The Fatigue Performance of Friction Stir Butt Welded AA 6061-T6511 Plate

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Abstract:

Very little data exists in the literature on aluminum friction weld fatigue behavior. Thus in order to compare the fatigue performance of Friction Stir Welding (FSW) with both the parent metal and conventional MIG welding, a series of FSW specimens were produced for strain-life fatigue testing. The friction stir welds performed better than the MIG welds at shorter lives, but were equivalent to MIG welds at longer lives. As expected the performance of the parent metal was better than either the FSW or MIG welded materials, especially at long lives.

Specimens:

Specimen were fabricated from 500mm by 100mm by 12mm thick AA_6061-T6511 plates, clamped and friction welded together along the 500mm edge. As shown in figure_1 fatigue specimens were then cut from the welded plates using an abrasive water jet cutter.

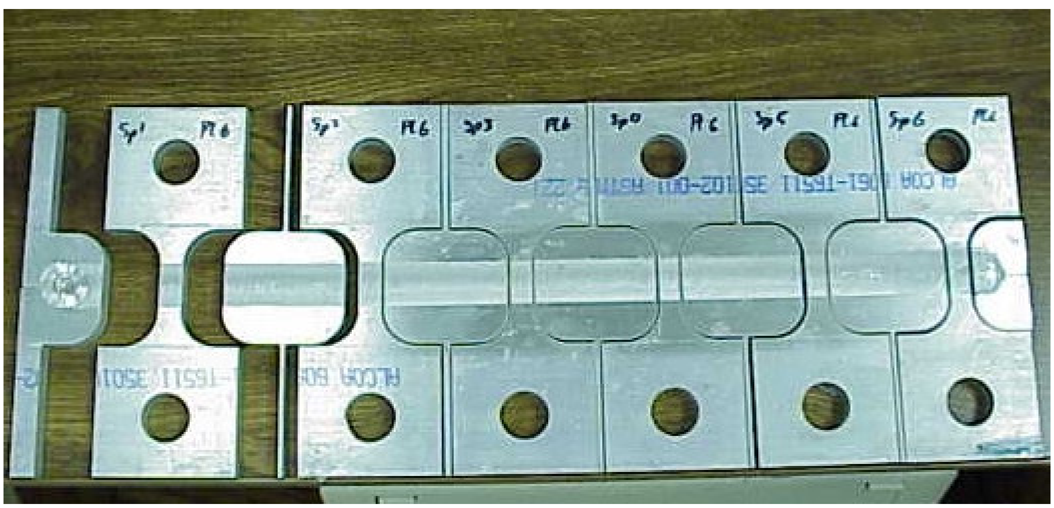

Fig. 1 : Fatigue Specimens as cut from Friction Stir Welded AA_6061-T651 Aluminum Plates

Because of the approximate 25mm length of the weld zone it was necessary to use 25mm gauge lengths (central parallel sided section), which, due to the necessity of avoiding cyclic buckling of samples during fatigue testing, restricted the maximum strain test amplitude to +-0.005_mm/mm. The weld beads on the plate surface side of the specimens were left in the as-welded condition, but the water cut edges had to be polished to a similar smoothness as the original plates. During axial fatigue testing, at the Univeristy of Waterloo, the samples were clamped between two grip plates by large bolts at each end of the specimens. Strain, the controlling test variable, was measured along the sides edge of the 25mm gauge length by a 0.3in gauge length extensometer. Testing frequencies ranged from less than 1Hz in short life tests to 100Hz in the long life tests. After cyclic stabilization of the stress-strain behavior, long life tests were switched to stress control.

Fatigue Test Results:

Mohamed Khalil at the University of Waterloo tested 10 samples in fatigue and one in a tension test (Sy=136 mpa, Su=227 mpa). Using the first cycle loading results the average elastic modulus was found to be 9853ksi (67900mpa). Although all samples failed just outside of the weld zone, as would be expected, the measurements of cyclic stress and strain allowed the creation of a fatigue curve. A comparison of the the weld data against the fatigue behavior of the base metal, AA_6061-T6511, plotted in a "Neuber" stress range vs. life arrangement. The vertical axis of figure_2 is equal to Elastic Finite Element stress range and is a better basis for design than stress vs. life or strain vs. life.

