ESRF	**Experiment title:** Coupling between precipitation and residual stresses in friction stir welds	**Experiment number**: ME-630
Beamline: ID31 BM02	**Date of experiment**: from: 12/02/04 to: 14/02/04 (ID31) from: 01/04/04 to: 05/04/04 (BM02)	**Date of report**: 24/08/01
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Report:

Introduction

Synchrotron radiation was used to investigate both the microstructure and the state of residual stresses resulting from friction stir welding of the high strength 7449 aluminium alloy. In fact the evolution of the microstructural features and the development of residual stresses during this process are governing the resulting mechanical properties of the material used in the aerospace industry.

The aim of this study was to investigate experimentally the state of precipitation (microstructure responsible for the remarkable performance of the alloy) and residual stresses on pieces performed under the same welding conditions. Moreover two different initial microstructures are studied: one naturally aged (T3) constituted of GP zones and an overaged material (T79).

Experimental method

The alloy studied is the new, sophisticated aerospace 7449 alloy, supplied by Pechiney Rhenalu as extruded plates and under two different ageing conditions : T3 (naturaly aged) and T79 (overaged obtained by two-step ageing) containing GP zones with very low thermal stability and a mixture of η'+ η precipitates respectively. Welding was carried out at TWI, UK on 6-mm thick plates. The parameters of welding were a rotating speed of 350 rpm and two different displacement speed conditions were carried out: 175 mm/min (designated as "low speed") and 350 mm/min (designated as "high speed").

To achieve the objective of this study, it was necessary to draw quantitative maps of the precipitate features as the microstructural evolution is 2-dimentional in the plane normal to the welding direction. **Small Angle X-ray Scattering** (SAXS) was shown (refer to Report ME 162) to be a well-adapted technique to the study of alloys of the 7xxx series (good contrast, precipitate size within 5-200Å, volume fraction 2-7%). The microstructure was investigated by using a 100*200 µm² beam at 8 KeV. Thanks to the high spatial resolution of the ESRF beam, mapping could be carried out by steps of 500 µm in the two directions perpendicular to the beam.

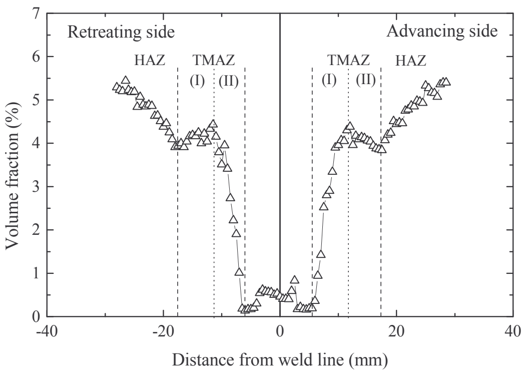
In order to characterise the residual stress distribution in these welds non-destructively, **diffraction experiments** using high-energy synchrotron X-rays were undertaken on the high-resolution powder diffraction beam line ID31. In this experiment a photon energy of 60keV was chosen. The residual strain distribution was determined by measuring the relative variation of position of the Al-311 Bragg reflection, which is known to show low plastic anisotropy and thus have a fairly linear relationship between stress and lattice strain.

Results

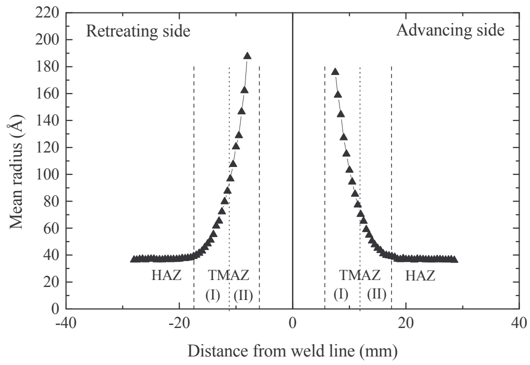
The characteristic regions of friction stir welds can be recognised from a profile in volume fraction, as illustrated in Figure 1.a. The heat-affected zone (HAZ) is characterised by a drop in volume fraction due to the high-temperature stage, leading to the partial dissolution of hardening precipitates, without significant change in the particle size (see Figure 1.b). The thermo-mechanically-affected zone (TMAZ) can be divided into two sub-zones :

- TMAZ (I): the decrease in volume fraction stops and becomes almost constant, even with a slight re-increase,
- TMAZ (II) is characterised by the decrease of the volume fraction down to zero as the peak temperature neighbours the solvus temperature of the precipitation phase.

