THE INFLUENCE OF SURFACE ENHANCEMENT BY LOW PLASTICITY BURNISHING ON THE CORROSION FATIGUE PERFORMANCE OF 7475-T7351 AND 2024-T351

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ABSTRACT

Corrosion fatigue and stress corrosion cracking (SCC) are primary failure mechanisms that reduce the structural integrity of aircraft. Conventional corrosion mitigation in aircraft involves coatings, alloy substitution, or modifications in design to reduce stresses. All are expensive solutions. This paper describes the use of low plasticity burnishing (LPB) to enhance the corrosion fatigue strength in 7475-T7351 and 2024-T351, without alteration of environment, material or component design.

The fatigue performance of LPB processing and shot peening of both 7475-T7351 and 2024-T351 were compared. Various processing and exposure conditions, typical of aircraft structures, were investigated including shot peening, anodization, thermal exposure and salt spray exposure. X-ray diffraction residual stress measurements revealed that LPB produced twice the depth of compression as shot peening. LPB produced a 10X improvement in life over shot peening for 7475-T7351 and a 50% improvement in life over shot peening in 2024-T351.

KEYWORDS

Low Plasticity Burnishing, shot peening, corrosion fatigue, residual stress, surface enhancement

INTRODUCTION

The pronounced fatigue strength reduction caused by salt corrosion pitting or corrosion fatigue in a marine environment is well established for aluminum alloys.[1] Fatigue cracks can initiate from corrosion pits in aluminum aircraft structural components. Annual costs for corrosion inspection and repair of Naval aircraft alone are estimated to exceed one billion dollars. By the year 2015 over 90% of military aircraft are expected to exceed 20 years of age.[2] A means of mitigating corrosion fatigue in aging aluminum aircraft structures is needed.

LPB [3,4,5] is a surface enhancement process that can be used with conventional CNC tools or robots, to produce deep compressive residual stresses on complex components. LPB produces lower cold working than conventional deep rolling which has been shown to improve the retention of compressive residual stresses at elevated temperatures.[6,7,8] The basic LPB tool consists of a ball supported by a flow of fluid in a spherical hydrostatic bearing. Figure 1 shows the LPB processing of fatigue specimens in a 4-axis CNC mill. The supporting fluid can range from standard cutting fluid used in most milling applications to pure water depending upon the application. The ball is rolled across a component in a sequence that is controlled via the CNC code. Tool pressures are designed to produce a specific compressive residual stress distribution. LPB does not remove material and leaves behind a very smooth surface finish often times with Ra values on the order of 5 μin. Dual ball LPB treatment is used to produce through-thickness compression in turbine blade edges to enhance the tolerance to foreign object damage (FOD).

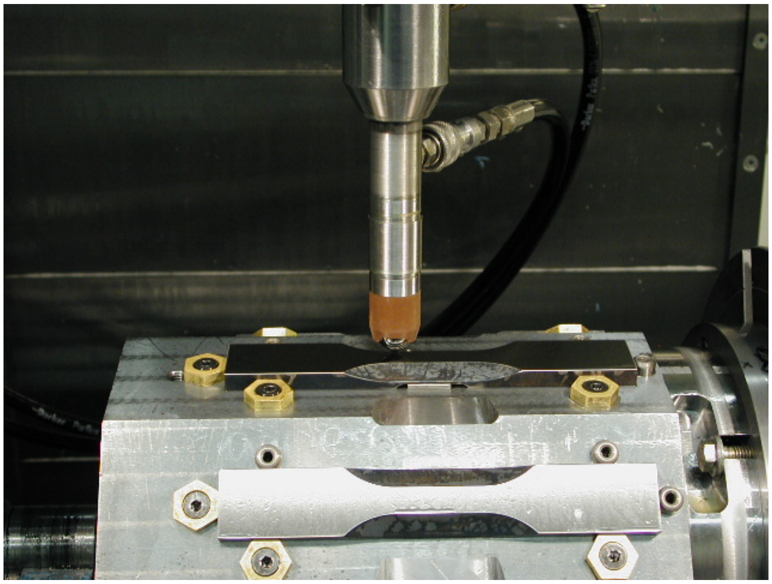

Figure 1 – LPB processing a set of eight fatigue specimens in a 4-axis CNC mill.

It has been demonstrated elsewhere that LPB improves high cycle fatigue (HCF) performance and damage tolerance and reduces the susceptibility for SCC of turbine engine components, airframe structures, nuclear weldments and biomedical implants.[9,10,11] This paper discusses the use of LPB on airframe materials, specifically 2024-T351 and 7475-T7351.

