**The Effect of Dilution on Near-Surface Residual Stresses In Multi-pass Welds**

**Using Low Transformation Temperature Filler Alloys**

*A novel technology now exists to enable the fabrication of welds in steels, where transformation plasticity is exploited to compensate for thermal contraction strains. This helps mitigate residual stresses and hence has consequences on the fatigue performance of the joints. However, there are significant discrepancies between measurements using high-energy X-rays or neutron diffraction data, that characterise the bulk state of stress; compared with low-energy X-ray data, which originate from near-surface regions. Many fatigue failures originate at the surface and the purpose of this work is to resolve the stress state in the surface regions of these “smart” welds.*

**Background to proposed experiment**

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| Figure 1: Longitudinal residual stress contours for a 3-pass weld estimated using neutron diffraction measurements at locations marked by crosses. |

It is known that the fatigue life of welded structures is often limited by the residual stresses generated during welding and considerable effort is required to address these issues. Techniques including: post-weld heat treatment and surface peening all contribute towards stress mitigation but a novel alternative approach is to exploit transformation plasticity as a method of self-stress-relief. In steels, the austenite (*γ*) to bainite/martensite (*α/α’*) phase transformation is associated with a large crystallographic shear that can relax the strains associated with thermal contraction of the filler material. However, because the martensite transformation temperatures (MS) for most filler alloys are well above room temperature, continued thermal contraction in the welded part after the transformation leads to the formation of large residual stresses as cooling continues to room temperature. Through judicious alloying additions, Ohta et al. [1-2] and Wang et al. [3] were able to suppress the transformation temperature sufficiently to realize the stress-relief benefits of this phenomenon and demonstrate a significant increase in the fatigue crack propagation resistance. However, less than optimal weld microstructures and limited toughness levels for the first generation of such filler alloys have limited commercial uptake. These issues have now been overcome using mathematical alloy design models and new candidate filler alloys have been identified which display the necessary microstructures and mechanical properties.

Residual stress measurements conducted on a single-pass weld at Chalk River have successfully demonstrated the stress-relief effect and possibility of generating compressive longitudinal stresses in the weld bead [4]. Further measurements by the proposer on 3-pass welds reveal compressive stresses in the weld (Fig. 1) but due to the gauge volume dimensions and measurement positions it would be inappropriate to extrapolate the stress contours to the surface. However, the fundamental purpose of using these types of alloys is to dispense with costly and time-consuming post-weld treatments to improve fatigue performance. It is therefore necessary to specifically investigate the surface regions of the weld and heat-affected zone to establish the stress magnitude and sign.

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| Figure 2: Fatigue performance of low transformation temperature (LTT) filler alloys [6]. |

Fatigue studies conducted by Karlsson et al. show that these types of alloys are capable of improving fatigue performance and that dilution of the filler alloy affects fatigue life (Fig. 2). Dilution of these highly alloyed fillers with the base material can significantly alter the martensite transformation start temperature (MS) and hence also the final stress state. The extent of dilution for a single-pass weld showed compositional changes up to 35% [5]. Critically, an optimised filler, specifically designed to compensate for dilution effects, showed remarkable fatigue performance, significantly greater than the first generation of low MS alloys. This improvement was achieved through increased alloying elements, which is expensive and could restrict application. Nevertheless, it still may be possible to achieve the outstanding fatigue performance by depositing layers of varying composition that can compensate for dilution in the initial pass, whilst subsequent layers require less alloying. Neutron diffraction will be used to study the effects of dilution on the near-surface residual stress state and how it may be compensated for with compositional modifications.

**Experimental Details**

We propose to obtain near-surface stress maps using the L3 – Stress Scanner. The welds will be made on notched ferritic plates (350 x 150 x 15 mm). The full weld will be formed of three layers: plate 1 will comprise of three welding passes made with a low transformation temperature filler alloy; plate 2 will have two passes made with a conventional filler and a final capping pass made from a low transformation temperature filler optimized for dilution; plate 3 will be a control specimen with the weld made entirely from a conventional filler.

Strain measurements will be made from a depth of 2.5 mm to the top surface in increments of 0.3 mm. For each of the three specimens, strain scanning will be performed across both sides of the weld bead into the heat affected zone and parent plate to identify any asymmetry in the stress fields. Measurements will be taken at 0, 4, 8, 12 & 16mm either side of the weld centerline to correlate with previously acquired data, Figure 1. Gauge volumes of 0.3 x 0.3 x 0.3 mm (longitudinal) and 0.3 x 0.3 x 30 mm (transverse & normal) will be used to achieve a balance between the spatial resolution required and counting statistics. With these gauge volumes and the number of points required to map the state of stress across the central section of the weld, it is anticipated that 20 days will be required to complete the measurements. In addition, as significant compositional variations are expected across the welds, strain free lattice parameters will be obtained from comb samples at the same positions as the strain measurements.

**References**

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