Development of Rework Procedure for AA7076-T6 P-3/C-130 Propeller Taper Bore Using Low Plasticity Burnishing (LPB)

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Abstract

Low plasticity burnishing (LPB) has been applied to the internal taper bore of the P-3 and C-130 propeller blade as a replacement to the current shot peen and reaming rework process. LPB processing of the P-3 propeller blade internal taper bore was performed with a 6-axis Fanuc robot. LPB produced a smooth surface finish, eliminating the need for reaming and further machining for proper contact between the bronze bushing and the internal taper bore. Results are shown that demonstrate the LPB process is equivalent or superior to the current shot peen + reaming process in terms of high cycle fatigue, residual stress, and surface roughness. LPB processing provides substantial rework cost savings, extended blade life, and superior performance.

Keywords Stress Corrosion Cracking, Fatigue, Residual Stress, Low Plasticity Burnishing.

Introduction

The propeller blade assembly for the P-3 and C-130 consists of an aluminum bronze bushing and a forged 7076-T6 aluminum propeller blade. The bushing is inserted into the hollow end-section of the propeller blade via an interference fit before assembling the propeller hub. The dissimilar metals in the assembly create a galvanic couple between the propeller and the bushing. Over time with environmental exposure, pitting corrosion occurs on the taper bore surface, creating the need to rework the bushing and taper bore area within the propeller blade. The pitting serves as an initiation site for intergranular SCC and fatigue crack initiation, and subsequent blade failure.

Currently, to prevent SCC, shot peening is used on the internal taper bore of the P3 propeller blade to impart compressive residual stresses. Shot peening is performed as a rework process, which requires reaming of the taper bore afterwards to reduce the surface roughness and maximize contact between the bronze bushing and the taper bore surface. The end-face of the blade must then also be machined to produce the proper interference fit. The entire process is time consuming, labor intensive, and therefore costly. Furthermore, the reaming and machining performed successively at required maintenance intervals ultimately reduces the service life of the blade as a result of metal removal from the taper bore and the blade end-face. Surface enhancement of these components using LPB was introduced to reduce labor and material cost associated with the current process. The change will decrease maintenance costs and dramatically increase the service life as a result of elimination of the reaming and machining processes.

Low plasticity burnishing (LPB) has been demonstrated to provide a deep layer of high magnitude compression of sufficient depth to mitigate fatigue damage and improve damage tolerance [1-4]. The LPB process can be performed on conventional CNC machine tools or robots at costs and speeds comparable to conventional machining operations such as surface milling. LPB produces a very smooth surface finish, which requires no need for further machining to maximize contact between the bronze bushing and the internal taper bore region.

In this program the LPB treatment is compared to the shot peen + reaming process that is currently used on the taper bore in terms of high cycle fatigue (HCF), surface roughness, and residual stress. High cycle fatigue tests reveal that LPB produces higher strength and life over shot peening with and without active corrosion. LPB produces an extremely smooth surface with Ra values an order of magnitude less than the shot peened + reamed condition.

Experimental Methods

LPB Processing

An LPB process was developed to impart a depth and magnitude of compression greater than the existing shot peening process. A CNC control code was developed to allow for positioning of the LPB tool in a series of passes around the inside diameter of the internal taper bore and control of the burnishing pressure to develop the desired magnitude of compressive stress with relatively low cold working. Figure 1 shows a photo of a P-3 blade being LPB treated via robotic control.

