Experimental report

11/09/2015

Proposal:	**1-02-175**	**Council:**	10/2014
Title:	Residual Stress Measurements in Fibre Laser Welded Plates		
Research area:	Engineering		

This proposal is a new proposal

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Samples: aluminium

Instrument	Requested days	Allocated days	From	To
SALSA	4	4	07/07/2015	11/07/2015

Abstract:

The aim of the experiment is to examine the influence of welding parameters, including the laser power, traversal speed, v, and wire feed rate on the residual stress distributions in butt welded AA2024-T3 aluminium alloy plates joined by a fibre laser beam welding (FLBW) process. Three plates are to be measured across the weld line at the welds mid length in three mutually orthogonal directions. The results will be used to validate finite element simulations of the LBW processes which will provide a tool to examine a wide range of welding conditions and further be used for structural integrity analyses.

Experimental Report: Residual Stress Measurements in Fibre Laser Welded Plates (SALSA Proposal: 1-02-175)

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Introduction

Applications of lasers in materials processing since its first demonstration in the 1960s have been constantly increasing with the development of more advanced laser welding technologies. A well-known example of its use in the aircraft industry is the replacement of riveted structures with laser welded integral airframe structures in civil aircrafts. The two most common industrial lasers currently used for high power laser welding are the CO_2 and Nd:YAG lasers, and for many years these two remained the only choices for high power applications. More recently, new laser sources such as the diode laser, disc laser and fibre laser have entered the industrial laser market and in particular, fibre laser has been considered suitable for high power laser welding. Improved beam quality and higher efficiency of the fibre laser over existing lasers mean that typical problems associated with laser welding such as keyhole instability, reflectivity, porosity and cracking in aluminium alloys may be solved. The 2024 aluminium alloy which is considered difficult to weld with lasers due to its crack sensitivity and propensity for porosity has led to the use of lower strength 6xxx alloys which are much easier to weld as alternatives in aircraft components. However, the possibility of welding AA 2024-T3 using fibre laser has been investigated and it was found that by correct choice of welding parameters and filler wire material, it is possible to avoid cracking and reduce porosity to a minimum in this material. The parameters were determined to produce acceptable weld quality, low distortion and optimum mechanical properties in 3.2 mm thick AA 2024-T3 sheets. As a consequence, fillet welded AA 2024-T3 demonstration components shown in Figure 1 were welded. Since fibre laser is not widely used yet especially in the aircraft industry and its performance is still being evaluated, there is a need to investigate the distribution and magnitude of residual stresses and distortion induced by fibre laser welding in these plates. Measurements were conducted to determine the residual stress at various locations of the welds in two welded components with stiffeners as illustrated in Figure 1.

Experimental Procedure

Neutron diffractions measurements were made on fibre laser welded specimens made of AA 2024-T3 sheets. The welded joints were produced using a laser power of 3.5 kW, welding speed of 1.8 m/min, a 4043 filler wire feed rate of 5 m/min at 30° tilt with no defocus. The order of welding the stiffeners was from the middle first and then the ones on each side, one at a time. Both the stiffeners and the base plate were from the same material and thickness of 3.2 mm. The geometry of the specimens measured is shown in Figure 1. Two specimens were tested, one with a single stiffener and the other with three stiffeners equally spaced at every 100 mm spacing.

Measurements were made transverse to the welding direction for both plates at mid-thickness as illustrated in Figure 1. Additional measurements were taken along the height of the middle stiffener in the plate with three stiffeners. Close to the weld, measurements were taken in 1 mm increments for the first ±5mm from the specimen centre, in 2 mm increments up to ±20 mm and then several points at larger increments far from the weld. The small increments near the weld was necessary to capture the large stress gradients in the weld region. Measurements were made in the longitudinal, transverse and normal directions to the weld. A 2 x 0.6 x 2 mm^3 gauge volume was used to make the residual stress measurements in the longitudinal direction, whereas, in the other two directions, a 2 x 10 x 2 mm^3 elongated matchstick shape gauge volume with its long axis aligned parallel to either transverse or normal direction was used. In these directions the strain field is not expected to vary greatly. The angular distortion of the plate with three stiffeners was measured using CMM in order to correctly position the measurement points. An acquisition time of around eight minutes was used in the normal and transverse direction while over 20 minutes were spent in the longitudinal direction.

