Diffraction Notes

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CHARACTERIZATION OF TENSILE RESIDUAL STRESSES IN 7050-T7651 ALUMINUM FRICTION STIR WELDS

INTRODUCTION

Salt spray corrosion pits are a common site of fatigue crack initiation in aluminum alloy aircraft components. Salt corrosion pitting occurs during exposure to the marine atmosphere and results in intergranular corrosion to a depth dependent on the time of exposure, temperature, and the service environment of the aircraft. The pronounced fatigue strength reduction caused by salt pit corrosion is well established for both steels[1] and aluminum alloys,[2] and typically reduces the endurance limit to nominally half of the uncorroded value.

Friction stir welding (FSW) allows the welding of even dissimilar aircraft alloys with up to 30% weight reduction and reduced manufacturing and maintenance costs. However, the FSW process has been shown to produce zones of tensile residual stress at the edges of the stir zone. Pitting and stress corrosion cracking have been observed to follow these regions of tension. Recent work performed at Lambda Research[3,4,5] to map the residual stress distributions in both aluminum and titanium friction stir weldments show that these zones of tension can extend completely through the weld. In addition, the surface produced by FSW, although relatively flat, is typically not adequate for aircraft applications. Beyond removing the burr generated during FSW, the swirled marks left by the tooling require removal.

A new surface enhancement technology has been developed which can provide a layer of surface compression of sufficient depth to effectively eliminate the influence of the salt pit corrosion. Low Plasticity Burnishing (LPB)[6] has been demonstrated to provide deep high magnitude compression at low cost. The LPB process can be performed on conventional CNC machine tools at costs and speeds comparable to conventional machining operations such as surface milling.

Recent preliminary studies[7] on salt spray corroded 7075-T6 aluminum have demonstrated full restoration of the original material endurance limit and a 10x increase in life in the finite fatigue life range, which exceeds that of the original machined surface.

LPB offers the opportunity to induce a layer of compressive residual stress at least 1 mm into the surface of the weld zone spanning both the parent metal and stir zones. The process could be performed after removal of the burr immediately following FSW or as part of the original welding operation. Figure 1 shows a

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ANNOUNCEMENTS

UPCOMING PRESENTATIONS

Aircraft Corrosion Workshop Presentation Entitled "The Influence of Surface Enhancement by LPB on the Corrosion Fatigue Performance of AA7075-T6"

A paper describing improved corrosion fatigue and high cycle fatigue initiation from corrosion pits in 7075-T6 aluminum with prior LPB processing will be presented at the Aircraft Corrosion Workshop, August 22, 2002 at the Holiday Inn Select in Solomons, Maryland. LPB prior to either salt fog pitting or active corrosion fatigue increased the HCF endurance limit by over 3X, higher than the original un-corroded material. Aging aircraft structural components are potential applications.

6th Joint FAA/DoD/NASA Aging Aircraft Conference

The 6th Aging Aircraft Conference will be held at the Hyatt Regency in San Francisco, September 16 – 19, 2002. Paul Prevéy will present the paper "Application of Low Plasticity Burnishing to Improve Damage Tolerance of the Ti-6Al-4V First Stage Fan Blades." The presentation will describe the application of low plasticity burnishing to increase the damage tolerance along the leading edge of Ti-6Al-4V fan blades by an order of magnitude.

7050-T7651 aluminum FSW specimen being low plasticity burnished. The introduction of deep compression should reduce the surface stress in service to a value less than the SCC threshold and eliminate stress corrosion cracking. Further, the burnishing process is inherently smoothing and may produce a surface finish in a single operation acceptable for airframe and structural aircraft applications. This study was intended to determine the nature of residual stress distributions present using existing FSW practice, establish optimal LPB parameters for FSW processing, and document the effect of the layer of compression and improved surface finish on fatigue performance with and without salt fog corrosion.

RESIDUAL STRESS

Friction stir weld (FSW) plates were supplied by Rockwell Scientific for the purpose of residual stress and fatigue analysis. The friction stir weld plates were manufactured from 0.25 in. thick 7050-T7651 aluminum plate and were supplied as nominal 6 x 12 x 0.25 in. weldments containing a single weld down the 12 in. length on center. Residual stress distributions developed by FSW and LPB were mapped in the directions parallel and perpendicular to the weld line using automated mapping apparatus developed at Lambda Research. X-ray diffraction (XRD) residual stress measurements were made at the surface on both the weld and root sides and at 1/4, 1/2 and 3/4 thickness from the weld side.

