ESRF	**Experiment title:** Residual Stress Field Under Fatigue Loading in MIG Welded Marine Grade Aluminium Alloy	**Experiment number**: ME 282
Beamline: BM 16	**Date of experiment**: from: 31/10/01 to: 4/11/01 and from: 7/12/01 to: 11/12/01	**Date of report**: 2/8/02
Shifts: 24	**Local contact(s)**: Dr Andy Fitch	*Received at ESRF:*

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Report:

This work required the facilities at the ESRF because of the availability of high flux, high energy X-rays and the established strain scanning facilities of BM16. The beamline has been optimised for residual strain measurement and allows a very significant amount of data to be generated in an acceptable time. This allows meaningful engineering questions to be posed regarding the through-thickness residual stress distribution in welded plates, and its modification under fatigue loading. This is very important for predicting fatigue life as it is greatly affected by the residual stresses. At present, lack of information regarding the magnitude and changes of residual stress that occurs during loading, means that their effects can only be incorporated empirically through assumed changes to mean stress in the fatigue cycle. This is not optimum for use of material resources, or in developing light weight, fuel-efficient structures. Ideally, one requires sufficient data and understanding of residual stresses, their variation and modification, to allow predicitive methodologies to be developed and incorporated in life prediction codes, that allow for inclusion of process and load variations.

This experiment is related to the work performed in ME 197, which considered solid-state friction stir welding (FSW) which should lead to low levels of tensile residual stress. ME 282 used MIG welded plates, in which residual stress levels should be a higher fraction of the yield stress. There are also significant grain size variations which affect stresses and their reliability of measurement (FSW is very fine grained ~ 10 μm, whilst MIG leads to grains > 100 μm in size). These two experiments encapsulate two very different, but widely used, industrial scenarios to join plates in the transport industry. Significant insights into effects of fatigue loading on residual stresses may allow some general conclusions to be formed and specific, focussed experiments proposed to answer the questions raised. ME 197 has already revealed some surprising results in the 5383-H321 aluminium alloy plate used. Firstly fatigue loading can lead to a four-fold increase in residual stresses to a tensile level of around 50% of yield - this is the **first observation of this effect** known to the investigators, and is contrary to received wisdom on the influence of fatigue cycling on residual stresses. Secondly, plate-to-plate variation in compressive residual stresses is much larger than anticipated. Data for the MIG welds is complementary to these results and of equal interest to the fatigue community. The results provide the first reasonably comprehensive insight into fatigue effects on residual stresses at welds.

The experimental matrix in ME 282 was designed to correspond with industrially relevant lives of 10^5 to 10^6 cycles of stress, and to elucidate trends in residual stresses as a function of load type. Residual strain measurements were made both in the as-welded state and after the application of fatigue loads. Applied loads included 1 cycle at R = 0 (zero-tension loading) with a peak stress of 150 MPa (equivalent to a fatigue life of 4 x 10^5 cycles), 1 cycle at R = -1 with a peak stress of 150 MPa (fully reversed loading) and 100 cycles at R = 0.1 with peak stresses of 100 MPa, 150 MPa and 200 MPa. Residual strains were mapped and stresses derived through the complete plate cross-section in the as-welded state for selected specimens of both low and high heat input welds, and at surface and mid-plane positions for all specimens.

Figure 1 below shows residual stress distributions in the as-welded state for low heat input (LI) and high heat input (HI) MIG weldS in 5383 aluminium alloy plate (AA5383). The X-direction is defined parallel with the weld (longitudinal) and the Y-direction transverse to it. Tensile residual stresses are seen to be around yield strength level with peak values occurring about 10 mm from the weld centreline.

