Diffraction Notes

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FATIGUE LIFE IMPROVEMENT AND MITIGATION OF PITTING CORROSION DAMAGE OF FRICTION STIR WELDED 2219-T8751 ALUMINUM ALLOY BY LOW PLASTICITY BURNISHING

INTRODUCTION

Friction stir welding (FSW) is a new solid state joining process for aluminum alloys including those alloys considered not weldable. However, the FSW process produces zones of tensile residual stress at the edges of the stir zone. Recent residual stress studies performed at Lambda Research on aluminum and titanium alloy FSW samples show tensile residual stresses throughout the weld thickness with maximum tension near the weld edges. Pitting and stress corrosion cracking has been observed to follow these regions of tension. Also, the surface produced by FSW, although relatively flat, is not adequate for many applications.

A new surface enhancement technology has been developed which can provide compression in the surface layer of sufficient depth to effectively eliminate the degradation in corrosion/fatigue life attributed to salt pit corrosion. Low plasticity burnishing (LPB)[1,2,3,4,5] has been demonstrated to provide deep high magnitude compression. CNC tools can be used to apply the process at costs and speeds comparable to conventional machining operations.

Salt spray corrosion pits are a common site of fatigue crack initiation in aluminum alloy structures. Salt corrosion pitting occurs during exposure to a marine atmosphere and results in intergranular corrosion to a depth depending 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[6] and aluminum alloys,[7] and typically reduces the endurance limit to nominally half of the uncorroded value.

Recent studies[2] 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. Studies on LPB processed 7050-T7651 FSW samples show a nominal 60% increase in endurance limit due to the LPB treatment.

LPB offers the opportunity to induce a layer of

ANNOUNCEMENTS

UPCOMING PRESENTATIONS

132nd TMS Annual Meeting & Exhibition
March 2-6, 2003, San Diego, California

A paper describing improved corrosion fatigue and high cycle fatigue initiation from corrosion pits in 2219-T8751 aluminum with prior LPB processing was presented at the TMS meeting. LPB prior to either salt fog pitting or active corrosion fatigue increased the HCF endurance limit by nearly 2X, higher than the original un-corroded material. Aging aircraft structural components are also potential applications.

44TH AIAA/ASME/ASCE/AHS
April 7-10, 2003, Norfolk, VA

Paul Prevéy will present a paper entitled “Application of Low Plasticity Burnishing to Improve Damage Tolerance of a Ti-6Al-4V First Stage Fan Blade.” This paper describes the benefits of applying LPB to the leading edge of the blade to improve damage tolerance and increase fatigue strength.

HIGH CYCLE FATIGUE CONFERENCE
April 14-16, Monterey, CA

Papers describing the effect of surface treatments on the HCF and FOD tolerance and fretting fatigue of Ti-6Al-4V will be presented. These papers detail the benefits of applying LPB to improve the HCF performance and FOD tolerance of a turbine engine vane and for dovetail fretting mitigation.

PORTABLE RING CORE APPARATUS

Lambda has developed a portable ring-core apparatus for the determination of principal residual stresses as a function of depth. Ring-core is a mechanical method of measuring the residual stresses in coarse grain weldments and castings. The technique consists of placing a strain gage on the sample and machining an annular groove around the gage. Stresses can be measured to a maximum depth of nominally 0.3 in. (7.6 mm) with the current instrumentation.

compressive residual stress into the weld surface, heat affected zone (HAZ), and adjacent parent metal while smoothing the weld crown. LPB was performed in the direction of the weld using multiple passes adjacent to and in the weld and the pressure was controlled to develop the desired magnitude and depth of compressive stress with low cold work. Figure 1 shows the process of LPB on a CNC milling machine.

All HCF samples (4-point bending fatigue) were milled on the weld side prior to LPB or salt fog exposure to reduce the influence from the weld flash and circular grooves left by the FSW process. The weld flash was milled flush with the parent metal. A total of four S-N curves were generated for the following groups of specimens:

Group No.	Group Identification
1	As-Welded + Milled
2	As-Welded + Milled + LPB
3	As-Welded + Milled + 100 hr. Salt Exposure
4	As-Welded + Milled + LPB + 100 hr. Salt Exposure

Prior to fatigue testing the as welded + milled and as welded + milled + LPB test specimens were exposed to a 5 percent (by weight) NaCl solution fog at a temperature of 95F for 100 hrs. The exposure was performed in a Singleton Salt Fog Cabinet in accordance with ASTM Specification B117-97.