XRD residual stress measurements were made employing a $\sin^2$ø technique and the diffraction of chromium Ká radiation from the (311) planes of the 7050-T7651 aluminum. It was first verified that the lattice spacing was a linear function of $\sin^2$ø as required for the plane stress linear elastic residual stress model.[8-11] The value of the x-ray elastic constants required to calculate the macroscopic residual stress from the strain normal to the (311) planes of the 7050-T7651 were determined in accordance with ASTM E1426-91.[12] Systematic errors were monitored per ASTM specification E915. The Ká$_1$ peak breadth was calculated from the Pearson VII function fit used for peak location during macroscopic stress measurement.[13] An empirical relationship was established between the material cold working and the Ká$_1$ line broadening for 7050-T7651 aluminum.[14] The percent cold work is a scalar quantity, taken to be the true plastic strain necessary to produce the diffraction peak width measured, based on the empirical relationship.

The residual stress distributions parallel and perpendicular to the weld line are shown in Figures 2 through 5. The as-welded sample contains tensile residual stresses, as high as +40 ksi, in the parallel direction at the surface and at all of the depths tested. There are relatively low tensile stresses, in the perpendicular direction, below the surface of the as-welded sample. The LPB sample contains compression at the surface of the weld (LPB'd) side in all directions. Tensile stresses, of the same nominal magnitude as the as-welded sample, were measured below the surface and on the root (unprocessed) side of the LPB sample.

The percent cold work results are shown at the bottom of Figures 2 through 5. The as-welded sample was found to have cold working of less than 1%. The LPB plate sample contains cold working of over 50% on the weld (LPB'd) side surface. The high surface cold work level is attributed, primarily, to the surface milling operation used to remove the weld flashing. LPB alone outside of the previously milled area produced less than 5% cold work.

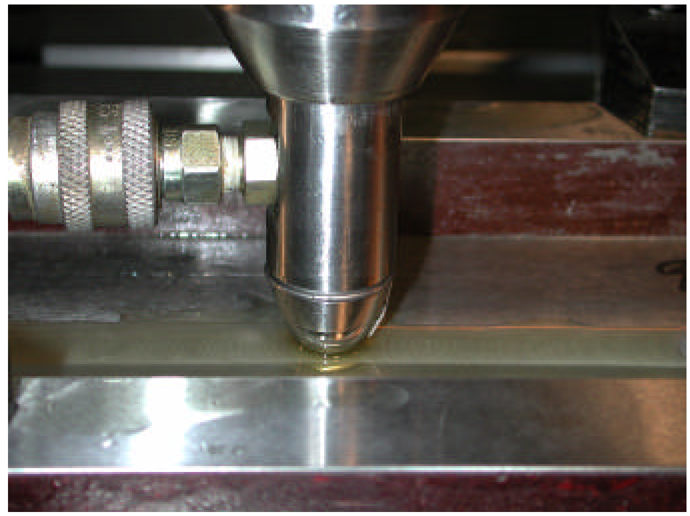

Figure 1 – LPB processing of 7050-T7651 friction stir weld.

High Cycle Fatigue Performance

Fatigue testing was conducted at ambient temperature (~72F) under constant amplitude cyclic loading in four-point bending mode. The cyclic frequency and load ratio, R, were 30 Hz and 0.1, respectively. Tests were conducted to the event of specimen fracture or until a "run out" life of 2.5 x 10^6 was attained, whichever occurred first.