EXPERIMENTAL METHOD

Residual Stress Measurements

X-ray diffraction residual stress measurements were made on fatigue specimens representing five different processing conditions for each of the two alloys. Measurements were made on an as-machined, shot peened and LPB processed specimen. Measurements were also made on a shot peened and LPB specimen after thermal exposure. The residual stress distributions were measured using the conventional sine-squared psi method that has been described in detail previously.[12,13,14]

Fatigue Testing

HCF tests were conducted on specimens manufactured from 7475-T7351 and 2024-T351. A trapezoidal cross-section sample was used to promote fatigue initiation from the highly compressive surface of the LPB or shot peened gage region.

A total of five specimens were tested in thirteen different conditions. A detailed description of the processes studied is listed in Table I. Fatigue strength was compared between as-machined, shot peened and LPB treated samples. Typical post shot peening cleaning and anodization were included in the fatigue study. The influence of thermal exposure and salt spray corrosion was also investigated.

Process	Description
Shot Peen	8 – 10A Intensity 100% Coverage
LPB	Low Plasticity Burnishing Treatment
Clean After Shot Peen	ATS recipe for clean after SP and/or stripping of Anodic Coating
Anodize	ATS recipe for CAA (Chromic Acid Anodize) without seal/without clean after SP
Clean + Anodize	ATS recipe for CAA (Chromic Acid Anodize) without seal but with clean after SP (A2) incorporated
Expose to Heat	Heat Damage - 30 hrs to 250±10°F
Salt Spray Corrosion	Neutral Salt Spray exposure (500 hrs)

Table I: Fatigue specimen process description.

Fatigue tests were conducted in four-point bending using constant amplitude sinusoidal loading. Specimens were tested at room temperature at a frequency of 15 Hz and a load ratio R of 0.1. Specimens were tested until failure or a run-out ($1x10^6$ cycles) occurred. The first specimen of each group was tested at a peak stress of 422 MPa (61.2 ksi). The alternating stress for each additional sample was adjusted depending on the life of the first specimen tested.

RESULTS AND DISCUSSION

Residual Stress Measurements

Residual stress results are shown in Figures 2 and 3. Machining produces a shallow and low magnitude compressive residual stress distribution. Shot peening produces a depth of compression on the order of 0.5 mm (0.02 in.). LPB causes a compressive distribution on the order 1 mm (0.04 in.), twice the depth of shot peening. Thermal exposure causes no measurable difference in residual stress for the LPB treated 2024-T351 samples. The compressive residual stress from shot peening is reduced by approximately 20% for both alloys as a result of the thermal exposure. Compression is reduced on the order of 30% for the thermally exposed LPB treated 7475-T7351 samples. Thermal relaxation is generally higher for the 7475-T7351 samples compared to the 2024-T351 samples.

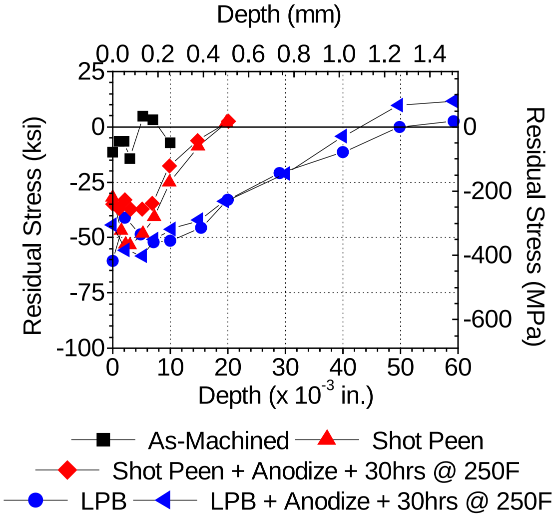

Figure 2 – Residual stress vs. depth in as-machined, shot peened and LPB treated 2024-T351 samples.

