LAMBDA
Technologies Group

Diffraction Notes
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Issue No. 42 Improving Component Life and Performance Winter 2017

MITIGATING SCC AND CORROSION FATIGUE OF SENSITIZED 5083 ALUMINUM WITH ENGINEERED COMPRESSIVE RESIDUAL

INTRODUCTION

A commonly used aluminum alloy in shipbuilding, AA5083-H116 is prone to low temperature sensitization leading to beta-phase (Mg2Al3) precipitation. The precipitation around the grain boundaries increases the material's susceptibility to stress corrosion cracking (SCC) and corrosion fatigue (CF). Sensitized material is commonly found in heat-affected zones (HAZ) from welding and other heat sources. The United States Navy has issued a directive to solve this problem, as it dramatically affects operation and maintenance (O&M) costs and fleet performance.

It has been shown that minimizing tensile stresses can lower SCC susceptibility and improve CF performance. Furthermore, a means of reliably introducing a deep layer of compressive residual stress in critical heat affected zones can reduce O&M costs by extending the service life of components.

An extensive study was conducted at Lambda Research to evaluate the effects of compressive residual stress on the CF and SCC properties of sensitized and unsensitized AA5083-H116 material.

SPECIMEN MACHINING & SENSITIZATION

Trapezoidal cross section fatigue samples were machined from AA5083- H116 plate at Lambda's full-service CNC machining facility. Half of these specimens remained in the Baseline (as-machined) condition while the other half were low plasticity burnished (LPB) at Surface Enhancement Technologies (SET) to produce a deep layer of high magnitude compression.

Select groups of LPB specimens and Baseline (as-machined) specimens were sensitized at two different temperatures using a computer-controlled oven. The degree to which the specimens were sensitized was quantified by nitric acid mass loss tests (NAMLT) performed in the Lambda Research Corrosion Laboratory per ASTM G67.

ANNOUNCEMENTS

SEM CAPABILITIES

Lambda has upgraded their imaging and material analysis capabilities with a new scanning electron microscope. This new machine utilizes backscatter, secondary electron, and x-ray detectors for quick imaging and analysis of samples up to 100 mm x 100 mm in size. The x-ray detector is used for energy dispersive spectroscopy (EDS), which allows for bulk elemental analysis, as well as high resolution elemental mapping and line scans. High resolution imaging capabilities will improve failure analysis capabilities. Enhanced imaging will improve the speed and accuracy of fatigue striation counting, which is a unique method used by Lambda to determine the applied cyclic stress a component experienced at the time of failure using the fracture face or a replica of the fracture face.

PORTABLE, MECHANICAL RESIDUAL STRESS SYSTEM

Lambda has recently introduced a new CNC based mechanical residual stress measurement instrument capable of measuring the principal residual stress vs. depth using either the center-hole drill (ASTM E837) or the ring core methods. The system allows for precision CNC machining using a high speed drill for hole drill measurement. The system can also machine annular grooves around a monitoring strain gage for ring core residual stress measurement. The system is portable allowing for measurements on large samples either at our laboratory facility or at our customer's site.

For more information on these or any of our other services, call 1-800-883-0851 or request more information through our website.

SALT WATER EXPOSURE

Prior to fatigue testing, select specimen groups were exposed, in Lambda's Corrosion Laboratory, to accelerate pitting and general corrosion damage via SCC alternate immersion testing. The active gage region was loaded in tension to 90% of the yield strength in specialized 4-point bend fixtures in an alternate immersion bath of 3.5% weight NaCl solution for 1000 hrs. per ASTM G44.

CF testing was performed by subjecting the gage region to an environment with 3.5% weight NaCl solution. Specimens were exposed to this corrosive environment for the duration of the test. Baselines were established by testing specimens from each process group with no corrosion.