Residual Stresses

The residual stress distributions measured as functions of depth and distance, using automated mapping apparatus developed at Lambda Research, from the weld centerline are presented in Figures 2a-e. Each plot presents residual stresses parallel and perpendicular to the weld line for a given depth through the thickness of the plate in ¼ thickness increments. On the weld surface and root surface, residual stresses were also measured in the 45° direction. At the weld surface, the as-welded samples are in tension in the parallel direction and compression in the perpendicular direction. Following LPB, the residual stress is compressive in all directions, ranging from –180 to –500 MPa at the weld surface.

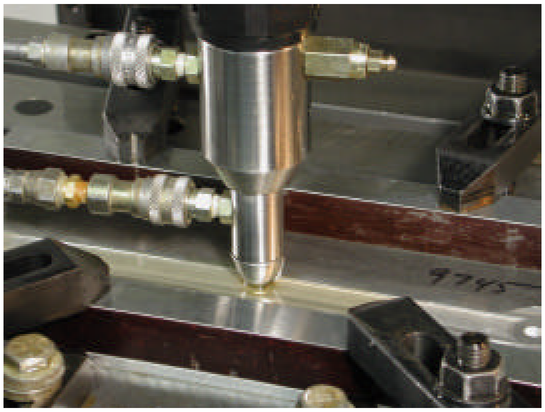
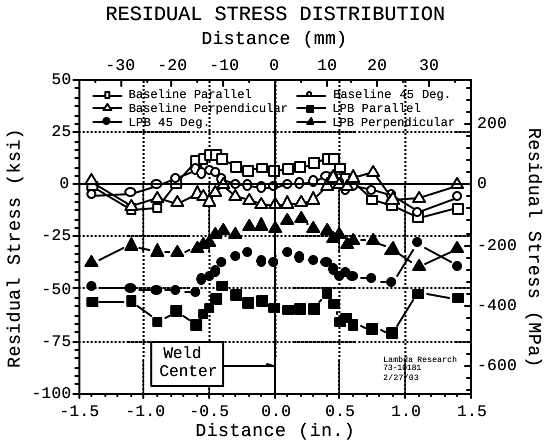


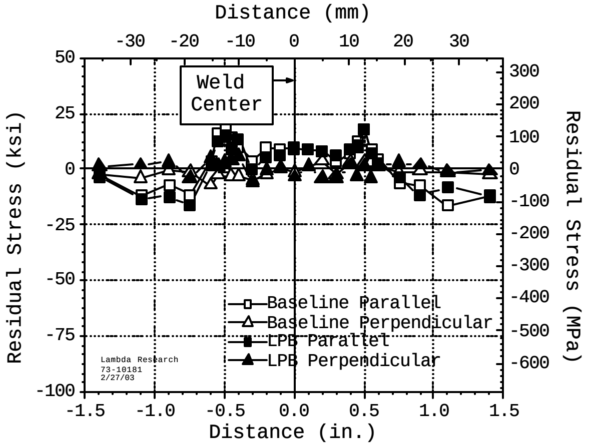
Figure 1: Photo of friction stir welded plate being low plasticity burnished with single ball tool.

Residual stresses vary as a function of distance from the weld centerline reaching minimums in the regions that correspond to the HAZ's on both the advancing and retreating sides. This is likely due to the LPB procedure. In this study, no attempt was made to adjust the burnishing load to the yield stress of the 2219 Al. Thus, in the softer HAZ's, the response to the LPB would be different than that in the higher yield stress weld zone and parent metal.

