sure@sunderland.ac.uk.

# Residual stress characterisation of a dissimilar metal electron beam welded plate using the contour method

N. Naveed[1,2] , F. Hosseinzadeh[2] J. Kowal[2] and P J Bouchard[2]
[1]University of Sunderland, Chester Road, Sunderland, SR1 3SD
[2]The Open University, Walton Hall, Milton Keynes, MK7 6AA
United Kingdom
Corresponding author: nida.naveed@sunderland.ac.uk

## Abstract

Dissimilar metal weld joints are widely used in safety-critical applications including nuclear power generating plants, chemical and petrochemical industries as well as conventional power systems [1]. When joining dissimilar metals the weld thermal cycle adversely affects the weld region, causing microstructural changes and large variations in physical, mechanical and chemical properties across the joint. These variations arise due to the metallurgical and physical incompatibility of the two metals. High energy density electron beam (EB) welding can reduce dissimilar metal joining problems to some extent and potentially produce satisfactory joints. The low heat input per unit length of EB welds results in a small weld bead size with a high depth to width ratio. This limits the extent of the heat affected zone, reduces distortion and restricts the range of tensile residual stresses. EB welding has been identified as a potential technique for joining stainless steel to modified 9Cr-1Mo ferritic steel for high temperature applications. However, EB welding has some disadvantages. The relatively small volume of molten material formed in the welding process rapidly solidifies and shrinks which can cause cracking in the weld metal and highly triaxial residual stresses with a steep gradient moving away from the weld line [2] that are difficult to measure and predict.

The contour method has emerged as a promising technique for the measurement of residual stresses in engineering components. This method was invented in 2000 by Mike Prime [3]. It is based on cutting the test component of interest into two halves by wire electro-discharge machining. The cut surfaces deform behind the cutting wire owing to the progressive relaxation of residual stresses. The deformation contours of the two cut surfaces are then measured, and used to back calculate a 2-dimensional map of original residual stresses acting normal to the plane of the cut. Nevertheless, like other residual stress measuring techniques, the contour method also suffers from factors that introduce uncertainties in the measured stresses impact and limit its spatial resolution.

In this paper, longitudinal residual stresses (acting in the welding direction) in an EB dissimilar metal weld joining AISI Type 316LN stainless steel to P91 modified 9Cr-1Mo steel were measured using the contour method. The narrow width of the EB fusion zone introduced short length scale residual stresses with steep stress gradients lateral to the weld line which presented a new challenge for the contour method. This challenge was addressed by taking special measures with respect to cutting and data analysis. A smaller cutting wire diameter (50 µm rather than standard 250 µm) was used to achieve a better surface roughness, the surface deformation was sampled at a higher frequency, the data smoothed over an optimum length-scale and an appropriate finite element mesh density chosen.

A cross-section map of the longitudinal residual stress measured by the contour approach described above is presented in Fig. 1. A line profile of contour results at 5.5 mm below the top surface of the plate is shown in Fig. 2. This result is compared with published data for the same component obtained by neutron diffraction and incremental centre-hole drilling residual stress measurement techniques [4]. Steep stress gradients on both sides of the weld centre-line (0 mm) have been resolved by the contour method with maximum tensile stress peaks situated just 2.3 mm apart. To the author's knowledge this is a shorter residual stress length scale than previously measured by the contour method.

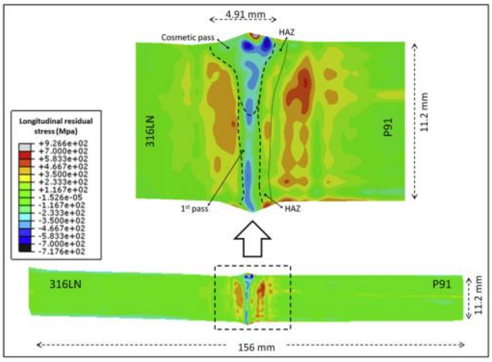


Fig. 1: Map of longitudinal stresses measured using the contour method

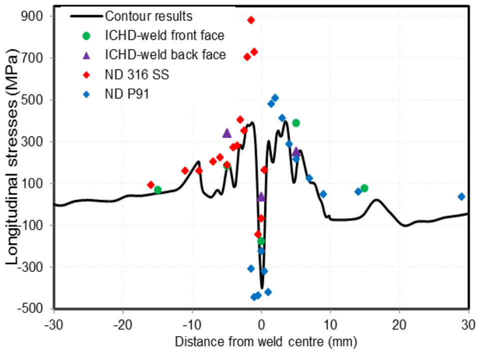


Fig. 2: Comparison of residual stresses measured by the contour method (5.5mm below the surface) with neutron diffraction data

## Acknowledgements

This work was financially supported by The Open University, UK. The test component was provided by the UK-India project DMW-Creep (co-funded by EPSRC grant EP/K007866/1). The author would also like to acknowledge workshop staff at the Open University for undertaking the contour cut.

## References

[1] Celik A, Alsaran A. Mechanical and Structural Properties of Similar and Dissimilar Steel Joints. Mater Charact. 1999 Nov;43(5):311–8.
[2] Liu C, Wu B, Zhang JX. Numerical investigation of residual stress in thick titanium alloy plate joined with electron beam welding. Metall Mater Trans B. 2010;41(5):1129–38.
[3] Prime MB. Cross-Sectional Mapping of Residual Stresses by Measuring the Surface Contour After a Cut. J Eng Mater Technol. 2000 Nov 3;123(2):162–8.
[4] Javadi Y, et al. Residual stress measurement round robin on an electron beam welded joint between austenitic stainless steel 316L(N) and ferritic steel P91, Int J Pres. Ves. & Pip., 2017, 154, 41-57.