RESIDUAL STRESS MEASUREMENT

X-ray diffraction (XRD) residual stress measurements were made on test specimens in the baseline, LPB, and LPB + 90°C sensitized conditions. Figure 1 shows the residual stress distributions for these three conditions. The optimized LPB parameters produced compressive stresses to a depth of approximately 0.050 in. with maximum compression on the order of ~35 ksi. While thermal treatments can often relax residual stress, more than two thirds of the compression induced by the LPB process was preserved after the 90°C sensitization.

HIGH CYCLE FATIGUE TESTING

All tests were performed at room temperature under constant amplitude loading at Lambda Research's Surface Integrity & Process Optimization facility (SIPO). Lambda's high cycle fatigue systems and supporting metallographic analysis capabilities provide a complete set of tools to accurately evaluate the influence of residual stress on fatigue.

The stress vs. life (S-N) results for the fatigue tests are shown in Figures 2, 3, and 4. Data are shown in a semi-log plot of maximum stress vs.cycles to failure. LPB improved the fatigue strength under most of the conditions tested with an increase of at least 20 ksi over the unprocessed baseline. The LPB + CF condition demonstrated a higher fatigue strength than both the Baseline and Baseline + CF conditions. LPB provided up to 100x improvement in CF

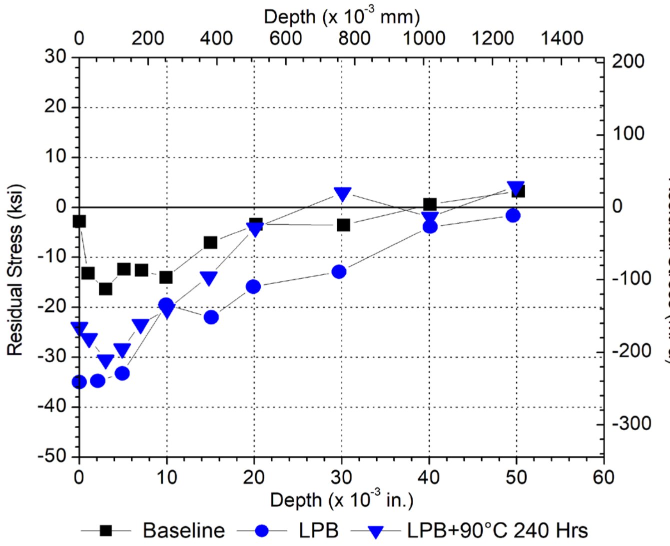

FIGURE 1: X-RAY DIFFRACTION RESIDUAL STRESS DISTRIBUTIONS AS A FUNCTION OF DEPTH SHOWING RELATIVELY DEEP COMPRESSION FROM LPB

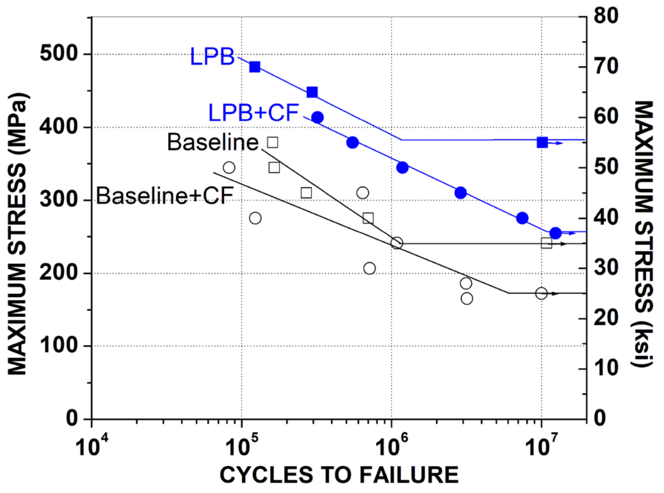

FIGURE 2: HIGH CYCLE FATIGUE RESULTS SHOWING GREATER THAN AN ORDER OF MAGNITDE INCREASE IN CF LIFE RESULTING FROM LPB

life over baseline specimens.

