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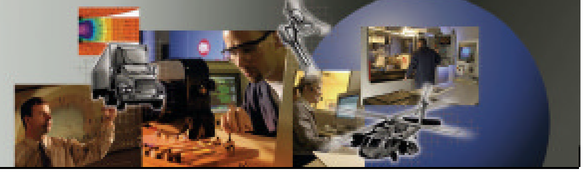


DIFFRACTION NOTES 5521 Fair Lane, Cincinnati, OH 45227 (513)561-0883 No. 32 Summer 2006

CHARACTERIZATION OF THE RESIDUAL STRESS, CORROSION FATIGUE STRENGTH AND STRESS CORROSION CRACKING BEHAVIOR IN SHOT PEENED AND LOW PLASTICITY BURNISHED 300M LANDING GEAR STEEL

INTRODUCTION

Stress corrosion cracking (SCC), corrosion fatigue, and foreign object damage (FOD) are generally recognized as significant degradation processes that affect naval aircraft landing gear components. Ultrahigh strength steels such as 4340, AF1410, and 300M are widely used in applications where a combination of high strength and fracture toughness is needed. Most of these ultrahigh strength steels have been known to be susceptible to SCC and corrosion fatigue.[1-4] The phenomenon of SCC is generally understood to be the result of a combination of susceptible material, corrosive environment, and tensile stress above a threshold. Previous solutions to reduce the susceptibility to corrosion and the environment have included modifying the material (alloy chemistry), or the use of protective coatings such as Cadmium and Chromium plating of the steel to retard corrosion and SCC.[4]

Introduction of compressive residual stresses in metallic components has long been recognized[5-8] to lead to enhanced fatigue strength. For example, many engineering components have been shot peened (SP) or cold worked with fatigue strength enhancement as the primary objective or as a by-product of a surface hardening treatment like carburizing/ nitriding, physical vapor deposition, etc. Over the last decade treatments such as low plasticity burnishing (LPB),[9] laser shock peening (LSP),[10] and ultrasonic peening[11] have emerged. In all surface treatment processes, key benefits are obtained when deep compression is achieved with minimal cold work of the surface. All of these surface treatment methods have been shown to benefit fatigue prone engineering components to different degrees.

ANNOUNCEMENTS

New Testing & Engineering Services

Lambda Research now offers additional engineering and testing services to compliment our existing core testing.

Lambda continues to provide the highest quality x-ray diffraction services including residual stress, percent retained austenite, texture, and phase analysis services that we have provided to our customers for close to 30 years.

In addition, Lambda now offers our customers a means of characterizing the affect of residual stress and cold working on performance. Lambda provides low and high cycle fatigue testing, stress corrosion and gross corrosion tests, finite element analysis, fractography and metallography, and decades of engineering experience in the field of surface integrity to assess the impact of such key properties as residual stress and surface condition on the performance of a specific component or alloy.

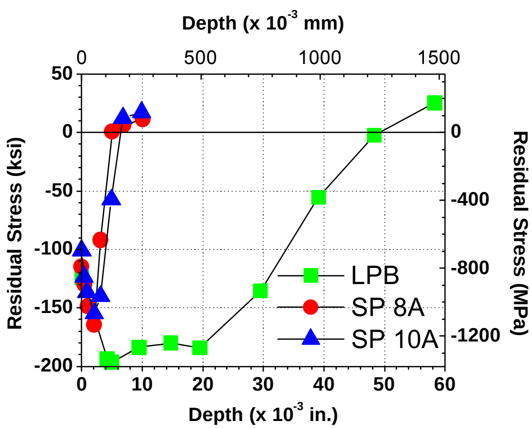
In addition, Lambda has developed and patented methods of determining the optimal residual stress and cold working to maximize the fatigue strength of a specific component for a given application and environment.

For more information visit either of our web sites at www.lambda-research.com, www.lambdatechs.com.

The goal of this research was to measure the residual stresses imparted by the LPB process and conventional SP surface treatment and characterize the influence of the two treatments upon the mechanisms of corrosion fatigue, FOD and SCC in 300M steel. Results of this effort are described in more detail in other technical papers.[12-14] These papers, as well as many other technical papers, can be downloaded from our website at www.lambdatechs.com.

RESIDUAL STRESS MEASUREMENTS

X-ray diffraction residual stress measurements were made at the surface, and at several depths, on both LPB and SP treated fatigue specimens. Measurements were made in the longitudinal direction in the specimen gage employing a $\sin^2\psi$ technique and the diffraction of chromium $K\alpha 1$ radiation from the (211) crystallographic planes of the 300M steel.



Shot Peening CCW14 Shot, 150% Coverage

Figure 1 - Residual stress distribution for SP and LPB processed specimens showing 10X greater depth and 30% greater peak compression for LPB process compared to shot peening.

