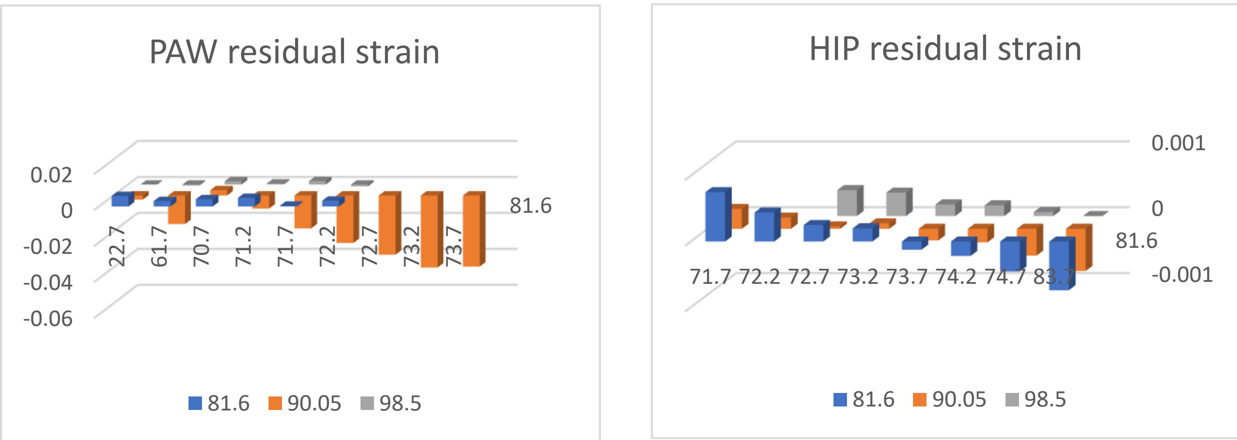

Figure 3 PAW approximated residual axial strains (left) and HIP approximated residual axial strains (left)

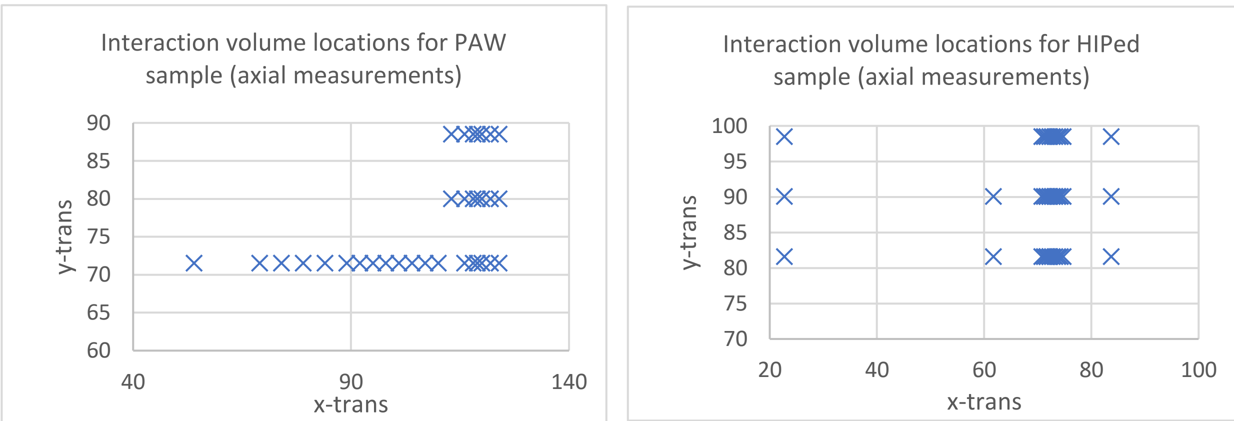

Figure 4 Locations of neutron interaction volumes

Overall approximated residual axial stresses in the PAW sample are larger as seen in Figure 3. Here, axial strains were shown due to having a more complete data set. Though this indicated higher residual strains these approximations may not be good quality due to following limitations:

1. Varying composition in the PAW joint due to use of nickel filler, thus approximations using austenite or ferrite reference may be unsuitable
2. Approximated d0 is not the true d0 for each interaction point

3. Some lack of clarity for which location corresponds to which reference crystal structure (some areas analysed with different reference crystal structures overlap thus it is unclear which is the most suitable reference to use for each point)

Next Steps

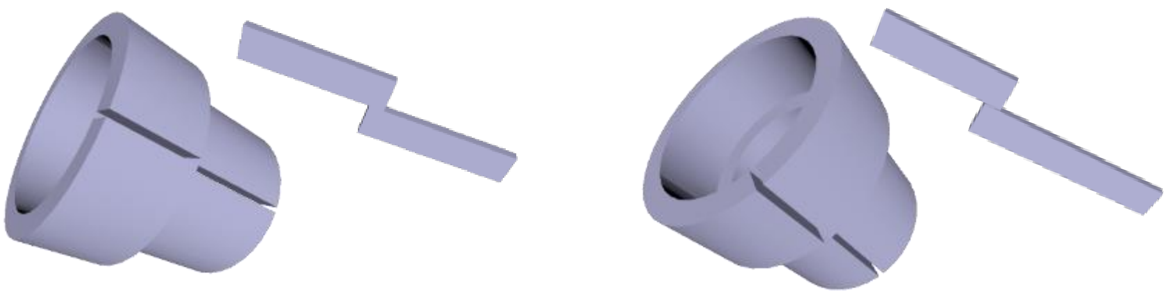

Figure 5 CAD of pipe joint demonstrators and machined d0 blanks (HIPed:right, PAW:left)

For part two of this neutron diffractions testing, the destressed d0 measurements must be found to enable the calculation of the residual stresses in the original components. To do this, the original component will be machined to produce destressed samples containing the original areas that were analysed in the work described above. A 5mm section from each pipe joint will cut machined via electron discharge machining (EDM) as shown in Figure 5.

The blank samples will have notches machined into them to produce a comb-like structure, with each ‘tooth’ of the comb containing destressed volumes of the material. The locations of the notches will be based on the locations of the interactions volumes as shown in Figure 4. Two versions of the destressed combs will be made:

1. Notches every 5mm along the length of the sample including at the weld interface
2. Notches every 5mm along the length of the sample including around the weld to leave the weld interface intact.