At ¼, ½, and ¾ thickness, the as-welded and LPB samples have similar residual stress patterns, Figs. 2b-d. The influence of LPB was limited to a depth of less than 1/4 thickness in order to minimize distortion. The results for both samples show an increase in tensile residual stresses in the parallel direction at mid-thickness. Tensile stresses are highest near the weld edges and approach +240 MPa. These are much higher values than reported previously where measurements were taken only near the crown and not at the root.[8] Residual stresses perpendicular to the weld direction are essentially zero. Figure 2e illustrates residual stresses on the weld root surface. For the as-welded sample within the weld zone, residual stresses are compressive and relatively low at approximately -100MPa in the parallel, 45°, and perpendicular directions.



(a)



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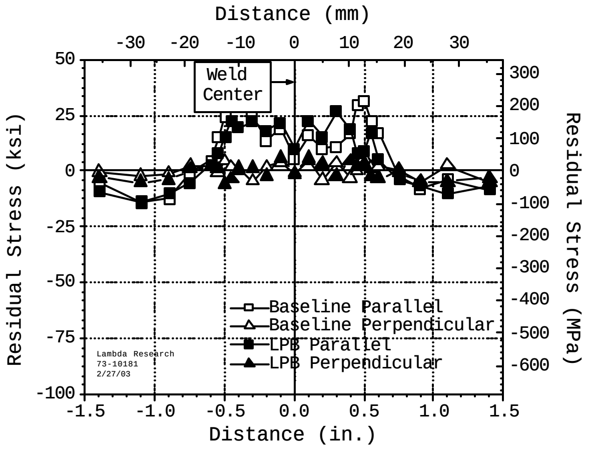
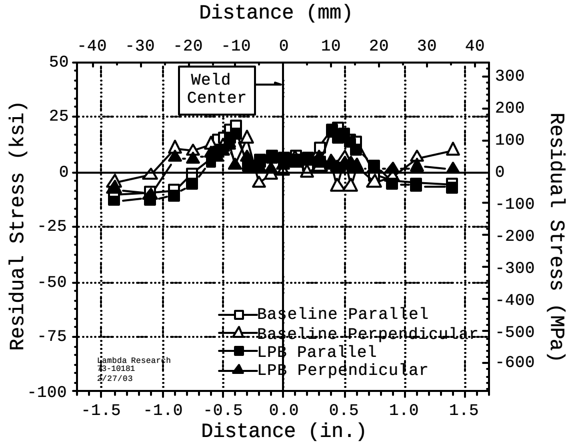
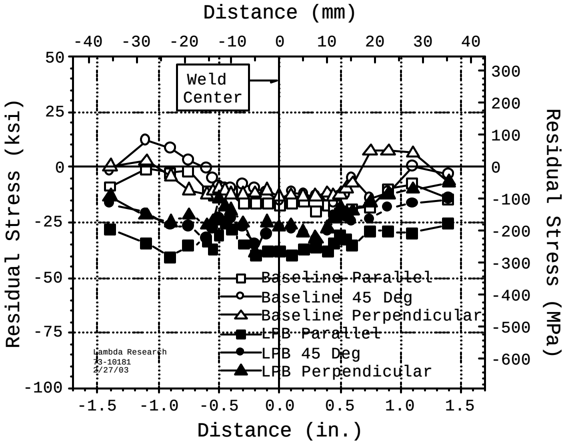


(c)



(d)



(e)

Figure 2: Residual stress measurements in FSW 2219 T8751 aluminum with and without LPB, (a) weld surface, (b) ¼ thickness, (c) ½ thickness, (d) ¾ thickness, and (e) weld root surface.

Following LPB, these stresses become more compressive ranging from -20 to –250MPa. Although only the top surface was treated by LPB, the bottom surface experiences compression due to plate bending.

Surface hardness measurements, made on an as welded + milled specimen are shown in Figure 3. The measurements are shown on a Rockwell B scale as a function of distance from the weld center. The results indicate relatively soft material in the weld as compared to the parent material. The softest material is located near the edges of the weld.