The residual stress distributions measured as functions of depth are presented graphically in Figure 1. Compressive stresses are shown as negative values, tensile as positive, in units of ksi (10^3 psi) and MPa (10^6 N/m^2). SP treatment at 8A intensity produces surface compression in the range of –100 to -115 ksi (-690 to -790 MPa), which becomes more compressive to about –150 ksi (-1035 MPa) at a depth of about 0.002 in. (0.05 mm), and rapidly relaxes to nearly zero at a depth of about 0.005 in. (0.125 mm). The 10A intensity peening produced slightly deeper compression to a depth of 0.007 in. (0.18 mm). LPB treatment produces surface compression of -100 ksi (-690 MPa), increasing to about -180 ksi (-1240 MPa) at depths of 0.005 to 0.020 in. (0.125 to 0.5 mm), and gradually decreasing to zero at a depth of about 0.050 in. (1.25 mm).

HIGH CYCLE FATIGUE TESTING

HCF tests were performed under constant amplitude loading on a Sonntag SF-1U fatigue machine. Fatigue testing was conducted at ambient temperature (~72F) in four-point bending mode. Corrosion fatigue testing was performed in a medium of neutral 3.5% NaCl salt solution prepared with de-ionized water. To simulate FOD, a semi-elliptical surface notch of depth of a_o=0.020 in. (0.5 mm) and surface length of $2c_o$=0.060 in. (1.5 mm) was introduced in selected groups of specimens by electrical discharge machining (EDM). The following table describes the test conditions used in this study:

	Baseline (LSG)	Shot Peened	LPB Treated
Base (No FOD, No Salt)	✓	✓	✓
Salt Exposure	✓	✓	✓
Simulated FOD	✓	✓	✓
Simulated FOD + Salt Exposure	✓	✓	✓

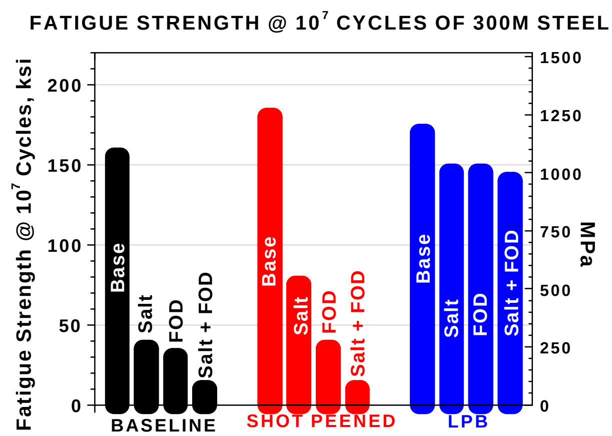


Figure 2 – Summary of fatigue results.

Figure 2 shows a chart summarizing the fatigue strength for baseline (as-machined), SP and LPB conditions. It is evident that for both baseline and SP materials, a 0.020 in. (0.25 mm) deep EDM notch greatly decreases the HCF and corrosion fatigue strength to a value between 30 and 10 ksi (200 and 70 MPa). Exposure to salt corrosion also greatly reduced the fatigue strength of both the baseline and SP conditions. In contrast, the LPB treated specimens withstood the same EDM notch and salt exposure with a fatigue strength of approximately 145 ksi (1000 MPa). The HCF and corrosion fatigue performance for the LPB treated specimens are consistent with the residual stress distributions seen in Figure 1.

STRESS CORROSION CRACKING TESTING

SCC tests were performed on C-ring specimens machined out of a 300M steel landing gear. The gage region of the C-ring specimen had a cross section similar to the fatigue specimens. This design made it possible to investigate the effect of surface treatments such as LPB for the SCC tests. Typically, when the c-ring specimen is loaded the outer surface of the gage region is in tension, and the tensile stress is nominally uniform over the gage section. From the knowledge of the applied forces on the (instrumented) bolt and the bending moment, the corresponding tensile stress on the outer surface can be calculated. Three sets of specimens (both in an untreated condition and LPB treated) were SCC tested at 150, 165 and 180 ksi (1034, 1138 and 1241 MPa). The SCC test consisted of alternate immersion of the loaded specimen in a neutral 3.5% NaCl solution prepared with de-ionized water (10 min. in solution and 50 min. in air at room temperature). The load was monitored as a function of time, and the time to failure was noted.

In Figure 3 the SCC test results show the untreated baseline material had time to failure of 261.8 hrs at 150 ksi (1034 MPa), 166.5 hrs at 165 ksi (1138 MPa) and only 12.9 hrs at 180 ksi (1241 MPa), respectively. The LPB treated specimens did not fail even after 1500 hrs of exposure at all three stress levels. When the specimens were loaded to higher stress levels in an attempt to force SCC cracking, the specimens were severely bent without ever cracking. These results indicate the deep surface compressive stresses from LPB prevent the surface in contact with the corrosive environment from ever reaching the SCC threshold stress, thus fully mitigating SCC as a failure mechanism in 300M.

