ESRF	**Experiment title:** Process and Performance Optimisation for Friction Stir Welds Using the Force Footprint and Strain Scanning	**Experiment number**: ME 992
Beamline: ID31	**Date of experiment**: from: 1/10/05 to: 5/10/05 and: 30/11/05 to: 5/12/05	**Date of report**: 7 July 2005
Shifts: 12	**Local contact(s)**: Francois Fauth; Michela Brunelli	*Received at ESRF:*

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Report:

Diffraction strain scanning was performed to determine the residual strain and stress state in friction stir welds in 5083-H321 alloy. The underlying aim of the work was to link variation in process parameters with residual stress and strain, and with mechanical properties and dynamic performance. These linkages will lead to prediction and control of optimised weld process conditions via use of an instrumented tool post (acting as a multiaxial transducer). The present authors have developed such a transducer for an automated FSW system that allows measurement of tool forces, torque and temperature continuously during the welding process [1]. FS welds were made in 6 mm 5083-H321 aluminium plate. This alloy is particularly interesting as it is known to be susceptible to formation of unusual planar defects [2]. Tool force data can be presented as a 'polar plot' which can be related to energy input and hence provides insight into modeling of the process-structure-performance relationship for the FSW process. Detailed knowledge of the residual stress and strain distributions is indispensible in linking process parameters with mechanical properties and fatigue performance. The final outcome will be a series of 'performance surface maps' as a function of energy input and weld pitch (defined as tool travel increment per revolution). These will allow predictions to be made of favourable process parameters for particular combinations of weld property characteristics.

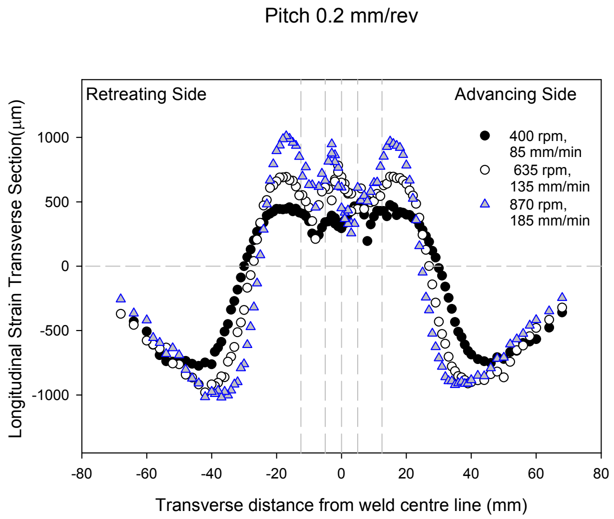
In this work the FS welds were made with a variety of welding parameters to create different rates of thermo-mehcncial energy input . Specimens comprised weld runs around 150 mm long between plates 75 mm wide. The table below details the experimental matrix considered.

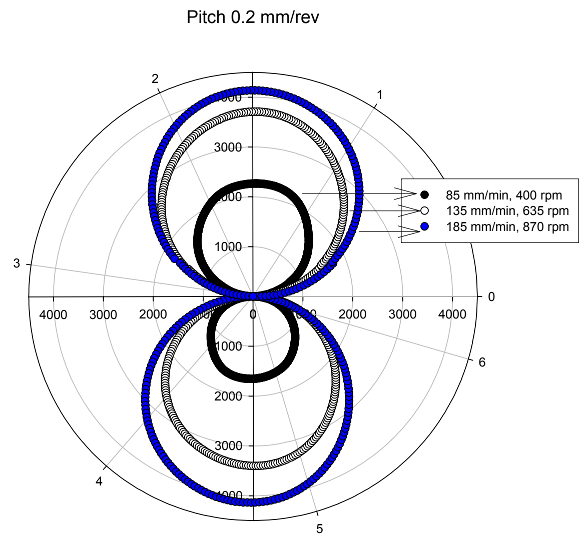
85 mm/min		135 mm/min		185 mm/min	
RPM	**Pitch**	**RPM**	**Pitch**	**RPM**	**Pitch**
425	**0.2**	550	**0.2**	675	**0.2**
283	**0.3**	367	**0.3**	450	**0.3**
213	**0.4**	275	**0.4**	338	**0.4**
		220	**0.5**	270	**0.5**

