C. Prediction of Residual Stresses and Property Distributions in Friction Stir Welds of Aluminum Alloy 6061-T6

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Introduction

Friction stir welding (FSW) is an innovative solid-state joining process that offers significant advantages over fusion welding processes for joining aluminum alloys. Because of the unique mechanisms of material joining in FSW, the residual stresses in a friction stir weld could be different from those of fusion welds. In addition, the thermal cycle in FSW introduces microstructural changes in the weld region of heat-treatable aluminum alloys. The resultant property field and residual stress field in a friction stir weld joint could have significant influence on the performance of frictions stir welded structures.

Technical Approach

In this study, an integrated thermal-mechanical-metallurgical model was used to study the formation of the residual stress field and the HAZ softening of Al6061-T6 friction stir welds. The simulations were conducted using a three-dimensional model, accounting for the frictional heating, aging and dissolution processes of the precipitates, and the mechanical contact effects of the moving tool. Temperature-dependent material properties were also considered in the finite element model. In addition, the residual stress fields of two friction stir welds made under different welding speeds were measured using the neutron diffraction mapping technique, compared with the 3-D model predictions.

Results and Discussion

For the ¼" thick friction stir welds used in this study, both the model simulation and neutron diffraction measurement show minimal depth dependence of the residual stresses, except for the region adjacent to the edge of the tool shoulder. Both the longitudinal and transverse stresses are tensile in the weld region, with the maxima located in the HAZ corresponding to the edge of the tool shoulder. The longitudinal residual stress is higher than the transverse one in the weld and the adjacent region. The longitudinal residual stress reaches the maximum value of approximately 200MPa, much lower than the yield strength of the base metal (300MPa). The numerical simulation indicates that a possible mechanism is due to the microstructural changes and associated softening of the HAZ and weld region.

For the two welding speeds (11 and 31 in/min) investigated, it was found that the residual stresses were higher in the high welding speed case. This correlates to the degree of HAZ softening. The higher welding speed case shows less HAZ softening, due to the faster cooling rate.

Al6061 and several other high-strength Al alloys undergo natural aging after welding. In general, the natural aging increases the strength of the weld from the as-welded condition. However, the residual stress field shows negligible changes after the natural aging. The mechanism behind this phenomenon will be discussed in the presentation.

The numerical simulations of the tensile test of the friction stir welds correlate well with the actual deformation and failure process observed experimentally. The location of failure is in the HAZ, at approximately 55 degree angle from the specimen surface. The model reveals that the failure of a friction stir weld under tensile load is due to the localization of deformation in the HAZ, under the combined effects of material softening and high residual stress.

Conclusions

The residual stresses in friction stir welds of Al6061-T6 were analyzed using an integrated thermal-mechanical-metallurgical model and neutron diffraction mapping. The residual stress distribution is strongly dependent on the welding process parameters and the degree of material softening in the as-welded conditions. The recovery of material strength from natural aging does not increase the residual stress in the weld. The failure of a friction stir weld under tensile load is controlled by the combination of the material softening and the high residual stresses in the HAZ.