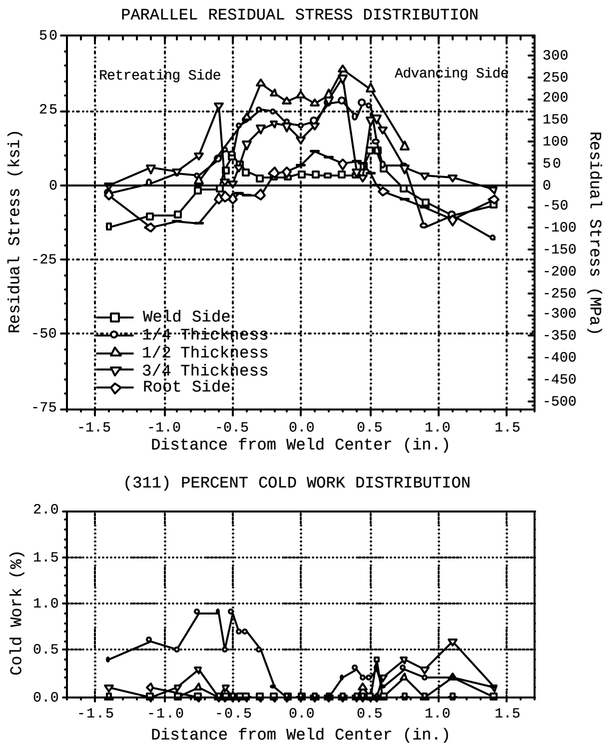

Figure 2 – The distributions of residual stress in the direction parallel to the weld line as a function of position across the width of the stir zone and at various depths in an as-welded sample.

A total of four S-N curves were generated from four groups of specimens as follows:

As-welded
Welded + LPB
As-welded + 100 hr salt fog (ASTM B117)
Welded + LPB + 100 hr salt fog (ASTM B117).

S-N results for the four groups of fatigue tests are presented graphically in Figure 6. The endurance limit for as-welded specimens (~25 ksi max stress) was substantially improved to nominally 40 ksi by first milling to remove flashing followed by LPB. The endurance limit for both as-welded and LPB specimens was degraded by 5-10 ksi after 100 hr exposure to salt fog per ASTM B117. The 10 ksi reduction is an estimate for the salt fog exposed LPB specimens, though no "run outs" were actually observed in this specimen group. LPB provided an order of magnitude improvement in fatigue life at stress levels above the endurance limit, with or without corrosion. The increased life is attributed to retardation of fatigue crack growth in the deep compressive layer developed by LPB. Salt fog exposure reduced fatigue life only slightly in the finite life regime for both as-welded and LPB specimens, although the

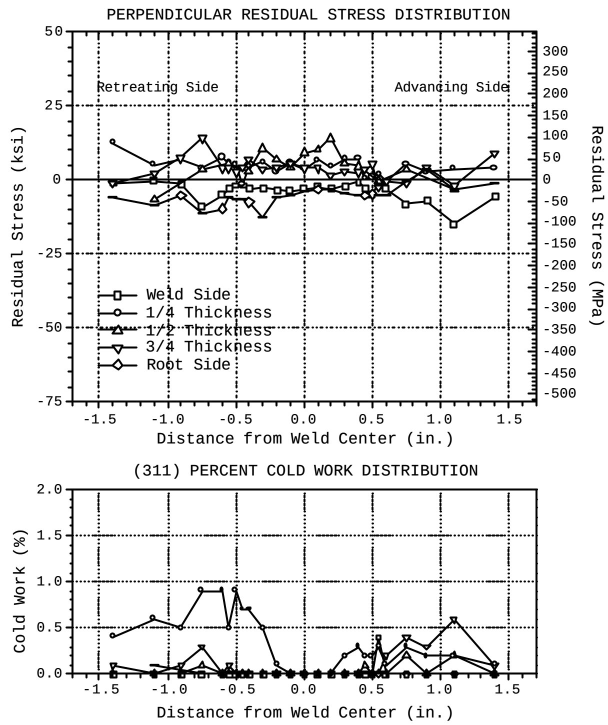

Figure 3 – The distributions of residual stress in the direction perpendicular to the weld line as a function of position across the width of the stir zone and at various depths through the thickness in an as-welded sample.

reduction was somewhat greater for the salt fog exposed LPB specimens.