Forces on the FSW tool (horizontal and vertical), torque and tool temperature were measured continuously during welding. Synchrotron X-ray diffraction experiments were performed on ID31. Bean energy was 60 keV, corresponding to a wavelength of 0.2065 Å. The incident and receiving slits were opened to 1.2 mm by 1 mm and the diffraction angle from

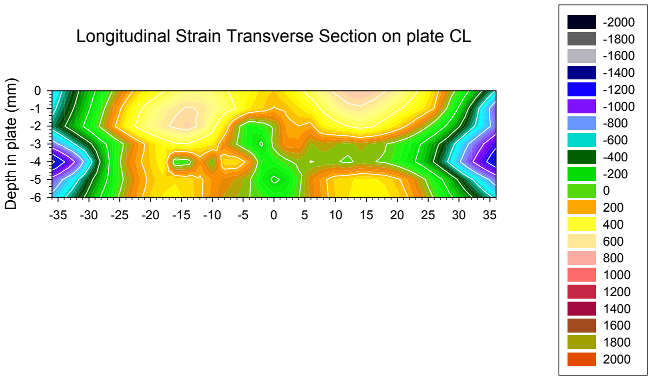
the {3 1 1} lattice planes was about 9.68°. Single line scans were performed across the centre of 11 welds to obtain representative transverse and longitudinal stress and strain profiles which could be related to the polar plot figures.

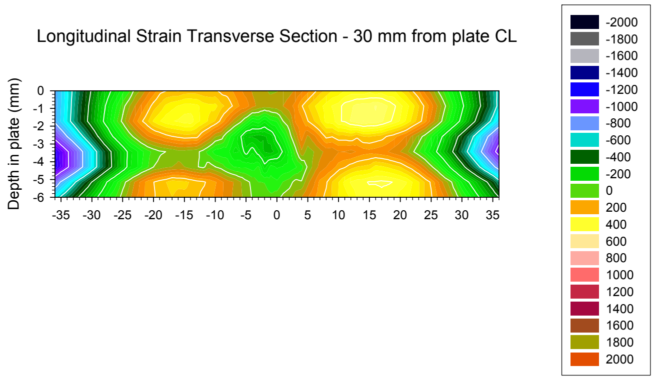
The figure below shows the longitudinal residual stress distribution across the as-welded transverse section of welds made with a constant pitch of 0.2 mm/revolution, but different combinations of tool speed and feed. The corresponding polar force plots are also shown. A clear trend of increase in maximum and minimum values of longitudinal strain with increase with tool speed and feed is seen. Associated with this is a decrease in spacing of the minima in the strain distribution. This data implies that more deformation is put into the weld zone as tool speed and feed increase at a constant pitch, and that the spread of heat energy outside the weld zone is less. The polar plots of tool force indicate that energy input into the weld (represented by area of the plot) steadily increases with tool feed and speed. Taken in conjunction with the mechanical property, metallographic and dynamic performance data clear insight into weld processes can be extracted. This work is current underway.





Selected welds, e.g. at a feedrate of 135 mm/min, and tool speeds of 270 rpm (pitch = 0.5 mm/rev) and 675 rpm (pitch = 0.2 mm/rev) were subjected to detailed mapping of the strains and stresses on longitudinal and transverse planes. The following positions were chosen: longitudinal planes 5 mm, 10 mm and 35 mm from the weld centreline, and transverse planes 15 mm and 30 mm from the centre of the plate. This is the first time that such detailed mapping of the residual strains and stresses have been performed in FS welds as a function of a consistent set of process parameters. Typical data for the longitudinal strain on transverse sections at the centre of the welded plate and 30 mm from the centre are given below.





[1] D G Hattingh, T I van Niekerk, C Blignault, G Kruger and M N James (2004), *Analysis of the FSW force footprint and its relationship with process parameters to optimise weld performance and tool design*, Invited Paper (INVITED-2004-01), IIW Journal Welding in the World, 48 No. 1-2 pp.50-58.
[2] M N James, G R Bradley, H Lombard and D G Hattingh (2005), *The relationship between process mechanisms and crack paths in friction stir welded 5083-H321 and 5383-H321 aluminium alloys*, Fatigue and Fracture of Engineering Materials and Structures, 28 pp.245-256.