ESRF	**Experiment title:** Design and Durability of Welded Aircraft	**Experiment number**: ME-281
Beamline:	**Date of experiment**: from: 07/11/2001 to: 13/11/2001	**Date of report**: 13/3/2002
Shifts:	**Local contact(s)**: Dr. Francois Fauth	*Received at ESRF:*

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Introduction:

Welding is currently being considered as a cost-effective alternative to mechanical fastening for aircraft metallic structures and components [1]. It is vital requirement of implementation that relationships between weld process variables and the fatigue durability of the aircraft structure are established. Without this knowledge, the optimum balance between airworthiness safety requirements and manufacturing cost reduction will not be achieved. In particular, the behaviour of fatigue cracks in terms of their location, growth rates and direction of propagation must be determined and related to the residual stress profile present in the welded structures. We are studying two candidate weld processes, Metal Inert Gas (MIG) weld and Variable Polarity Plasma Arc (VPPA). Each can be used for both upper wing structures, that are buckling design limited and so are made from 7150 aluminium alloy, and lower wing structures, which are damage tolerance design limited, and so are manufactured from 2024 aluminium alloy. Experiment ME-281 was designed to measure through-thickness residual strains and local near surface residual stresses around key crack initiation sites in two 7150 samples: a MIG and a VPPA weld. 2024 MIG and VPPA welds were to be studied in a later experiment. However, process development in VPPA welding is continuous and ongoing. As the welds available in Nov. 2001 were not fully optimised, we investigated optimised 7150 and 2024 MIG welds in the experiment. The detailed strain maps presented here have been used in conjunction with maps of the normal (through-thickness) and transverse strains obtained by neutron diffraction on the ENGIN diffractomer at the ISIS pulsed spallation source to produce full 3D stress tensor distributions in the thick aluminium welds studied. This hybrid methodology, which we believe to be novel, is currently being published [1].

Samples:

Two 12.5 mm thick AA7150 plates were welded in the W51 condition using AA5039 filler wire. The weld orientation was parallel to the rolling direction (RD) of the parent plates. A conventional peak aging treatment was applied following welding, resulting in a T651 condition in the far field parent material and related conditions in the heat affected zones and double-V shaped fusion zone (FZ). Finally, the 280 mm square welded plate was reduced in thickness to 7 mm by machining following likely industrial practice. Two identical dog-bone specimens of weld, 380 mm long and 80 mm wide at their narrowest, were also prepared by the same procedure. The 1st specimen was in the as-machined condition whilst the 2nd contained a crack, that had initiated, propagated and arrested under commercial aircraft spectrum loading conditions. The 2024 double-pass MIG weld was produced using 12.1 mm thick plates in the T351 condition and AA2319 filler wire. The specimen was 280 mm parallel to the welding direction and 186 mm wide.

Experimental Method and Results:

BM 16 was set-up to allow synchrotron strain scanning in transmission. Measurements were made in the middle of the plates over the cross-sectional area perpendicular to the weld seam. The sampling volume was defined using the incident and receiving slits. A 2 mm horizontal slit used to ensure there was sufficient number of grains in the gauge volume and a 0.5 mm vertical slit opening was used to give increased spatial resolution in the normal direction (ND).

Studies of preferred orientations in both alloys carried out using Electron Back Scatter Diffraction (EBSD) and conventional X-ray diffraction prior the synchrotron experiment showed that the parent material (PM) and heat-affected zones (HAZ) in the 7150 weld are characterized by a strong texture in which the Brass, <211> (110), texture is one of the main components, whilst texture in different zones of the 2024 weld was relatively weak. This information was used to identify the most appropriate reflections for the synchrotron strain scanning. (422) and (222) reflections were used to measure the 7150 samples in longitudinal (LD) and transverse (TD) direction, respectively. (311) reflection was selected for the measurements in both directions in the 2024 sample, as the strongest reflection in a given diffraction angles range, where elongation of the gauge volume was relatively small. Angular peak positions were obtained using the fitting routine ESRFit developed by Dr. Darren Hughes (University of Salford).

Correction of measured strains to allow for variation in the stress-free lattice spacing (d_0) was made by measurement of 'comb' specimens removed from the welds by EDM. d_0 measurements were made at orientations corresponding to equivalent measurements in the bulk material. The dimensions of each individual 'tooth' of the comb were 2.4×2.7 mm^2 in the LD-TD plane and 9 mm along ND.