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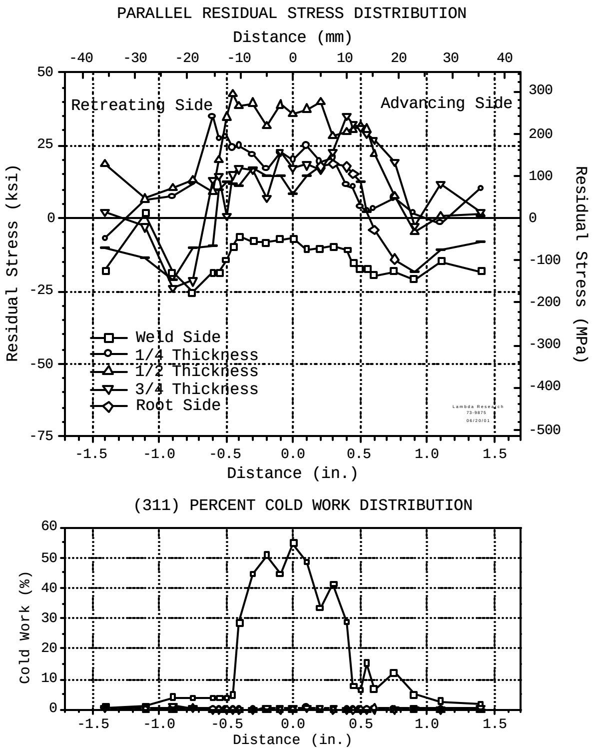

Figure 4 - The distributions of residual stress in the direction parallel to the weld line as a function of position across the width of the stir zone and at various depths through the thickness in an LPB processed sample.

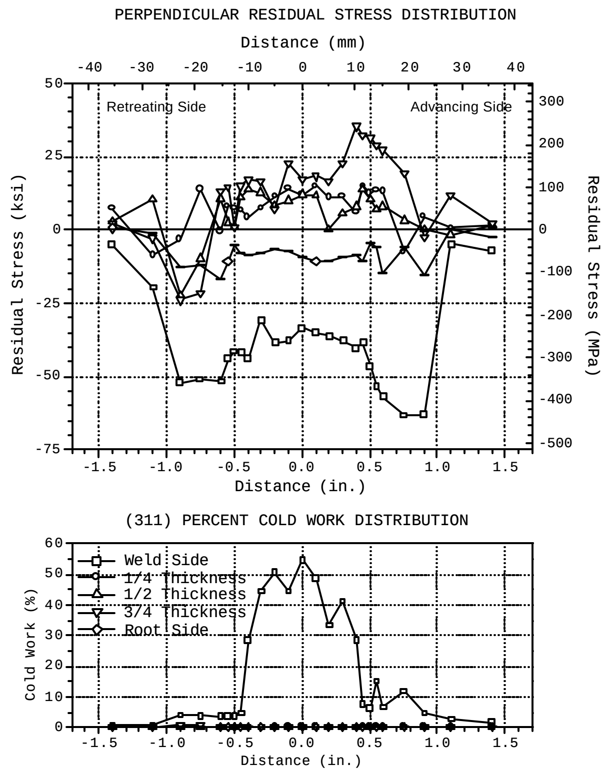

Figure 5 - The distributions of residual stress in the direction perpendicular to the weld line as a function of position across the width of the stir zone and at various depths through the thickness in an LPB processed sample.

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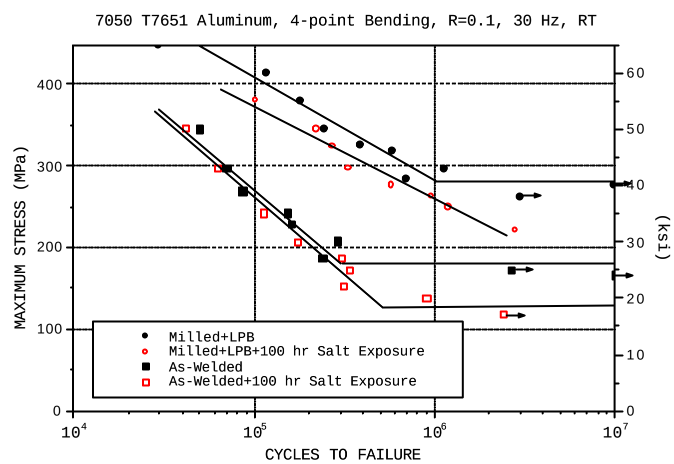

Figure 6 – High cycle fatigue results for 7075-T651 aluminum.