ESRF	**Experiment title:** Residual Stress Field in Friction Stir Welded Marine Grade Aluminium Alloy	**Experiment number:** ME 197
Beamline: BM 16	**Date of experiment:** from: 3-7 March 2001 to: 9-14 July 2001	**Date of report:** 11 February 2002
Shifts: 12	**Local contact(s):** Dr Andy Fitch; Dr Francois Fauth	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

Professor M Neil James*, University of Plymouth, England

Professor Peter J Webster*, University of Salford, England

Dr Darren J Hughes*, University of Salford, England

Dr Danie G Hattingh*, PE Technikon, South Africa
Gareth Bradley*, University of Plymouth, England
Dr Gordon Mills*, University of Salford, England

Report:

This work required the facilities at the ESRF because of the high flux, high energy X-ray and the established strain scanning facilities of BM16. These allow a very significant amount of data to be generated in an acceptable time. In the present case, some 16 000 lattice strain measurements were made during the allocated beam time. This high productivity rate allows meaningful engineering questions to be phrased regarding the through-thickness residual stress distribution in welded plates, and its modification under fatigue loading to be studied. In turn, this means that aspects of their influence on fatigue life prediction can be realistically addressed. The importance of such work to the engineering and manufacturing community is very high, because ensuring structural integrity and reliability in the context of cracking problems often requires the incorporation of residual stress.

The experiment was highly successful, yielding information useful to life prediction for an extensive matrix of peak fatigue loads, number of applied cycles, and two different friction stir welding processes. The large amount of data meant that significant processing effort was required to get it into final form, but enough information has already been extracted for several publications. These are currently in preparation and publications are planned for the Journal of Strain Analysis, Materials Science and Engineering, and Fatigue and Fracture of Engineering Materials and Structures.

Both single-pass (SP) and double-pass (DP) friction stir welds (FSW) were made joining 8 mm plate of 5083-H321 marine grade aluminium alloy (supplied by Corus). FSW is a relatively new solid-state joining technique, which offers high joint quality and good fatigue performance. The process approximates a solid-state keyhole welding process, in that a hole to accommodate a tool pin is generated, then filled as the weld is made. It offers the potential for high productivity rates, but lack of information regarding residual stress levels and fatigue properties currently limits industrial take-up of the process in industries like ship building, despite the competitive advantage offered. Thus the experiment was both timely and useful.

Plates 150 mm by 190 mm were cut from larger welded plates and the residual stresses were determined in the directions transverse and parallel to the weld run. Data were obtained in some cases in nine-line scans at 1 mm intervals through the thickness to allow maps of peak intensity (which gives information on preferred orientation and texture in the material), peak width (which yields information on variation in d_o and hence microstructural variation) and scattering angle $2q$ (which gives strain and stress information). Generally, however, to increase the number of specimens that could be considered in the allocated beamtime, three-line scans were done through the thickness at 3 mm intervals. Reflections were obtained from the (3 1 1) planes in all cases, which offer an 'averaged' response to applied strain. The table below details the experimental matrix considered.

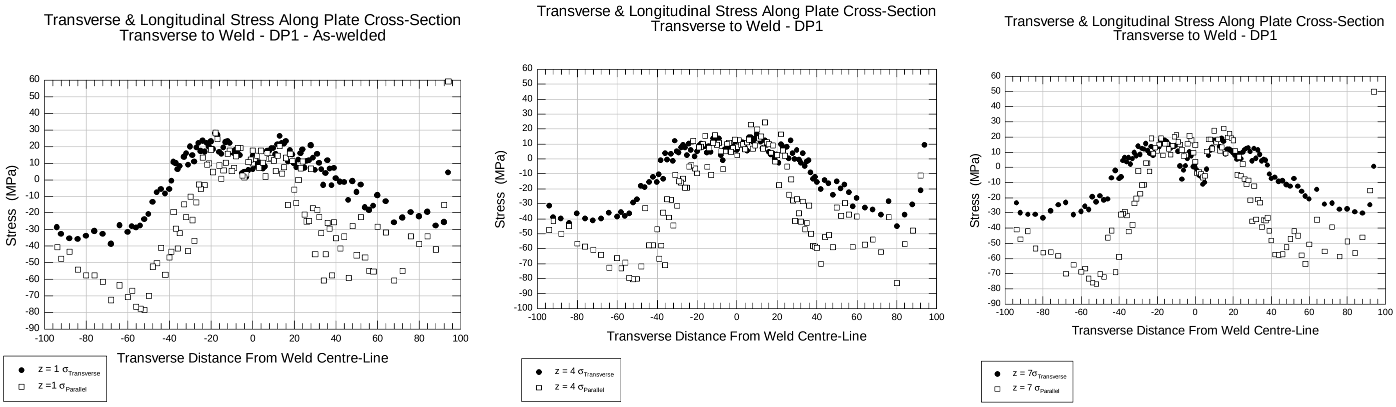
Table 1 The matrix of test parameters used in the experiment.

