RESIDUAL STRESSES IN WELDED ALUMINIUM JOINTS FOR AEROSPACE APPLICATIONS

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The drive for lighter, more fuel-efficient and environmentally-friendly passenger aircraft is having a major impact on many of the design philosophies that underpin the construction of modern wide-bodied passenger jets. New designs such as the Airbus A380 and the Boeing 7e7 use a greater proportion of composite materials in their construction, and manufacturing methods are being developed to replace some mechanical joints by welded structures.

Traditionally, aircraft joining has relied heavily on rivets for fixing of the fuselage and wing skins. Welding offers the advantage of significant weight saving in joint design, as well as the possibility of fabricating internal structural members that would be difficult to manufacture by conventional routes.

The change to welding means that different design philosophies have to be implemented, as welding leads to:

- An integral structure with single load path construction, removing the crack-arresting features such as panel edges where sections are riveted and so leading to an overall loss in damage-tolerance for the structure.
- Creation of a microstructure near the fusion- and heat-affected zones of the weld with a changed grain size and reduced strength.
- Formation of new sources for defect initiation not present in the wrought alloy.
- Creation of a local and global residual stress field.

All these factors, in particular the creation of a variable residual stress field across the weld, have profound influence on the fatigue life of the welded metallic members and components. The civil aircraft design specification demands damage-tolerance characteristics in safety-critical parts. Therefore, before implementation of such a process change it is necessary to understand and be able to predict the fatigue crack growth behaviour under the influence of the residual stress field. The relationship between the fatigue crack growth in the welded microstructure and the distribution of residual stress field is the most essential input for the damage-tolerant, fail-safe design of safety-critical components.

We have been undertaking a programme of work to analyse and quantify the residual stress distribution around welded joints in aerospace aluminium alloys. We have looked at three candidate welding processes: metal-inert-gas (MIG) welding; variable-polarity plasma-arc (VPPA) welding; and friction-stir welding (FSW).

Neutron diffraction has become a key technique in the determination of residual stresses in welded components and structures. Because neutrons can penetrate several centimetres into most metallic materials, they act as an effective probe of the strains within a sample. Measurement of the three principal strains allows the residual stress to be calculated, and by measuring at many locations a ‘map’ of the stress field around a weld can be constructed.

We have used the G5.2 spectrometer at LLB to measure the strains in Al2024 and Al7050 welded plates. These alloys are the principal damage-tolerant aluminium alloys used in upper and lower wing-skins. By careful positioning of the plates, a series of measurements can be made to measure strains at many locations, which can subsequently be converted to stress. Information on the diffraction peak intensity can also be obtained, which gives insight into variations in the preferred crystallographic orientations (texture) within the plate and the weld.

Figure 1 shows a macrograph of the cross-section of a MIG-welded Al2024 alloy plate.

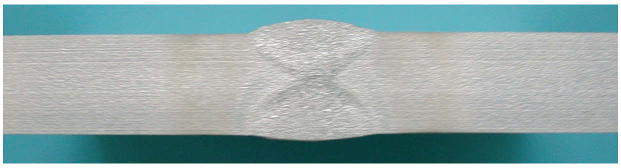

Figure 1. Macrograph of weld cross-section showing the double-V shape of the weld. The weld was fabricated in two passes, on either side of the plate.

Example plots of the strain distribution near the centre of the MIG weld are shown in Fig. 2.The pattern of the residual strain field variation is tensile along the longitudinal direction, while the transverse and normal directions are compressive. These values, obtained at a series of lines through the plate thickness, can be combined to produce a map of the residual stress as shown in Fig. 3.