Data shown in Figure 3 demonstrates the improved CF performance of LPB in sensitized AA5083-H116 material. During CF testing LPB remained an improvement over the unprocessed condition after sensitization of up to 90°C for 240 hrs. Also, when applied after the sensitization process, LPB greatly improved the fatigue life and fatigue strength in material sensitized up to 175°C for 240 hrs. When this more severe sensitization occurred after the LPB process the fatigue strength decreased to the level of the unprocessed material due to the relaxation of the beneficial compression.

Similar CF performance benefits from LPB were also seen with the precorroded SCC specimens detailed in Figure 4. In these tests LPB showed an improvement in CF life over unprocessed material for every tested condition, including those sensitized at the more severe 175°C for 240 hrs.

SUMMARY

- XRD results indicate LPB produced beneficial compressive residual stresses to a depth of approximately 0.050 in. with maximum compression on the order of -35 ksi.
- At least 2/3 of this compression was retained after a sensitization of up to 90°C for 240 hrs.
- Fatigue strength was reduced as a result of NaCl solution exposure.
- Deep compression imparted by the LPB process provided up to a 100x improvement in CF life and a nominal 25% improvement in CF strength.
- A nominal 40% improvement in CF strength was seen due to LPB processing prior to a sensitization of 90°C for 240 hrs.
- LPB process greatly improved CF performance when applied after the more severe 175°C sensitization.
- Surface enhancement methods improve corrosion fatigue life, damage tolerance, and SCC performance in sensitized AA5083-H116 components, ultimately reducing operational costs.

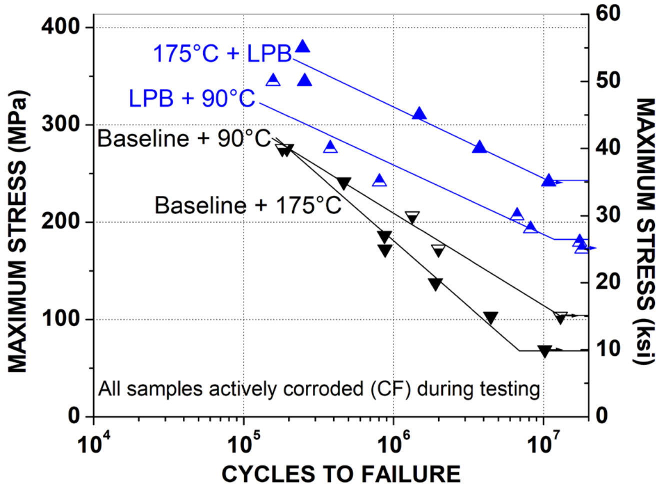

FIGURE 3: HIGH CYCLE FATIGUE RESULTS OF SENSITIZED SPECIMENS SHOWING UP TO AN ORDER OF MAGNITUDE INCREASE IN CF LIFE RESULTING FROM LPB

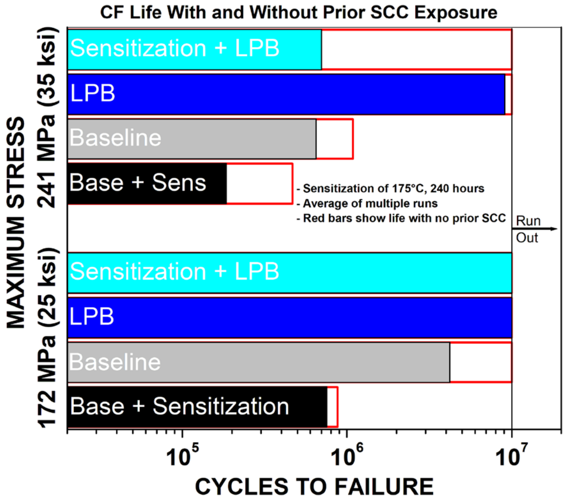

FIGURE 4: HIGH CYCLE FATIGUE RESULTS OF SENSITIZED AND PRE-CORRODED SPECIMENS SHOWING AN INCREASE IN CF LIFE RESULTING FROM LPB