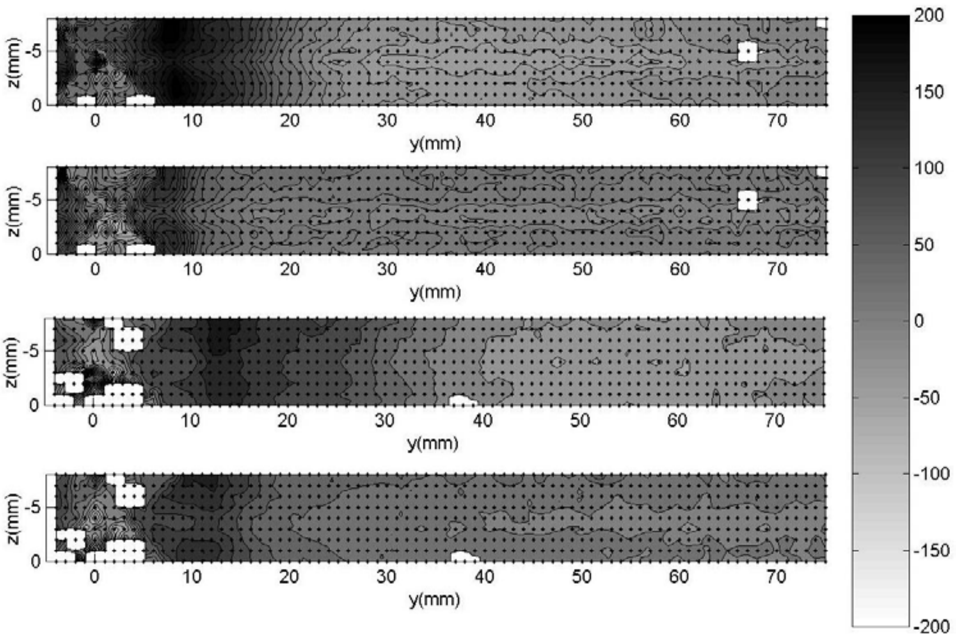


Figure 1 The variation of residual stress in the X and Y directions for both the LI and HI welds. Residual strains are shown in units of MPa from top to bottom as:

TOP AA5383 LI X direction
AA5383 LI Y direction
AA5383 HI X direction
AA5383 HI Y direction

The position of the peak tension approximately corresponds to the boundary between the HAZ and the parent plate for both LI and HI welds. Figure 2 shows the diffraction peak width variation, which is an indicator of dislocation density within a grain, with narrower peaks indicating lower densities. It hence provides information on the microstrain level and its variation within grains, and can therefore also indicate microstructural changes such as annealing and tempering. However, peak width also decreases as a strong function of decreasing grain size. The weld filler metal was 5183 alloy, and the grains in the weld metal will have different texture, larger sizes and lower dislocation densities than the HAZ region or the extruded plate. The peak width maps show the weld profile very clearly, as well as indicating the extent of the HAZ. This allows one to link residual stress effects to the various weld regions.

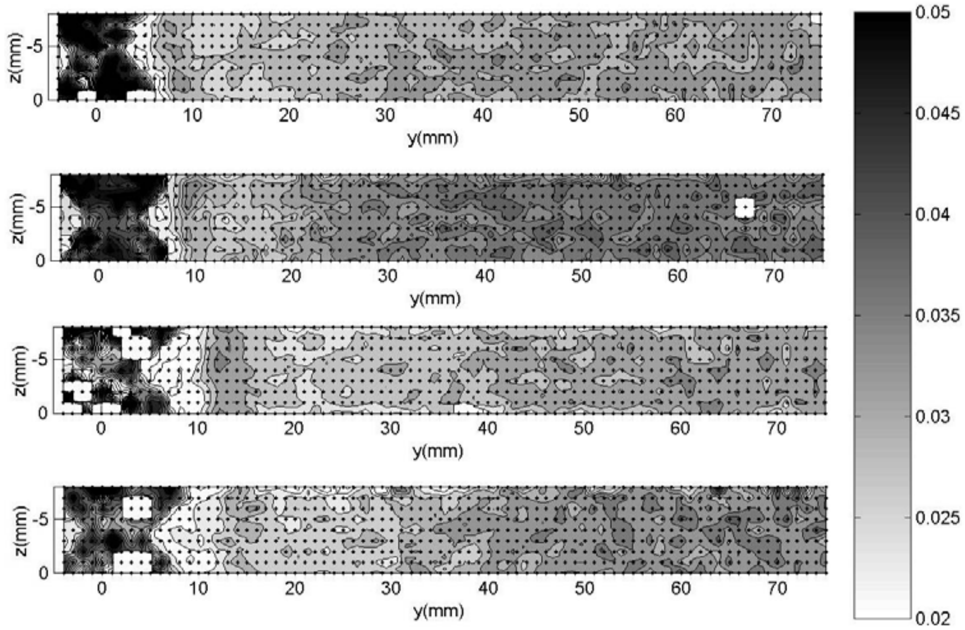
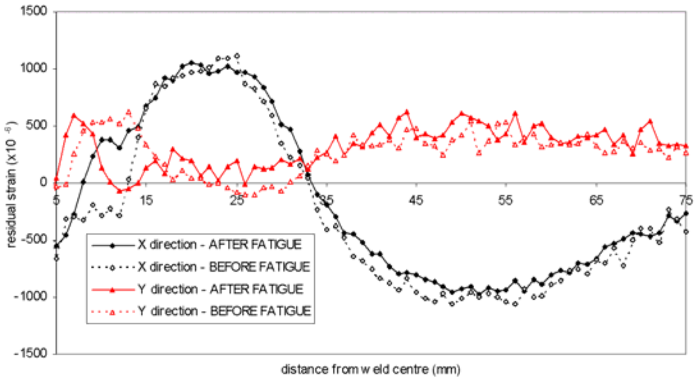