Finally no initial precipitates have survived in the nugget. New small precipitates can be evidenced by hardness; these are GP zones formed during the low temperature regime of the welding process.



a. Volume fraction



b. Particle size

Figure 1 : Evolution of the volume fraction of precipitates (excluding GP zones) along the different characteristic regions of a friction stir weld (T79 low speed at mid-plate).

Results of SAXS measurements performed on the various welds are displayed in Figure 2 as maps of volume fraction and mean radius in the transverse direction of the welds. No major differences concerning the characteristics of the precipitates have been found between the advancing and the retreating side. The characteristic shape of the weld nugget and the through thickness variations can be observed. The influence of the welding speed and of the initial state will be discussed later.

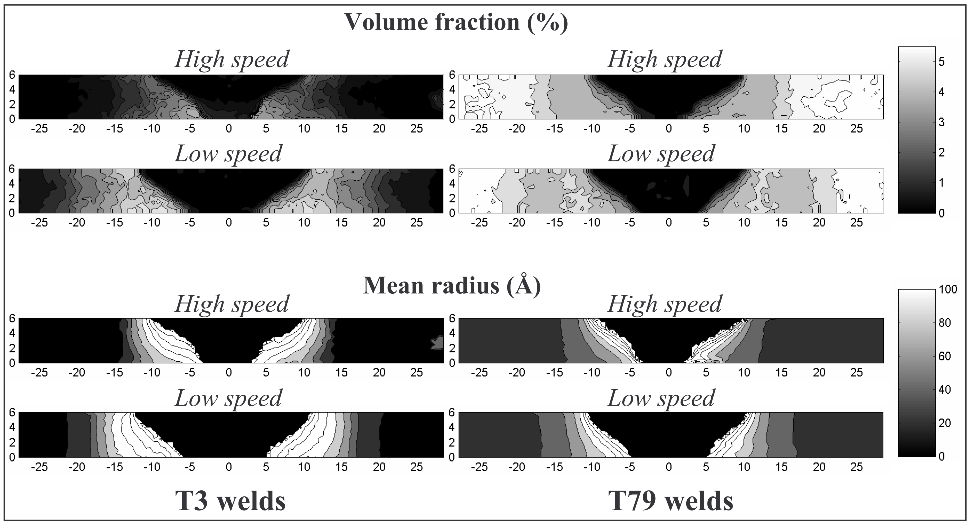


Figure 2 : SAXS maps (volume fraction and size) of T3 and T79 welds under high and low welding speeds.

Measurements of the strain distribution using X-ray diffraction were performed on the 6-mm low speed welds in the T3 and T79 tempers. Strains are obtained from the measured peak locations using the equation:

$$\varepsilon = -\cot\theta \, \Delta\theta$$

where $\Delta\theta=\theta-\theta_0$ is the difference between measured peak position and the equivalent peak position of the unstrained lattice spacing d0. Both longitudinal and transverse directions were investigated. Results of the measurements are displayed in figure 3.

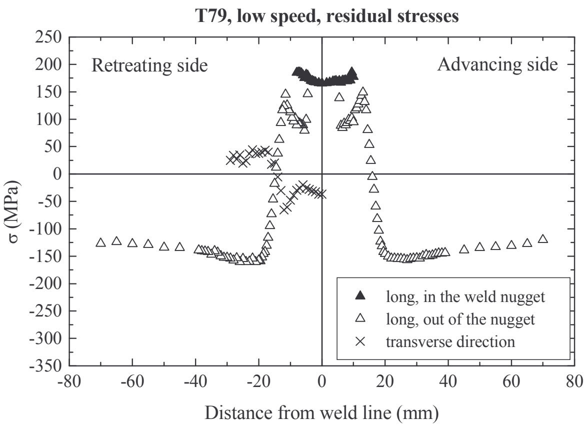


Figure 3 : Profiles of residual stresses in the longitudinal direction (long) and in the transverse direction for T79 low speed welds.

Conclusions

This fruitful double experiment, completed by some transmission electron microscopy and microhardness measurements, will be the subject of a paper in the next months.

We are grateful to the ESRF staff, especially on the ID31 and BM02 beam lines, for their help.