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The effect of tensioning and sectioning on residual stresses in aluminium AA7749 friction stir welds

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Abstract

Using synchrotron X-ray diffraction the residual stress distribution has been measured in a series of AA7449-W51 aluminium friction stir welds that had been tensioned to different loads during welding. By modifying the stress accumulation path, the application of a tensioning stress has reduced the tensile magnitude of the final residual weld stresses. In the present case the residual stresses were minimised when the applied load is ∼35% of the room temperature yield stress of the parent material. Subsequent sectioning of the weld into shorter test lengths, as might be necessary for weld testing, resulted in a progressive and significant relaxation of the residual stress field. The effect of tensioning on the weld component distortion also has been investigated.

Keywords: Friction stir welding; AA7449; Residual stress; Mechanical tensioning; Stress relaxation

1. Introduction

The presence of residual stresses in welded components are known to have a significant influence on the lifetime [1]. Recent work [2–7] has substantially improved our understanding of the residual stress distribution in components joined by friction stir welding (FSW), however, this remains an area of uncertainty. The effect of many easily controlled parameters, such as welding speed, tool type, downward force, clamping method, alloy type/temper or the weld geometry, have not been characterised in a systematic way. Nevertheless, some features can be said to be well established and in agreement with theory [8]. In common with most, if not all, welding methods, the region around the weld is associated with tensile residual stresses which tend to be largest in the welding direction. In a number of instances residual stresses approaching the local room temperature yield point have been found in friction stir welds [7,9]. In practice there is a limit to the extent that residual stress can be reduced simply by optimising the FSW conditions [7]. Furthermore, other requirements, such as avoiding the introduction of flaws and maintaining production rates, may constrain the parameter range that can be employed.

Tensile loading of welds during the welding process has been suggested as a means of significantly reducing the residual stresses [10,11]. This loading can be performed during or after welding and can be categorised as *global*, where the entire component is mechanically loaded, or *local*, where the additional loads are applied to a small region around the location of the tool. The latter includes various localised heating or cooling methods which indirectly alter the stress state [12].

Weld tensioning works by reducing the level of local misfit that accumulates between the soft metal in the weld vicinity during welding [21]. Staron et al. used strain measurements by neutron diffraction to determine the stress state in welds produced in 3.2 mm and 6.3 mm thick AA2024 sheet with and without mechanical tensioning applied during welding [10]. They found that while low levels of tensioning reduced the tensile peak stresses, tensioning to 70% of the room temperature yield stress of the parent material caused the residual stress profile to change from tension to compression (peak stress of −200 MPa as against +150 MPa without tensioning). The same tendency has been observed using synchrotron X-ray diffraction measurements on 3.2 mm thick AA2024 over a wider range

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of tensioning levels [13]. In this case the longitudinal residual stresses were predicted to be close to zero at an applied stress of ~25% of the room temperature yield stress of the parent material. The change in the sign of the stresses was accompanied by a switch in the plate distortion from concave to convex (relative to the surface onto which the tool was forced).

Several authors have found residual stresses in simple friction stir welds that are substantially lower than the yield point of the material (~100 MPa) [3,5,6]. However, in these cases the samples were cut from larger plates and the extent of relaxation was not quantified. This raises an important question, especially when evaluating the residual stresses or cross-weld properties in cut-down samples or test-pieces. The extent to which residual stresses relax on cutting down the plates and thus the extent to which they are representative of those which might be found in a welded engineering component is difficult to estimate.

The aims of this paper are twofold. Firstly, to present a systematic study, both experimentally and using FE modelling, of the effect of global mechanical tensioning during welding on the residual stress distribution and component distortion in friction stir welded AA7449-W51 aluminium plates. Secondly, to examine the effect of cutting up welded components on the residual stress field. In this context, we succeeded in finding a simple phenomenological formula for the prediction of stress relaxation. These results have important implications in cases where test-pieces are cut out from longer welds for evaluation, for example to determine cross-weld tensile strength or when investigating the fatigue behaviour, which is significantly influenced by residual stress fields.