	As-welded	150 MPa 1 cycle R = 0	150 MPa 100 cycles R = 0.1	200 MPa 1 cycle R = 0	200 MPa 100 cycles R = 0.1	250 MPa 1 cycle R = 0	250 MPa 100 cycles R = 0.1
SP	SP1 - SP2	SP1	SP3	-	-	-	-
DP	DP1 - DP4	DP2	DP5	DP8	DP6	DP4	DP7

The 0.1% proof strength of both the SP and DP weld metal is around 165 MPa, while the proof strength of the parent plate is about 250 MPa. Thus these levels of applied stress were chosen to represent the low cycle fatigue region and bracket the stress levels where a range of yield phenomena (from localised yield at stress concentrations through to bulk yield of the alloy) would affect the fatigue performance. The plates used in these measurements will be cut into smaller fatigue specimens and used to determine S-N curves. The combined residual stress distribution and applied stress level can then be related to fatigue life, in a unique and powerful insight into the effects of fatigue cycling on residual stress and its consequences for life prediction. To obtain a comprehensive dataset would require additional work to be done at lower applied stresses (equivalent to longer lives) and on as many SP as on DP specimens. It would be extremely advantageous, in terms of information acquisition and efficiency of beam use, to be able to apply loads to simple specimen geometries at the ESRF, preferably on-line, rather than back at the home laboratory between beamtime allocations.

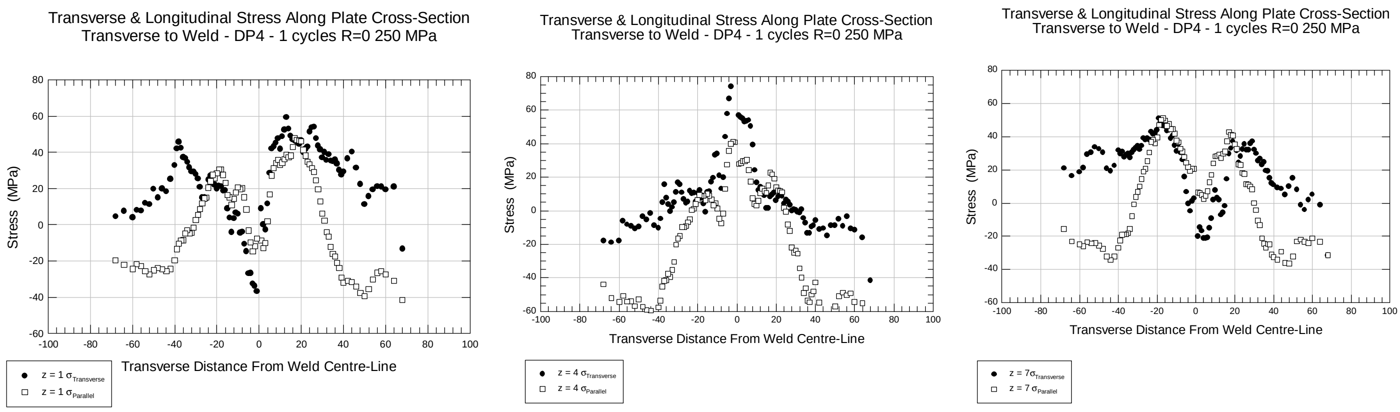
Sample output of two-dimensional stress information are given in Figs. 1-3 below.

Figure 1 Illustrative output for Weld 15 - specimen DP1 : As-welded.



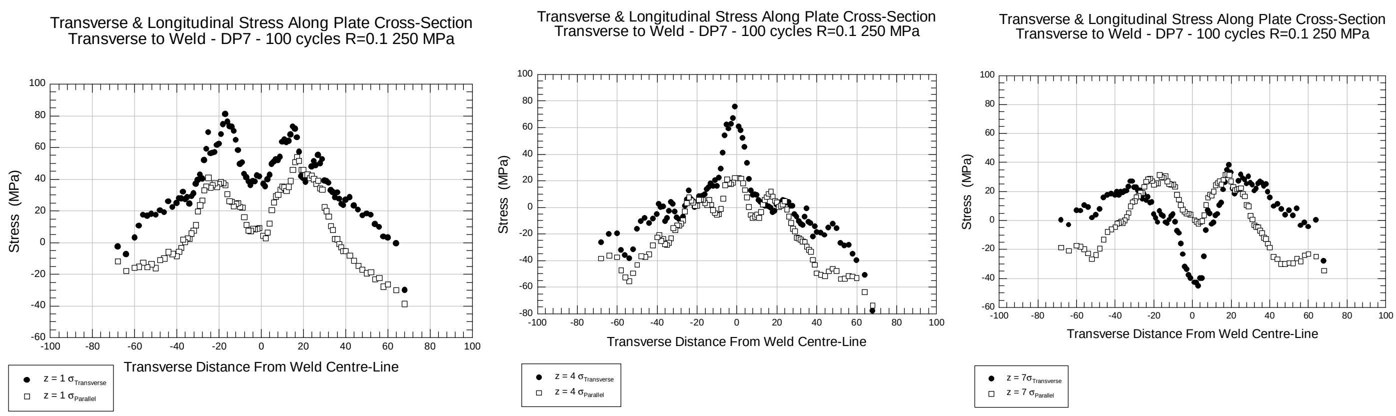
a) **z = 1 mm** **b)** **z = 4 mm** **c)** **z = 7 mm**

Figure 2 Weld 10 - specimen DP4 : 1 cycle - R = 0, s_{max} = 250 MPa.



a) **z = 1 mm** **b)** **z = 4 mm** **c)** **z = 7 mm**

Figure 3 Weld 15 - specimen DP7 : 100 cycles - R = 0.1, s_{max} = 250 MPa.



a) **z = 1 mm** **b)** **z = 4 mm** **c)** **z = 7 mm**

These graphs can be analysed to obtain the elastic-plastic effects of stresses applied as a single monotonic peak load, or as repeated reversed cycles. Plate-to-plate differences in the as-welded state can be subtracted out, and are useful in themselves, in highlighting the likely variability in predictive certainty. The synchrotron data represent a significant and unique gain in information that should facilitate an increased understanding of residual stress/applied stress interaction and engineering residual stress analysis.