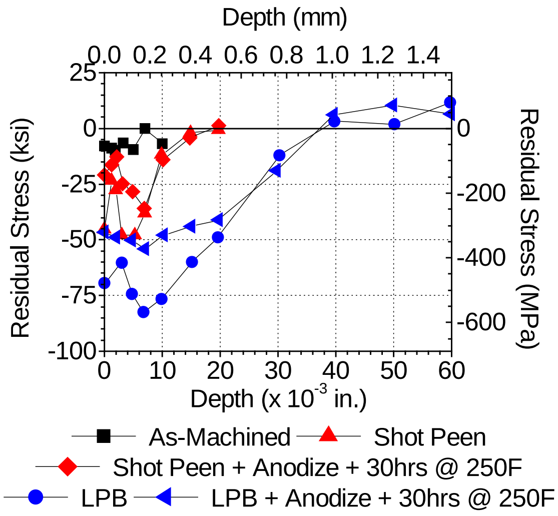

Figure 3 – Residual stress vs. depth in as-machined, shot peened and LPB treated 7475-T7351 samples.

Fatigue Testing

In order to consolidate the results, fatigue lives are compared at a maximum alternating stress of 61.2 ksi (422 Mpa). Data are presented in bar chart form for the following groups of samples; 1) Baseline & LPB, 2) Heat Damage and 3) Salt Spray Corrosion.

Fatigue lives for as-machined, shot peened and LPB treated samples are shown in Figures 4 and 5. As-machined specimens have the lowest fatigue strength of the group. Shot peening produces a nominal 3X increase in life above the as-machined condition. Anodizing leads to a slight debit in fatigue life for the as-machined and shot peened specimens. LPB treatment produces the highest fatigue lives for both alloys. LPB provides over a 4X improvement in life over the baseline condition for 2024-T351 and over an 8X improvement for 7475-T7351.

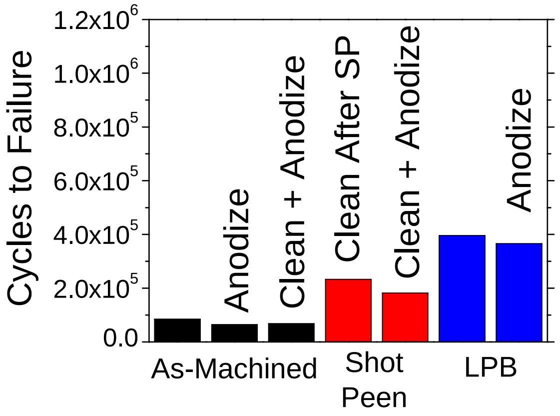

Figure 4 –Cycles to failure at maximum stress of 422 MPa (61.2 ksi) for 2024-T351 as-machined, shot peened and LPB samples.

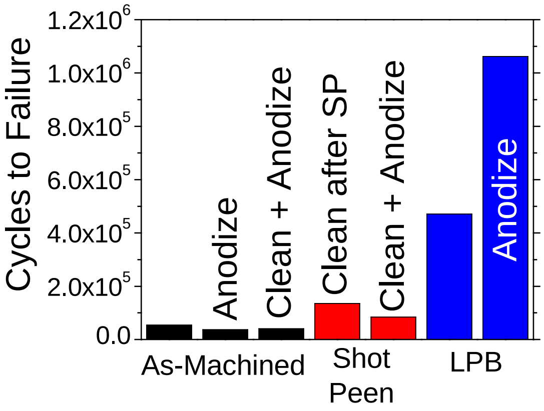

Figure 5 - Cycles to failure at maximum stress of 422 MPa (61.2 ksi) for 7475-T7351 as-machined, shot peened and LPB samples.

Fatigue results for thermally exposed 2024-T351and 7475-T7351 specimens are compared to those with no thermal exposure in Figures 6 and 7. A 30 hr. thermal exposure at 250F reduced the life in both alloys for all three conditions. Thermally exposed shot peened 2024-T351 samples had a nominal 3X improvement over thermally exposed baseline specimens. However, thermally exposed shot peened 7475-T7351 samples had only a small improvement over the exposed baseline samples. Thermally exposed LPB samples had a fatigue life greater than the shot peened samples.

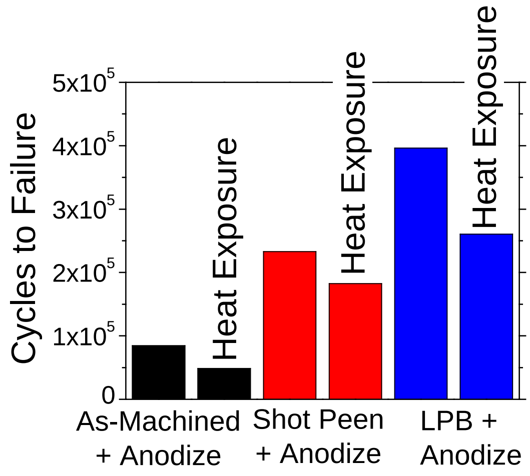

Figure 6 – Cycles to failure at maximum stress of 422 MPa (61.2 ksi) for 2024-T351 thermally exposed samples compared to baseline results.