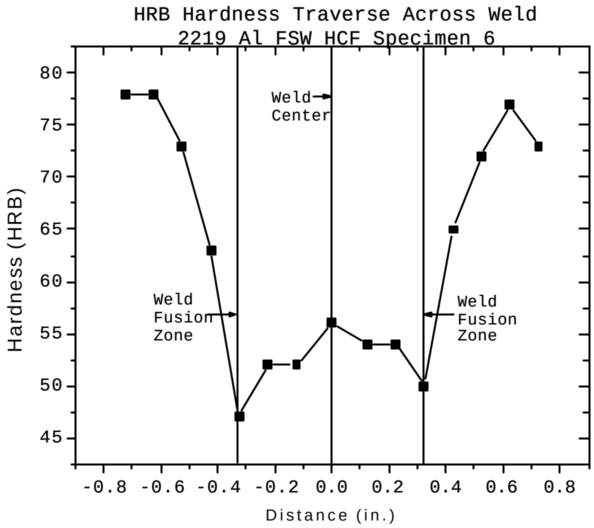


Figure 3: Surface hardness traverse on Milled fatigue specimen showing softened weld material.

High Cycle Fatigue

High cycle fatigue results are presented in Figure 4 for different test conditions. For FSW material, with the flash and circular tool pattern removed by milling, the endurance limit was nominally 230MPa. The endurance limit for the Milled specimens was decreased by nominally 25% after the 100 hr salt exposure. LPB of the Milled samples increased the endurance limit to 300MPa. The 100 hr. salt exposure had little influence on the fatigue strength of the LPB specimen.

Fatigue initiation sites for the milled specimens were typically at the surface within the gage region. Specimens that were cycled at higher maximum stresses had multiple initiations within the gage. Almost all the initiation sites were outside of the weld material. LPB moved the fatigue initiation site from the surface of the gage section to the corners. At low stresses, crack initiation was located subsurface at the corners. Subsurface initiations, originating below the highly compressive surface, do not effectively demonstrate the full effect of LPB processing on fatigue performance. Presumably, an even higher applied stress would have been required to initiate failure from the surface. However, the occurrence of failures below the LPB compressive layer reveals the substantial fatigue enhancement benefits of LPB.

Fatigue initiation sites for salt corroded specimens were comparable to that for samples not corroded. However, the corroded bars exhibited more multiple initiation sites as a result of numerous corrosion pits, especially for the milled + 100 hr salt specimens. Samples treated via LPB prior to corroding failed subsurface and not fom the corrosion pits. LPB was effective in preventing the corrosion pits from acting as fatigue crack initiation sites.

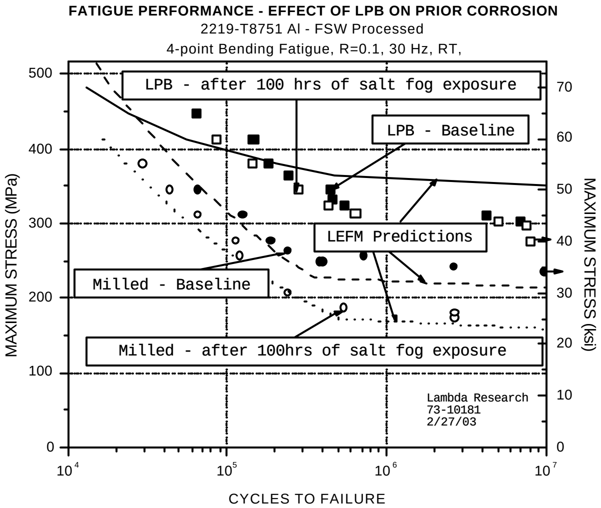


Figure 4 - Fatigue test results for friction stir welded 2219-T8751 aluminum with and without LPB.

CONCLUSIONS

- LPB was shown to produce high compressive residual stresses in 2219-T8751 aluminum friction stir welds. LPB was performed using conventional CNC machine tools at costs and speeds comparable to conventional machining operations.
- The As-welded samples had tensile residual stresses greater than +200 MPa in the direction parallel to the weld line. After LPB the surface of the FSW specimen was in compression, as high as –450 MPa, in all directions.
- LPB increased the endurance limit by nominally 60% in salt corroded FSW specimens. Specimens that were LPB and salt corroded had the same nominal fatigue strength as samples that were LPB processed without corrosion indicating the LPB process eliminated any fatigue debit from salt fog corrosion.
- Fatigue failures for some LPB samples initiated below the surface. The occurrence of failures below the LPB compressive layer demonstrates the dramatic fatigue enhancement associated with LPB.

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