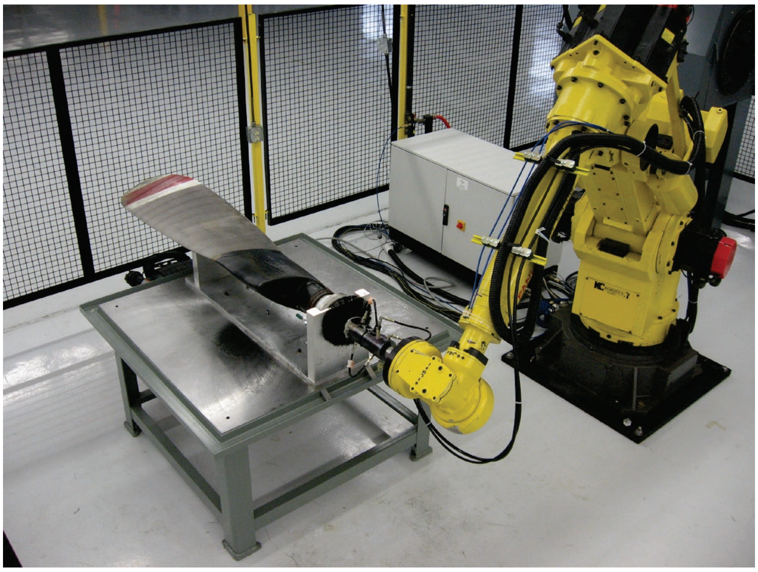


Figure 1: Robotic LPB Processing of Full Propeller Blade.

Residual Stress

X-ray diffraction residual stress measurements were made on the inside diameter of an LPB treated taper bore to verify the depth and magnitude of compression. Measurements were made using a $\sin^2\psi$ □technique a
(311) planes, of the 7076-T6. [5-8] Material was removed electrolytically for subsurface measurement in order to minimize possible alteration of the subsurface residual stress distribution as a result of material removal. The residual stress measurements were corrected for both the penetration of the radiation into the subsurface stress gradient [9] and for stress relaxation caused by layer removal.[10] The value of the x-ray elastic constants were determined in accordance with ASTM E1426-91.[11] Systematic errors were monitored per ASTM E915.

Surface Roughness:

The surface roughness of the internal taper bore of LPB processed propeller blade was compared to a bore with shot peening and reaming applied. Several surface roughness measurements were obtained for both conditions using a Mitutoyo SJ-201 Surface Roughness Tester.

High Cycle Fatigue Testing

All HCF tests were performed under constant amplitude loading on a Sonntag SF-1U fatigue machine. Fatigue testing was conducted at room temperature in four-point bending mode. The cyclic frequency and load ratio, R, were 30 Hz and 0.1 respectively. The process condition for each group of fatigue samples are shown in Table 1.

Table 1. High Cycle Fatigue Test Specimen Identification

Group No.	Group Identification
1	LPB
2	LPB + Active Corrosion
3	Shot Peened + Reamed
4	Shot Peened + Reamed + Active Corrosion
5	Shot Peened + Reamed + Pitted + LPB

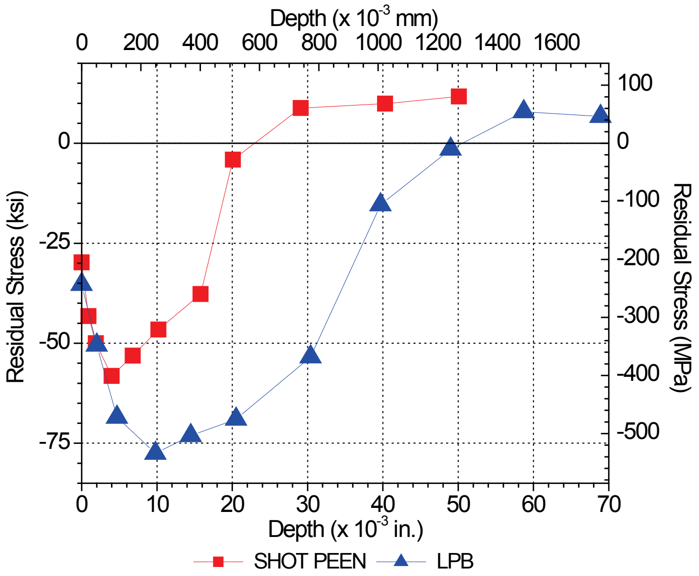
A fatigue sample with a trapezoidal gage cross section was used for the HCF testing. The fatigue sample was specifically designed to force fatigue failures to initiate in the compressive gage section. All test samples were taken from the airfoil portion of a P-3 propeller blade. The samples were milled on the active surface of the gage prior to any surface enhancement process.

During this investigation, the fatigue tests conducted under active corrosion were exposed to a 3.5 weight % NaCl solution. Pitting was accomplished in the Group 5 samples by exposing the specimen to a 3.5 weight % NaCl solution prior to fatigue testing at 32.2°C (90° F) for 300 hours of alternate immersion exposure per ASTM G-44. The Group 5 samples simulated the condition of LPB reworked blades that were previously shot peened and reamed.