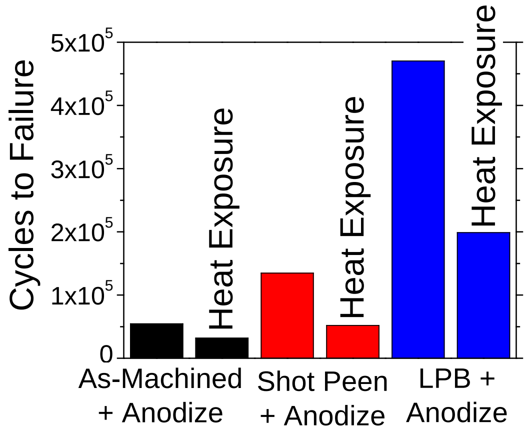

Figure 7 – Cycles to failure at maximum stress of 422 MPa (61.2 ksi) for 7475-T351 thermally exposed samples compared to baseline results.

Fatigue results for salt spray corroded samples are shown in Figures 8 and 9. As-machined, shot peened or LPB treated samples were fatigue tested to half of the expected life for each condition. Samples were exposed to a salt spray for 500 hrs., after which they were further fatigue tested to failure. Salt spray corrosion caused a reduction in life for all conditions in both alloys. Salt spray corroded shot peened samples provided a relatively small benefit over as-machined the salt spray corroded samples. LPB samples had the highest life following salt spray exposure, with an 8X life improvement over the baseline condition, and a 3X life improvement over corroded shot peened samples for both alloys.

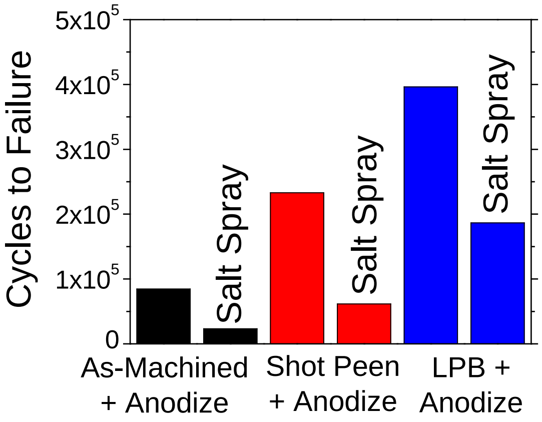

Figure 8 – Cycles to failure at maximum stress of 422 MPa (61.2 ksi) for 2024-T351 salt spray corroded samples compared to baseline results.

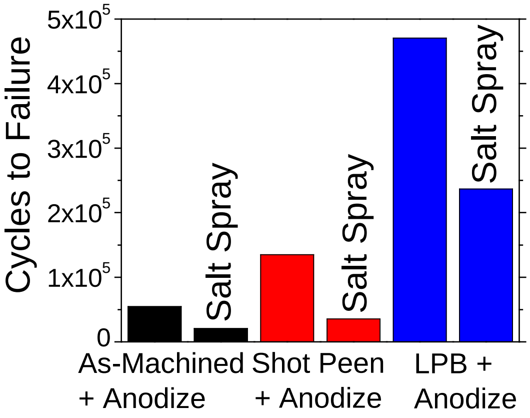

Figure 9 – Cycles to failure at maximum stress of 422 MPa (61.2 ksi) for 7475-T351 salt spray corroded samples compared to baseline results.

CONCLUSIONS

- LPB produced nominally twice the depth of compression compared to shot peening in both 2024-T351 and 7475-T7351 aluminum alloys.
- Anodization caused a slight fatigue debit in both the as-machined and shot peened conditions.
- Anodization had little to no effect on the fatigue life of LPB treated samples.
- Thermal exposure of 250F for 30hrs. caused a reduction in life for the as-machined, shot peened and LPB conditions. The reduction was more pronounced for the 7475-T7351 samples compared to the 2024-T351 samples.
- LPB samples had a greater fatigue life after thermal exposure compared to shot peened samples with no thermal exposure.
- Anodization + Neutral salt spray reduced the fatigue life of the as-machined and shot peened specimens by over 1/3 and that of LPB by approximately 1/2 of their baseline values.
- LPB + salt spray corrosion samples have equivalent or greater fatigue life than the shot peened samples.

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