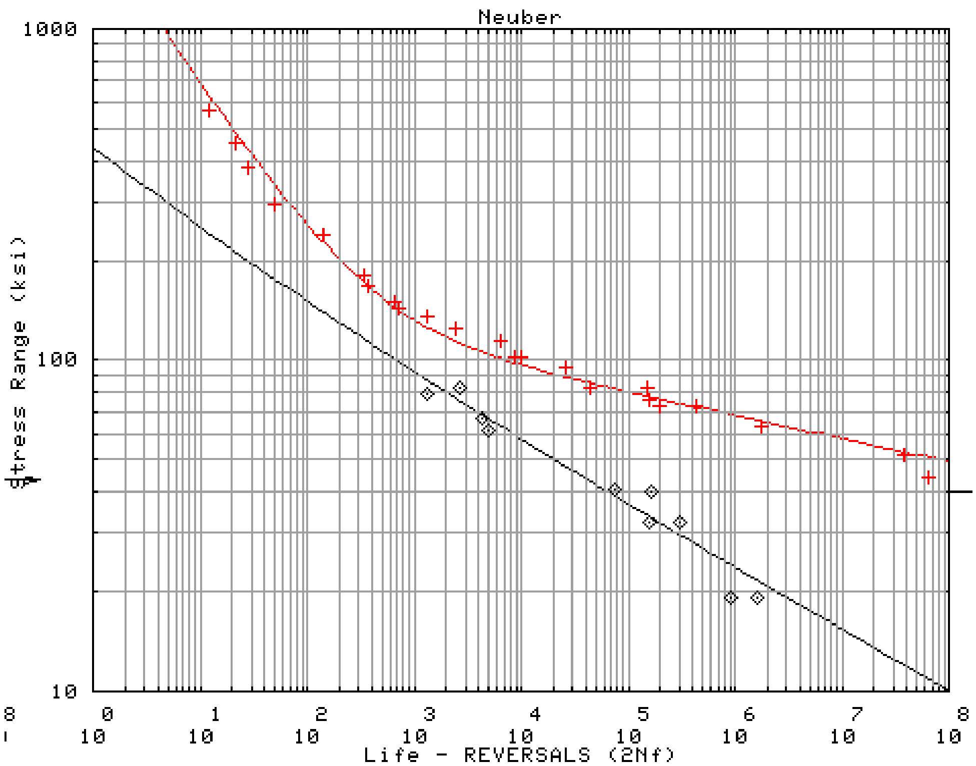

Fig. 2 : Neuber Plot of Stress Range of base AA 6061-T6511 data and Friction Stir Welded Fatigue tests.

It is clear from the data that friction stir welding reduces the fatigue performance of the alloy when compared to the parent metal. At medium life levels (10^3-10^4) the difference is small, but at long life (10^6) the difference is considerable -- a factor of three in Neuber stress.

The same data has also been cross-plotted alongside the regular MIG Fusion weld data available in the literature**:**