The elastic strain response of the (222) lattice plane was measured in these tests. The reflection (311) did not exist or was very weak due to texture. The welds were made in the direction parallel to the rolling direction. With an incident neutron beam wavelength of 1.28 Å for the plate with one stiffener and 2.52 Å for the plate with three stiffeners, the samples were set up with an angle, 2θ, of 80.502° between the incident and scattering beam.

Stress free measurements were made from coupons machined from the weld and from the parent material. In addition, far field measurements were made at edge of the sample, far from the weld line which was expected to be stress free. Since the d_0 values used were only taken from two positions, one from the weld and the other from the parent, it may be necessary to measure additional points using combs to measure the d_0 values in the same measurement points in the sample to obtain the correct elastic lattice strains. The reference d-spacing is likely to vary throughout the sample as different regions of the material have experienced different thermal cycles during welding. The possibility of variation in d-spacing due to local compositional changes from welding with filler wire will also cancel out by using combs.

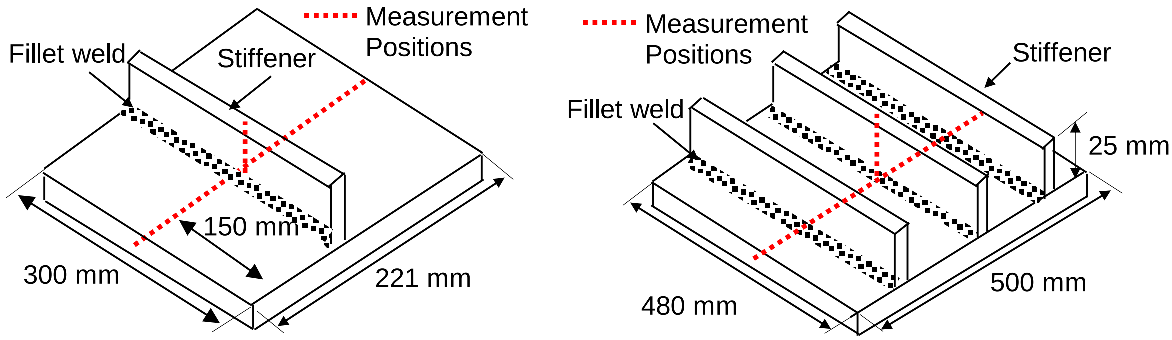


Figure 1 Illustration of 3.2 mm thick T-joint fillet welded aluminium alloy 2024-T3 sheets. Dotted lines in red through the mid-thickness of the plates indicate neutron diffraction measurement positions with more points near the weld at smaller intervals.

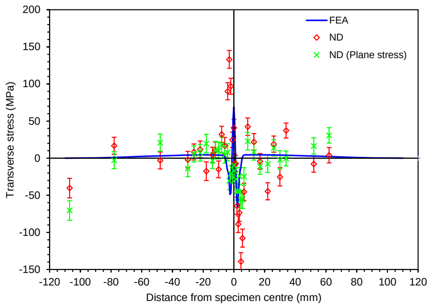
Results and Discussion

The residuals stress distribution measured in the plates are shown in Figure 2 and 3. Although, the results are not shown here, measurements were also performed within the stiffener itself. The measurements taken in three principal components were used to calculate residual stresses in the longitudinal (along the welding direction), transverse (transverse to the weld joint) and normal directions (through thickness) to the weld. Stress components for both of the specimens were compared to residual stresses predicted from numerical simulations.

Peak tensile residual stresses of approximately 300 MPa comparable to the yield strength of 345 MPa were measured in the longitudinal direction near the weld. A trend where the stresses on the side of the stiffener welded first was around 20 MPa lower than the side welded second, was observed in all three stiffeners. Heat conduction from the thermal cycle during the second weld pass to the first pass is likely to have resulted in reducing and redistributing the residual stress in this region. The tensile residual stress region extends approximately 10 mm from the specimen centre in the transverse direction and then quickly becomes compressive to around -50 MPa which levels off towards the edge of the plates.