Transverse strains in the rectangular samples were also measured in the subsequent neutron diffraction experiment. The excellent comparability of the two techniques is exemplified by the results shown in terms of pseudo-strain for the 7150 weld in Fig.1. It should be noted, however, that measurements with 40keV X-rays are substantially faster than with neutrons due to the very high photon flux at ESRF. About half the maximum in the pseudo-strain variation observed in the FZ is due to variation in the composition of the Al-based solid solution present in the filler metal, which essentially defines how d_0 changes across the weld.

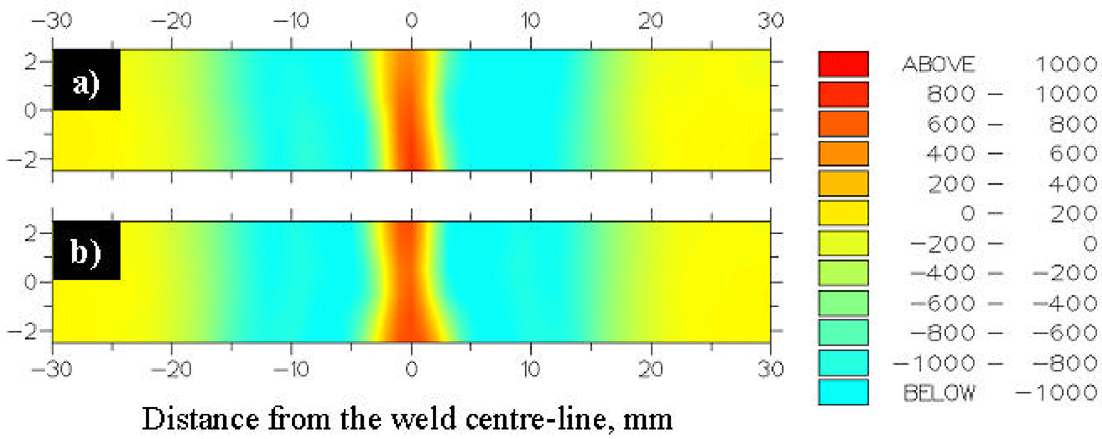

Figure 1: Maps of pseudo-strain calculated using data obtained for TD in synchrotron X-ray (a) and neutron (b) diffraction experiments and a constant d_0, the average *d*-spacing for *PM*.

Contour maps presented here were obtained using bilinear interpolation of several hundred individual strain/stress values using Gsharp 3.1 software [2]. Figure 2 shows stress maps calculated from the d_0 corrected strain maps using the reasonable assumption that the measurement directions were aligned with the principal stress axes, and Hooke's Law:

$$\sigma_i = \frac{E}{1+\nu}\varepsilon_i + \frac{\nu E}{(1+\nu)(1-2\nu)}(\varepsilon_{LD} + \varepsilon_{TD} + \varepsilon_{ND}),$$

where i stands for the LD, TD or ND. The elastic modulus, E, was taken as 71 GPa and Poisson's ratio, ν, as 0.35. Comparison with the stress distribution in the original 12.5 mm thick sample obtained in a separate neutron diffraction experiment, showed that the residual stresses are substantially reduced (by up to 100 MPa) by machining [4]. The stress distribution in the 2024 sample (Fig. 2b) is characterized by presence of maxima forming large distorted double-V shaped feature, which correlates well with the location of the HAZ.

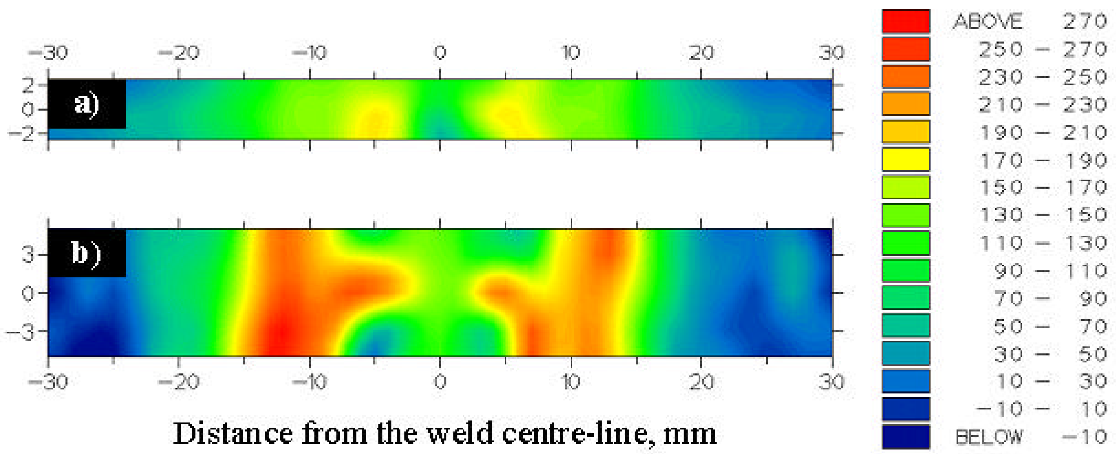

Figure 2: Longitudinal stress distributions in the 7150 weld (a) and the 2024 weld (b).