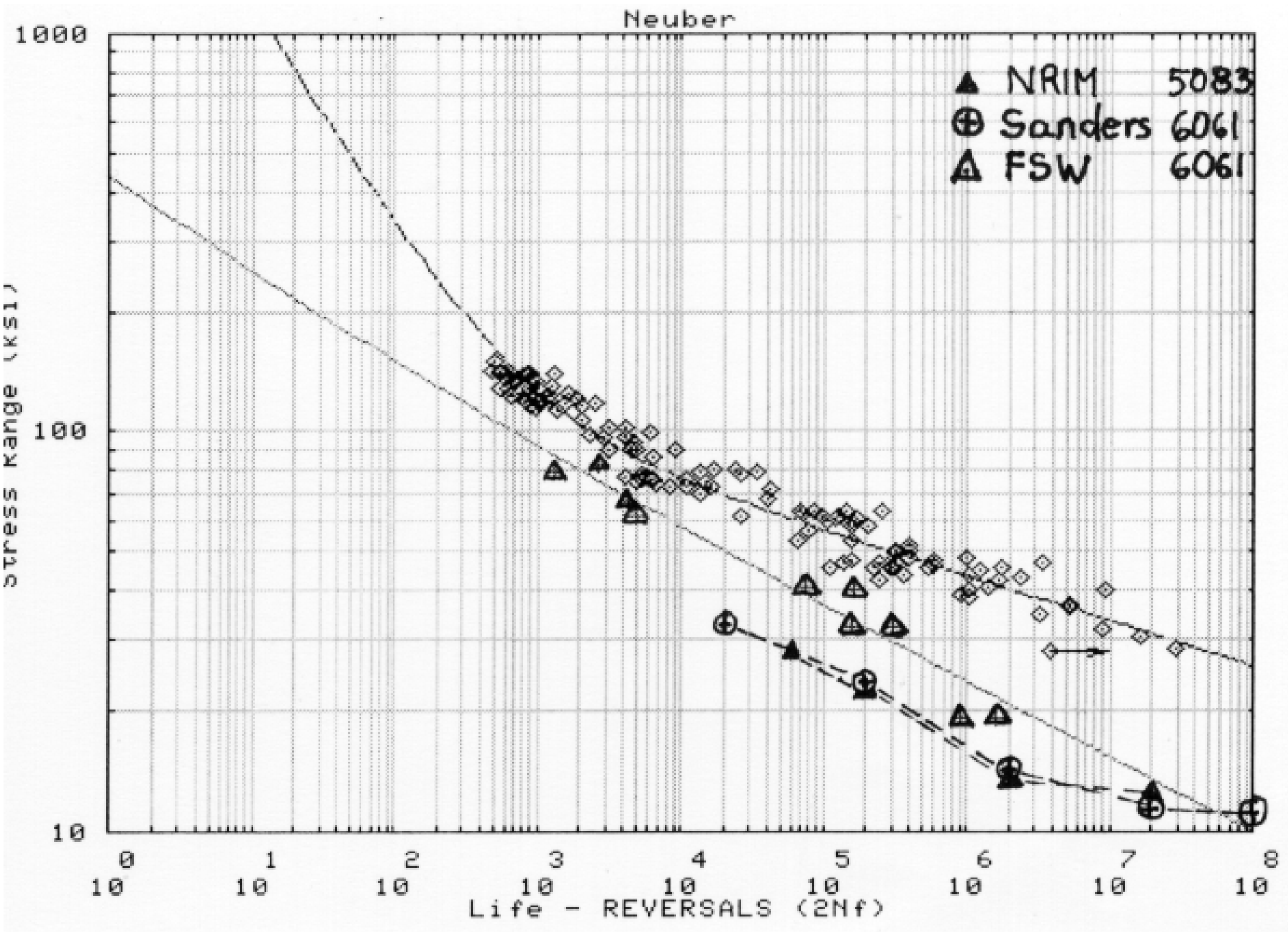

Fig. 3 : Neuber Plot of Stress Range of base AA 6061-T6 data, Fusion Welded data sets, and Friction Stir Welded Fatigue tests.

It appears that the friction stir welding process is much better than fusion welding in the short life region, but tends to be equivalent to fusion welding in the long life region of the fatigue life curve.

Discussion:

It is not clear why the friction stir weld fatigue tests show a greater effect at long life than at short life. One suggestion is that the welding effectively heat treats the material near the end of the weld and thus yields different fatigue strengths. Another possibility is that the weld seams were left in the as-welded condition, with an additional stress concentrating effect of the beads at the weld edge. This concentration would be less noticeable at high strain levels where plasticity dominates. Plasticity may also affect any residual stresses, both tensile and compressive, that could be expected to occur around a given weld. It may be instructive to have a data set tested with weld surface machined off and/or heat treated to remove possible residual stress effects.

References:

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2. Koebler, H.-G., "Beurteilung der Schwingfestigkeit von Schweissverbindungen aus AlZnMg1 auf dem Weg einer Oetlichen Dehnungsmessung (Teil 2), Aluminium, Vol.50, No.7, 1974, pp.445-449.
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