Experimental Results

Residual Stress

The residual stress results are shown as a function of depth in Figure 2. Shot peening produced compression to a depth on the order of .6 mm (0.025 in.) with maximum compressive residual stresses on order of -400 MPa (–58 ksi). LPB produced a depth of compression on the order of 1.3 mm (0.05 in.) with a peak stress of slightly greater than –500 MPa (–73 ksi).



AA7076-T6 P3 PROPELLER BLADE SHANK
I.D. of Taper Bore, 2.0 in. From Bottom

Figure 2: Residual Stress Distributions Comparing LPB and Shot Peening on Internal Bore of P-3 Propeller Blade.

High Cycle Fatigue Testing

The S-N results for the HCF fatigue tests are presented graphically in Figure 3. The results are shown in a semi-log plot of maximum stress in units of ksi (10^3 psi) and MPa vs. cycles to failure. Each data point represents a single fatigue test. LPB treated specimens have higher fatigue strength than shot peened for all conditions tested. LPB treated samples have an endurance limit of approximately 350 MPa (51 ksi) compared to 290 MPa (42 ksi) for the shot peened samples. The shot peened + pitted + LPB samples were as strong as the LPB only samples. This indicates the LPB reworked blades would have the same level of fatigue strength as new production blades with LPB treatment. The HCF life of all samples was considerably affected by the introduction of an actively corrosive NaCl salt environment during testing. LPB outperformed shot peening in active corrosion fatigue testing. LPB + active corrosion samples had a nominal fatigue strength of 240 MPa (35 ksi) compared to approximately 140 MPa (20 ksi) for shot peened + active corrosion samples at lives approaching 1x10^7 cycles.

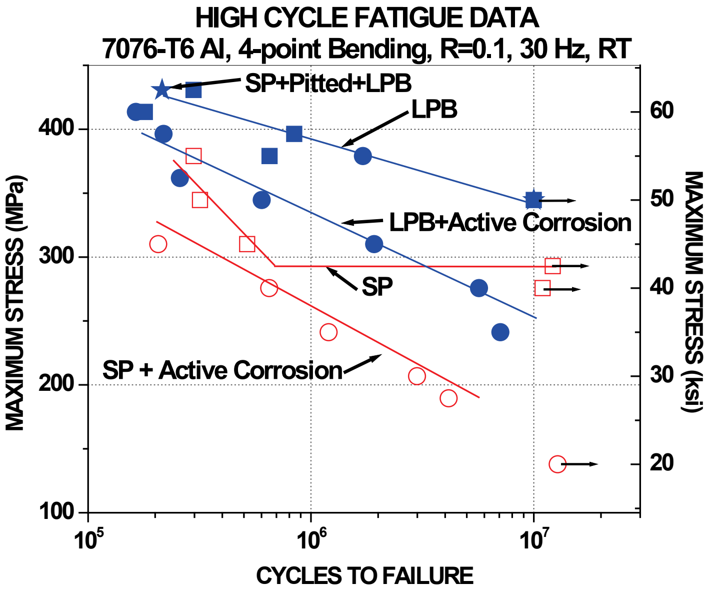


Figure 3: Fatigue Results Comparing LPB to Shot Peen Condition.
LPB Treated Samples Exhibited Superior Performance
Compared to Shot Peening.

Surface Roughness

The surface roughness of the internal taper bore of an LPB processed propeller bore is compared to an as-received bore in Figure 4. The surface roughness is dramatically reduced as a result of LPB processing. Surface roughness is reduced by approximately a factor of 30 compared to the as received condition (Shot Peened + Reamed). The reduced surface roughness from LPB eliminates the need for the reaming process, which dramatically reduces the overall rework cost and increases the service life of the blade.