2. Experimental

2.1. Weld trials

The welds were produced from 12.2 mm thick plates of AA7449 having a nominal composition of 7.5–8.7 Zn, 1.8–2.7 Mg, 1.8–2.4 Cu, 0.25 Ti/Zr and 0.20 Mn (wt%) with the remainder aluminium and minor impurities. The plates were supplied in the W51 temper, i.e. solution heat-treated and stress relieved by stretching the material to 0.5–3%. No elevated temperature ageing treatment was applied. In this condition, the material has a 0.2% yield strength, σ_{ys}, of 583 MPa. Although beyond the scope of this paper optical microscopy indicates a microstructure consistent with the prior literature, i.e. a partially recrystallised microstructure with pancake-shaped grains up to 1 mm in length in the longitudinal direction and possessing a substantial substructure with sub-grains of the order of 1–10 μm [14].

Two 1000 mm × 150 mm plates were clamped and mounted in a butt-weld configuration (see Fig. 1). Global tensioning was applied using hydraulic rams attached to each end of the plates using serrated, hardened grips that extended to 125 mm width. Slipping was further restricted by five 17.5 mm diameter pins in each grip that passed through pre-made holes in the plates. Welds were produced in a single pass with a weld track 800 mm long.

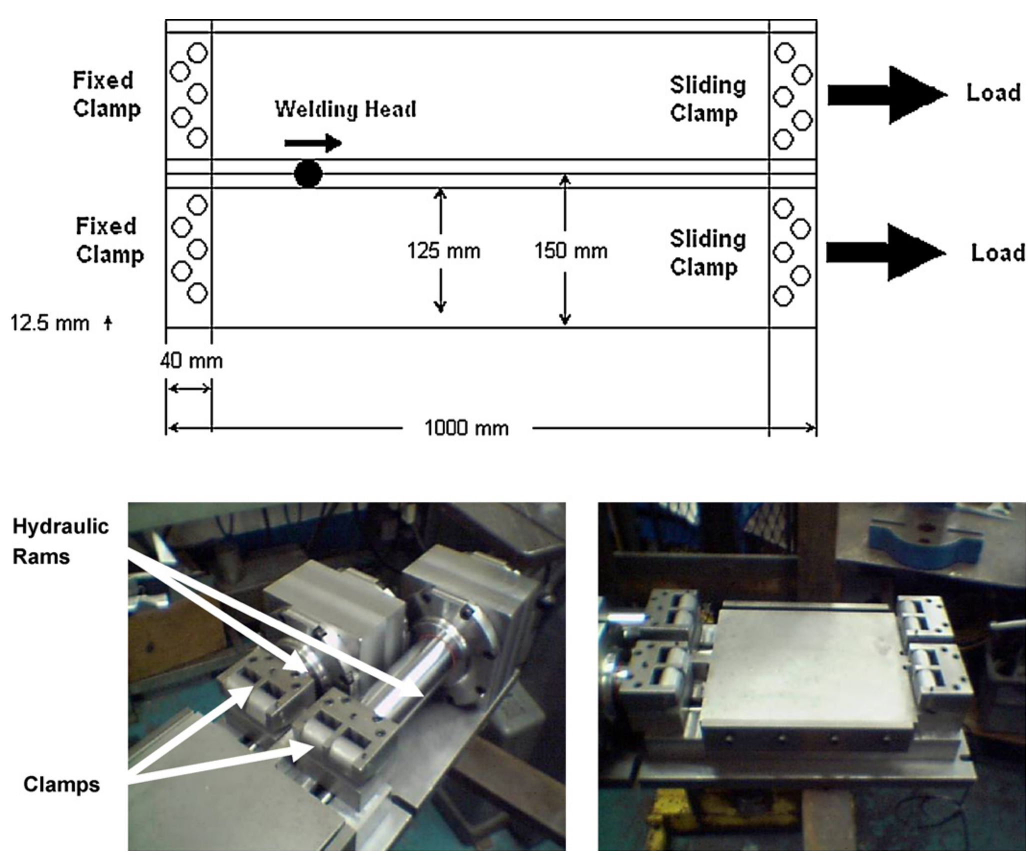

Fig. 1. Mechanical tensioning method and equipment used to generate the sample welds.