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Report:

Solid state phase transformations in steels are known to have a pronounced effect upon the residual stresses that arise as a result of welding. In pioneering work, Jones and Alberry[1] illustrated the dramatic effect reducing the transformation temperature has on the residual stresses produced on cooling of a constrained sample. In this work, a 60% reduction in the residual stress was achieved by reducing the transformation temperature by 100ºC. In principle, this phenomenon offers the opportunity to optimise (lower) the residual stresses typical of welding. However, in order to effectively exploit this effect, it is crucial that the extent and stress-dependence of such phase transformations under cooling trajectories representative of welds is understood and quantified. Once such an understanding has been developed, it may be possible to design alloys which optimise the state of residual stress to meet design criteria and hence could offer considerable performance benefits. Models have been developed capable of accelerating the weld design process, however, they are dependent upon the acquisition of reliable experimental data. It was therefore the aim of this experiment to; test apparatus capable of providing the experimental conditions required to simulate welding and, subsequently, to characterise the temperatures and stress dependence of the transformation for a particular weld filler composition. Once such data has been reliably obtained it may be fed back into the models to develop filler compositions tuned to give the appropriate transformation behaviour.

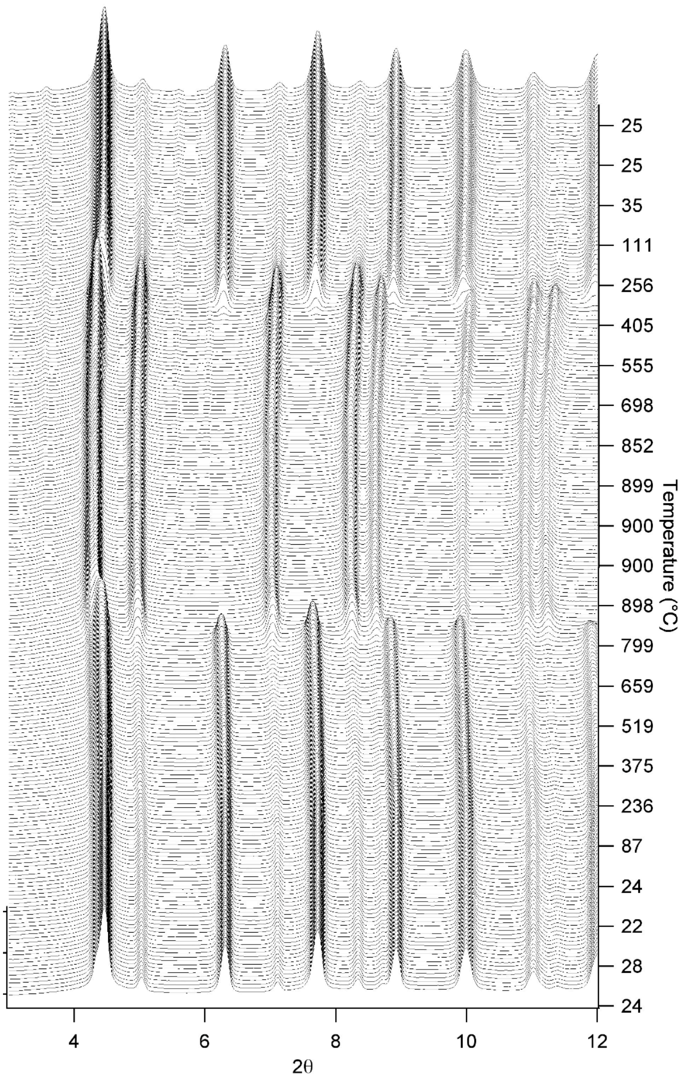

Figure 1: Diffraction data acquired during thermal cycling of steel weld filler material at 10°C/s

Experimental Results

In this study, a prototype of a novel thermo-mechanical loading rig capable of applying loads and cooling rates rate akin to those encountered during arc-welding was tested. This was the first operation of such an apparatus at a synchrotron facility and its use offers access to a range of experimental conditions hitherto inaccessible for diffraction experiments but of considerable relevance to materials processing studies. The issues of synchronisation of the data acquisition between the loading rig controller and the esrf systems were overcome and operation of this apparatus was successfully demonstrated. However, issues were encountered with temperature measurement and control on this prototype system which limited the data that could be acquired. Preliminary tests were also performed on a steel weld filler material under varying cooling rate (from 0.5°C/s to 50°C/s) and applied stress (from -100MPa to +100MPa). An example of the diffraction data acquired during a load - temperature cycle is given in Figure 1. From the data gathered it has been possible to obtain the evolution of the fractions of the principal phases and their lattice strains. An example of which is given in Figure 2.