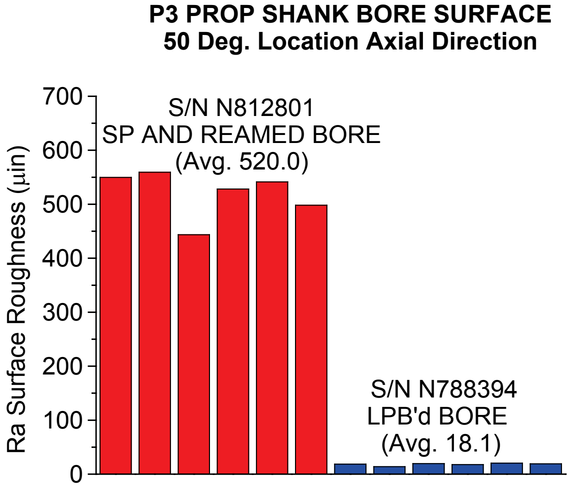


Figure 4: Surface Roughness Comparison Between
As-Received (Shot Peen + Ream) and LPB Taper Bore
Showing a Dramatic Decrease in Surface Roughness
from LPB Processing.

Conclusions

It has been demonstrated that the LPB process is superior to the shot peen + reaming process that is currently used on the taper bore in terms of high cycle fatigue, surface roughness, and beneficial residual compression. LPB treated specimens showed marked HCF improvement over the current shot peening. In the absence of a corrosive environment LPB treated samples had an endurance limit of nominally 350 MPa (51 ksi) vs. 290 MPa (42 ksi) for the shot peened samples. LPB also outperformed shot peening when exposed to a NaCl actively corrosive environment during HCF testing. Though no endurance limit was established under this condition, the LPB treated samples had a nominal fatigue strength of 240 MPa (35 ksi) at $1x10^7$ cycles compared to only nominally 140 MPa (20 ksi) for the shot peened condition.

The LPB produced higher magnitude compression with nominally twice the depth of compression over the shot peening process.

Surface roughness is greatly improved by LPB. LPB reduced the surface roughness by nominally a factor of 30 over shot peening. LPB eliminates the need for reaming to ensure sufficient bushing/taper bore contact.

REFERENCES:

[1] P.S. Prevéy, J. Telesman, T. Gabb and P. Kantzos, *"FOD Resistance and Fatigue Crack Arrest in Low Plasticity Burnished IN718*," Proceedings of the 5th Nat.Turbine Eng. HCF Conference, 2000.

[2] J.T. Cammett, P.S. Prevéy, "*Low Cost Corrosion Damage Mitigation and Improved Fatigue Performance of Low Plasticity Burnished 7075-T6*," Proceedings of the 4th International Corrosion Workshop, Aug. 22-25, 2000.

[3] P.S. Prevéy, M. Shepard and P. Smith, "*The Effect of Low Plasticity Burnishing (LPB) on the HCF Performance and FOD Resistance of Ti-6Al-4V*," Proceedings: 6th Nat. Turbine Eng. HCF Conference, 2001

[4] J. Cammett and P.S. Prevéy, "*Fatigue Strength Restoration in Corrosion Pitted 4340 Alloy Steel via Low Plasticity Burnishing*"

[5] Hilley, M.E. ed.,(1971), Residual Stress Measurement by X-Ray Diffraction, *SAE HS-784*, (Warrendale, PA: Society of Auto. Eng.).

[6] Noyan, I.C. and Cohen, J.B., (1987) Residual Stress Measurement by Diffraction and Interpretation, (New York, NY: Springer-Verlag).

[7] Cullity, B.D., (1978) Elements of X-ray Diffraction, 2nd ed., (Reading, MA: Addison-Wesley), pp. 447-476.

[8] Prevéy, P.S., (1986), *"X-Ray Diffraction Residual Stress Techniques," Metals Handbook*, **10**, (Metals Park, OH: ASM), pp 380-392.

[9] Koistinen, D.P. and Marburger, R.E., (1964), Transactions of the ASM, **67**.

[10] Moore, M.G. and Evans, W.P., (1958) *"Mathematical Correction for Stress in Removed Layers in X-Ray Diffraction Residual Stress Analysis,"* SAE Transactions, **66**, pp. 340-345

[11] Prevéy, P.S., (1977), *"A Method of Determining Elastic Properties of Alloys in Selected Crystallographic Directions for X-Ray Diffraction Residual Stress Measurement,"* Adv. In X-Ray Analysis, **20**, (New York, NY: Plenum Press, 1977), pp 345-354.