FRACTOGRAPHY

Following fatigue testing, each specimen was examined optically at magnifications up to 60x to identify fatigue origins and locations thereof, relative to the specimen geometry. Pictures were taken with a Nikon 990 digital camera through a Nikon Stereoscopic microscope at 15x. A representative photograph of a typical failure for each specimen group was obtained. A few selected specimens were also examined under a Cambridge S90B Scanning Electron Microscope (SEM).

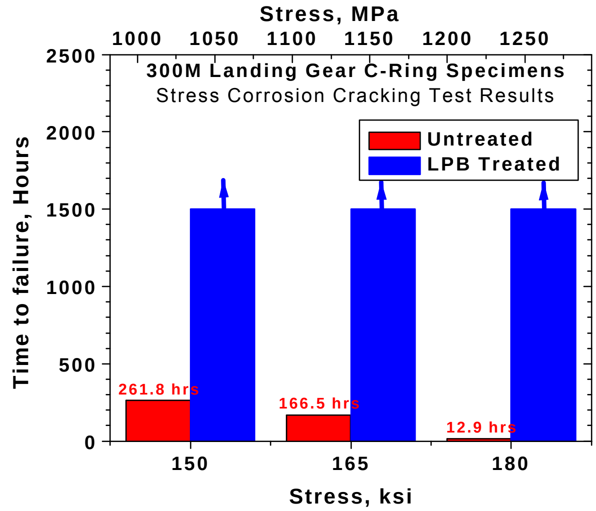
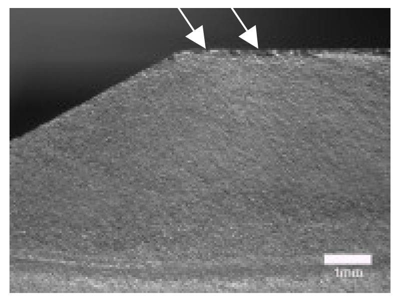


Figure 3 - SCC test results.



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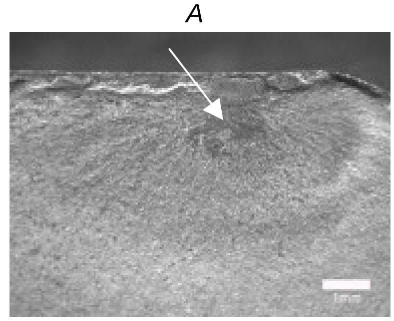

B

Figure 4 – (A) Fracture surface of shot peened specimen showing multiple surface initiations indicated by the arrows. (B) Fractrograph showing subsurface initiation in LPB specimen.

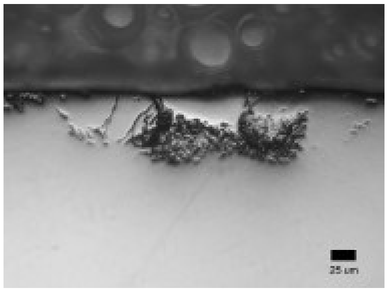

Figure 5 – Cross sectional view of a typical corrosion pit in a shot peened corrosion fatigue test specimen.

Fractographic analyses presented here in Figures 4 and 5 are limited to unnotched corrosion fatigue tested specimens with SP and LPB conditions. Figure 4a shows the fracture surface of a SP specimen with multiple crack initiations site near the corner of the trapezoidal cross-section. Subsurface crack initiation is evident in the LPB specimens as shown in Figure 4b despite the presence of deep corrosion pits. An SEM photo of a corrosion pit is shown in Figure 5. In all cases, pitting of the gage surface is evident, and the cross-sectional views indicate a gradual increase in the depth of corrosion pitting damage with increased time of testing. In both baseline and SP specimens, the corrosion pits resulted in early crack initiation at low stresses, leading to final failure. In contrast, for LPB specimens, despite the higher stress levels and deeper corrosion pitting damage, due to the longer exposure time during testing, the corrosion fatigue performance is minimally affected.

CONCLUSIONS

The influence of LPB and SP on the residual stress, corrosion fatigue strength and SCC properties was characterized. LPB introduced a layer of compression approaching the yield strength in magnitude and extending to 0.050 in. SP produced a depth of compression of up to 0.007 in. (0.18 mm) with maximum compression slightly less than that produced by LPB. The LPB treatment effectively mitigated FOD up to 0.020 in. (0.51 mm) deep and eliminated the large fatigue debit caused by exposure to salt water. Because the LPB treated surface remains in compression even under high tensile applied loads, stress corrosion cracking was effectively entirely mitigated in salt water exposure.

The performance of LPB treated 300M steel demonstrated here supports the application of LPB to military and commercial aircraft landing gear with the combined potential benefits of reduced incidents of landing gear failure from either SCC or FOD, especially in salt water exposure, and potentially significant reductions in inspection maintenance requirements.

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