Longitudinal strain distributions obtained for the dog-bone samples (Fig. 3 a, b), appear on first inspection, to be indistinguishable. However, if the difference between the two measurements is mapped, features are revealed as can be seen from Fig. 3c. Some of them are obviously caused by the crack, expected boundaries of which are shown by the dashed line in the figure. Interpretation of this data is ongoing.

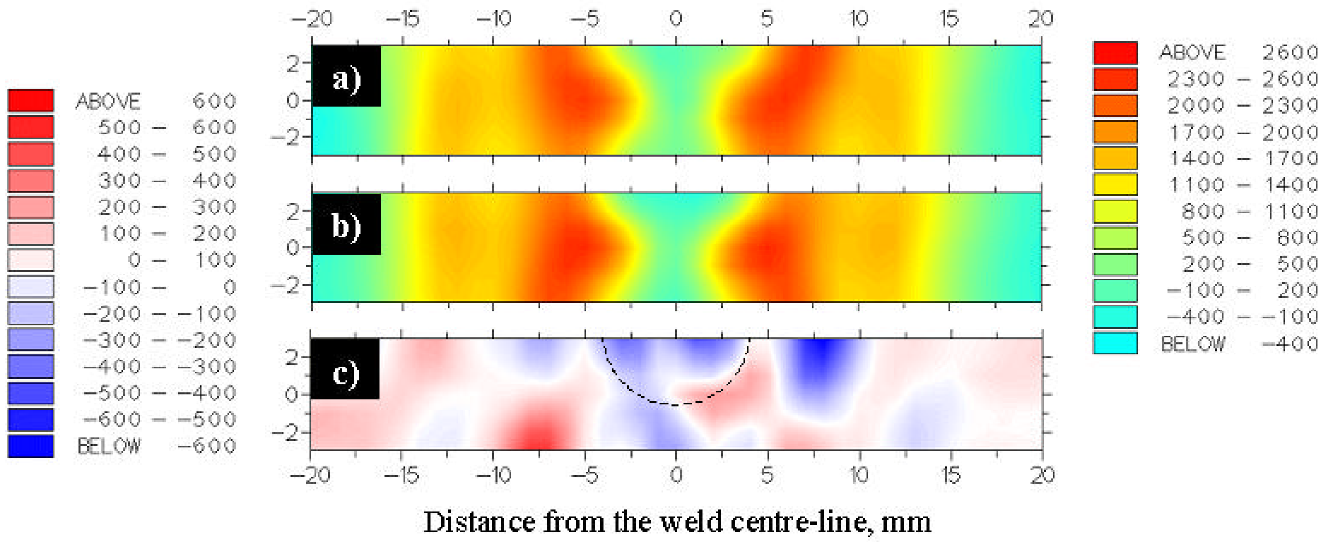

Figure 3: Longitudinal strain distributions for as-machined (a) and pre-cracked sample (b). The difference given in (c) on another scale is mapped as a 'point-to-point' change.

The stress distributions detemined in this work [4] are currently being used to develop models for crack initiation and growth in aerospace welds as part of a major EPSRC funded engineering structural integrity program on Design and Durability of Welded Aircraft involving the proposers, Airbus UK, and Cranfield and Southampton Universities.

References:

[1] S. Graeme, S & S.W. Williams: Welding and Metal Fabrication, Vol. 67 (1999), p.6
[2] V. Stelmukh, L. Edwards, J. R. Santisteban, S. Ganguly and M.E. Fitzpatrick: *Weld Stress Mapping Using Neutron and Synchrotron X-ray Diffraction.* Accepted for presentation at ECRS6 (6^{th} European conference on Residual Stresses, Coimbra, Portugal, July 2002 and published in Material Science Forum
[3] GSharp, Advanced Visual Systems, Waltham, Massachusetts, USA; (www.avs.com)
[4] V. Stelmukh, L. Edwards, J. R. Santisteban, S. Ganguly and M.E. Fitzpatrick: *Evolution of the Residual Stresses in an Aerospace MIG Weld due to Fabrication and Machining.* To be submitted to Metallurgical and Materials Transactions. A. 2002.