The residual stresses predicted by the numerical simulation show a similar distribution to that measured by ND. The FE model reasonably predicts the magnitude of the tensile residual stresses. However, the trend mentioned above was not obvious in the model. While the results are in close agreement for the mid-stiffener, some differences were found with the other two stiffeners on the sides welded first with lower tensile stresses. As predicted by the FE model, the magnitude and the region of compressive stresses measured by ND in the longitudinal direction were very small. This is possibly due to the fact that only small compressive stresses are needed over a much wider volume relative to the very narrow weld zone in tension, to achieve a force equilibrium.

In both specimens, the residual stress predicted by the FE model in transverse and normal directions were relatively smaller than measured experimentally with a difference of around 50 to 100 MPa. However, the magnitude of stresses in these directions were considerably smaller than in longitudinal directions.



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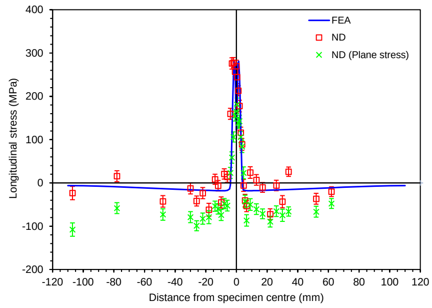

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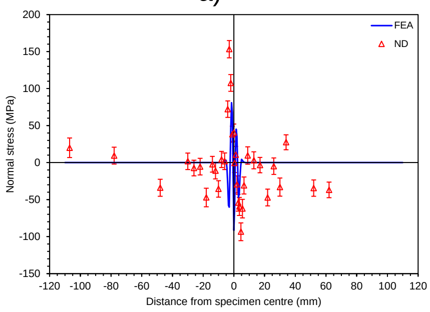
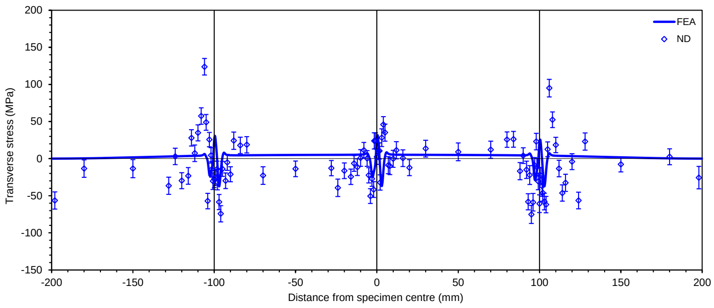


c)

Figure 2 Comparison of the RS measured perpendicular to the welding with FE in the a) transverse, b) longitudinal and c) normal directions for the plate with a single stiffener



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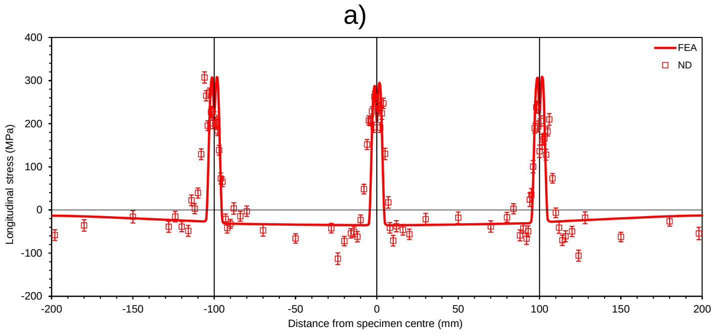

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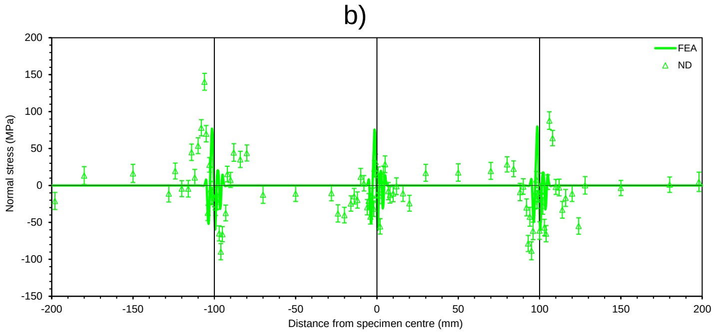

c)

Figure 3 Comparison of the RS measured perpendicular to the weld with FE in the a) transverse, b) longitudinal and c) normal directions for the plate with a single stiffener.