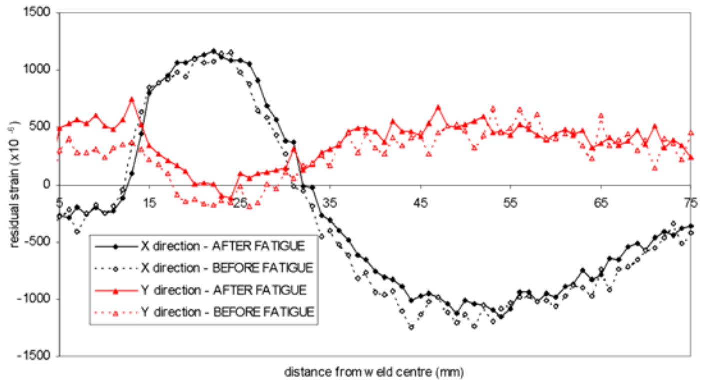
Figure 2 The variation of peak width (FWHM) in the X and Y directions for both the LI and HI welds. Peak widths are shown in units of degrees two theta from top to bottom as:

TOP AA5383 LI X direction
AA5383 LI Y direction
AA5383 HI X direction
AA5383 HI Y direction

Figure 3 shows the changes in residual stress that occur after fatigue testing of a AA5083 HI MIG weld at 200MPa (100 cycles at R = 0). Three line profiles are shown at 1, 4 and 7 mm from the crown surface of the weld (the plate thickness is 8 mm). It can be seen that the changes in residual strain due to fatigue cycling occur mainly in the range 0 – 25 mm from the weld centre. There are significant changes in both the X and Y direction strains close to the weld, which are particularly noticeable in the two data sets close to the plate surfaces.

The unique data obtained in this study will enable the development of a more thorough understanding of the residual stress–fatigue–lifetime relationship in welded joints and should lead to improved predictive techniques.





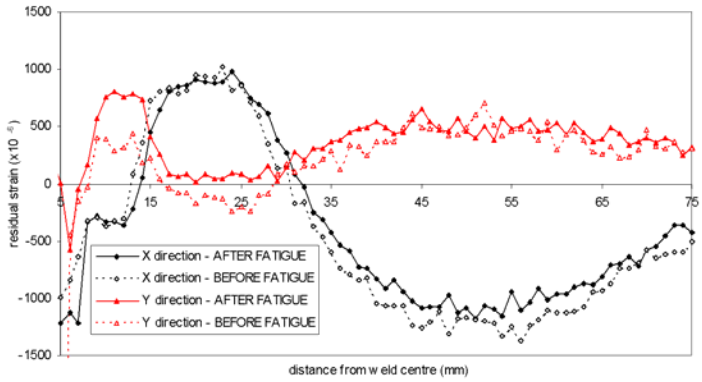


Figure 3 Effect of fatigue cycling a AA5083 HI MIG weld for 100 cycles at 200 MPa (R = 0). Top left : X and Y direction residual strains at 1 mm from the weld crown surface. Top right : X and Y direction residual strains at 4 mm from the weld crown surface. Bottom left: X and Y direction residual strains at 7 mm from the weld crown surface.