Obtaining strain/stress maps of this detail allows additional information to be obtained. For example, figure 4 shows the matrix of data points that were measured from an Al7050 friction-stir weld:

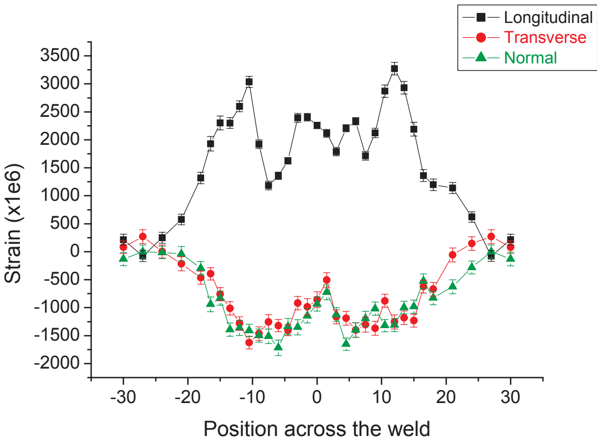

Figure 2. Strain distribution across the weld in the three principal directions near the central through-thickness line of the weld.

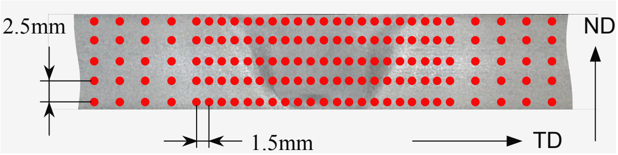

Figure 3. Macrograph of a friction stir weld, showing the matrix of points measured.

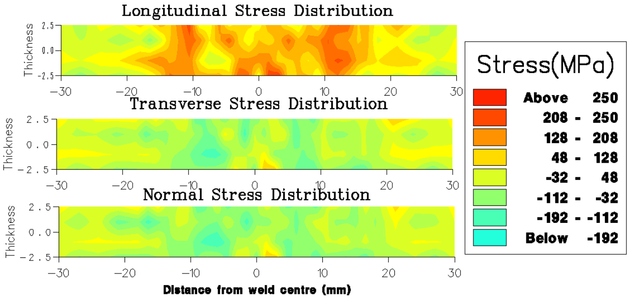

Figure 4. Stress distribution in MIG welded 2024-T351Al alloy.

We have demonstrated that residual strain distributions in specimens of this kind can be obtained by measurements of specific advantageous (hkl) peaks from the same family of preferentially-orientated grains present in both the parent material and the heat affected zones, and from a randomly-oriented fine grain structure within the weld's centre. The resultant strain distributions were converted into the longitudinal stress distribution, which is shown in Fig. 5b. Fig. 5a also shows the peak intensities obtained from measurements of the Al 111 planes at one of the orientations used (LD-19.5°). The changes in the crystallographic texture in the specimen can be seen clearly, with the texture changing across the weld zone.

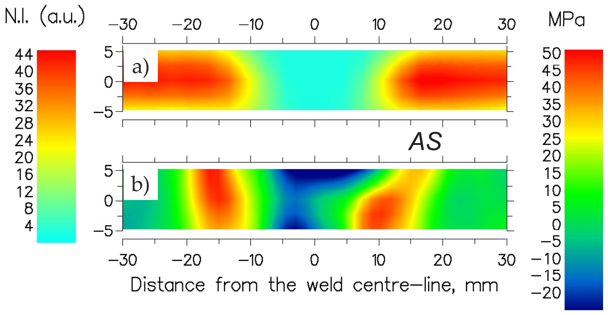

Figure 5a. Maps of normalized intensity (N.I.) of the (111) peak measured in the LD-19.5° direction ; and (b) the resultant longitudinal stress. The position of the mapped area relative to the specimen's surfaces can be easily seen, as the distance between horizontal axes of each map is set to to the plate's thickness.

These measurements have been correlated with macroscopic fatigue crack growth data and strength measurement to give insight into the mechanisms of damage within the weld, and to develop models of the damage tolerant behaviour of components based on these welding technologies.

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References

S. Ganguly, V. Stelmukh, M. E. Fitzpatrick, and L. Edwards,. *J. Neutron Res*., 2004:1-3:225-231