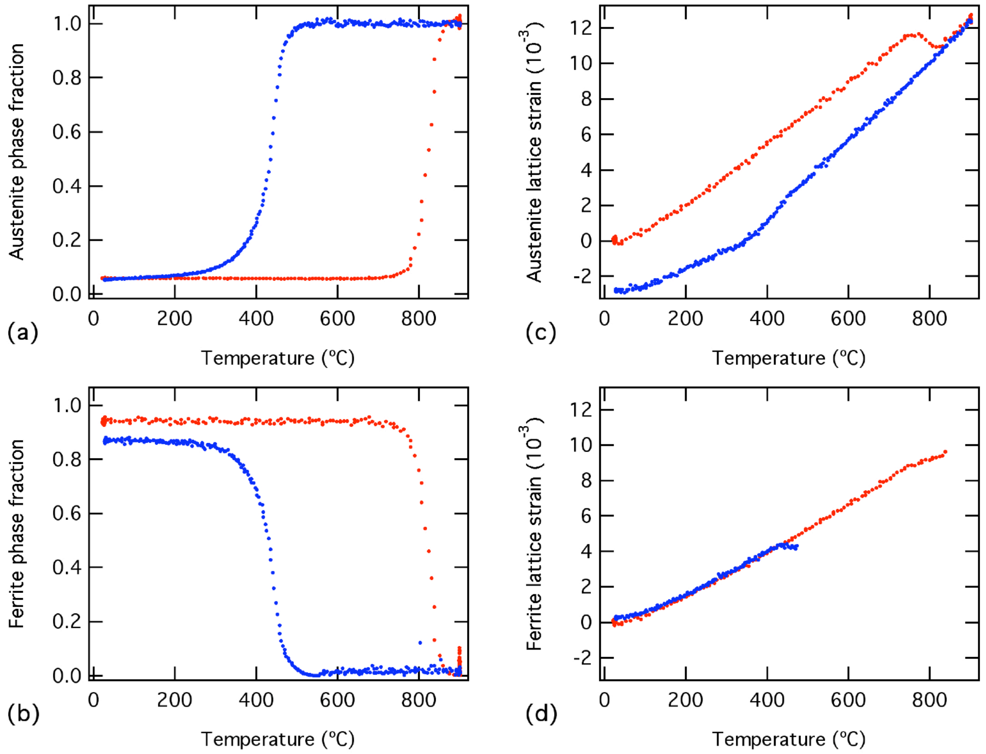

Figure 2: Temperature dependence of the phase fraction of Austenite (a) & Ferrite (b) and their lattice strains (c) & (d) on heating (red) & cooling (blue).

Implications of the results

These experiments constitute the first studies in which diffraction-based measurements of phase transformations in steels under welding-type conditions have been successfully performed during which the temperature & mechanical constraint were known. In work by Elmer and Ressler[2] and Babu et al.[3] at the Stanford synchrotron and later by Dye[4] a the ISIS neutron facility, studies were performed directly on coupons welded in the beam. However, in those experiments, detailed determination of the local thermal & mechanical conditions was not possible. As demonstrated in this experiment, thermo-mechanical simulation of welding overcomes this limitation and makes it possible to quantify the effects that these rapidly varying, complex conditions have on the materials investigated. Following the success of this preliminary experiment, second generation versions of the testing equipment are being produced. For these units the difficulties encountered during the tests run with this prototype unit will be addressed, particularly those with temperature determination. The first of these units will be available from October and will be subject to extensive testing and refinement prior to testing at the esrf facility. A second unit is due to be obtained in January 2005 and will be maintained by the FaME38 facility (ILL) for use by experimenters from other institutions.

References

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3. S.S. Babu, J.W. Elmer, S.A. David, and M.A. Quintana, Proc. R. Soc. Lond, 2001. 458A: p. 811-21.
4. Dye, D. Unpublished data.