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Diffraction Notes

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FATIGUE LIFE EXTENSION OF STEAM TURBINE ALLOY 450 USING LOW PLASTICITY BURNISHING

INTRODUCTION

Low Plasticity Burnishing (LPB®) has been previously shown to dramatically improve the damage tolerance of titanium alloy blades. In this article LPB was applied to Alloy 450, a martensitic stainless steel, to study the effects of the surface treatment on corrosion fatigue and pitting in the low-pressure sections of steam turbine blades. Condensation in the low-pressure steam turbine environment supports corrosion pitting and corrosion fatigue in martensitic stainless steels, which are the primary failure mechanisms driving steam turbine repair and operational expense. Sodium chloride corrosion fatigue results, with and without high k_f surface damage, are compared for both ground and LPB treated conditions. The depth and magnitude of compression achieved by the surface treatment are documented. LPB increased the undamaged fatigue strength of Alloy 450 in acidic salt by 50% and mitigated damage to the 0.04 in. (1 mm) depth of compression. The cyclic stress corrosion component of corrosion fatigue was eliminated by the deep LPB compression, effectively restoring the endurance limit lost in active corrosion fatigue.

TECHNIQUE

Fatigue Specimen Processing

Fatigue specimens specially designed to test the benefits of compressive residual stress in 4-point bending were used for this investigation. Samples were finished machined using low stress grinding (LSG). To simulate surface damage from any source (handling, FOD, corrosion pitting, or erosion), a semi-elliptical surface notch of depth of a_o = 0.010 in. (0.25 mm) and surface length of $2c_o$ = 0.060 in. (1.52 mm) was introduced by electrical discharge machining (EDM). EDM produces a pre-cracked recast layer that is in residual tension at the bottom of the notch, producing a large fatigue debit with a high k_f.

Surface Treatment

LPB process parameters were developed to impart a depth and magnitude of compression on the order of 0.04 in. (1 mm), sufficient to mitigate the simulated FOD with minimal cold work. Figure 1 shows a set of 8 fatigue specimens in the process of being low plasticity burnished on the four-axis manipulator in a CNC milling machine.

Corrosion Fatigue Testing

Active corrosion fatigue tests were carried out in an aqueous 3.5 wt% NaCl acidic (pH = 3.5) salt solution. At the start of cyclic loading, filter papers soaked with the solution were wrapped around the gage section of the fatigue test specimen and sealed with a polyethylene film to avoid evaporation. There was no exposure to the corrosive solution prior to the fatigue tests. LPB and LSG baseline samples were tested with and without EDM damage. A few LPB samples were also tested with 2x and 3x deeper damage to determine the capability of the LPB treatment for deeper damage.

Residual Stress

X-ray diffraction residual stress measurements were made to characterize the residual stress distribution from LPB. Measurements were made in the gauge region of an LPB treated fatigue sample employing a $\sin^2\psi$ technique and the diffraction of chromium Kα1 radiation from the (211) crystallographic planes. Material was removed electrolytically for subsurface measurements 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 and for stress relaxation caused by layer removal.

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RESULTS

Residual stress results for the LPB condition are shown in Figure 2. Maximum compression is nominally -140 ksi (-965 MPa) at the surface, decreasing to zero over a depth of about 0.035 in. (0.89 mm). Deep compression in the post-fatigue tested sample indicates significant retention of compression.

The corrosion fatigue performance in acidic NaCl solution is shown in Figure 3. The LSG baseline condition is compared with LPB with and without the EDM notch. With no notch the baseline fatigue strength at 10^7 cycles is nominally 100 ksi (690 MPa). The 0.010 in. (0.25 mm) deep EDM notch decreases the baseline fatigue strength to approximately 10% of its original value. The fatigue lives at higher stresses show a corresponding decrease of over an order of magnitude as a result of the notch

In contrast, unnotched LPB processed samples have a fatigue strength of about 160 ksi (1103 MPa). The notch had a marginal effect on the LPB fatigue strength reducing it to 125 ksi (862 MPa), well above the fatigue strength of the undamaged baseline specimens.

LPB treated samples containing the 2x damage depth had fatigue lives comparable to undamaged LSG specimens, within the limits of experimental scatter. However, the LPB sample with a 3x damage depth had a substantial decrease in fatigue life, indicating the notch effectively penetrated the layer of LPB compression.

SUMMARY

LPB imparted highly beneficial compressive residual stresses on the surface, sufficient to withstand pitting and/or surface damage up to a depth of nominally 0.020 in. (0.51 mm). LPB provided a 50% increase in corrosion fatigue strength in the absence of surface damage, and a 12x increase in strength for 0.010 in. (0.25 mm) deep damage. The fatigue strength improvement is attributed to the depth and magnitude of surface compression.

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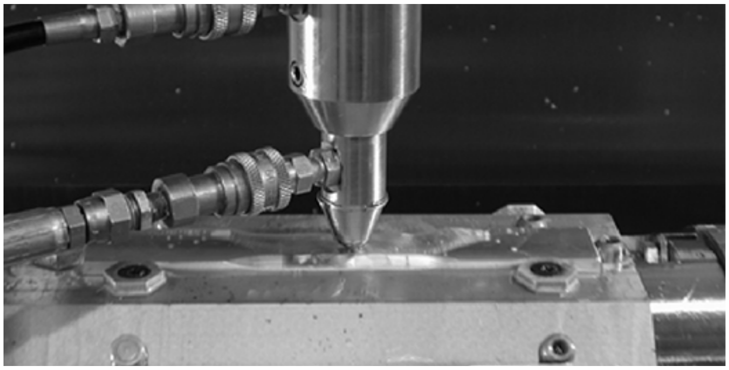

Figure 1

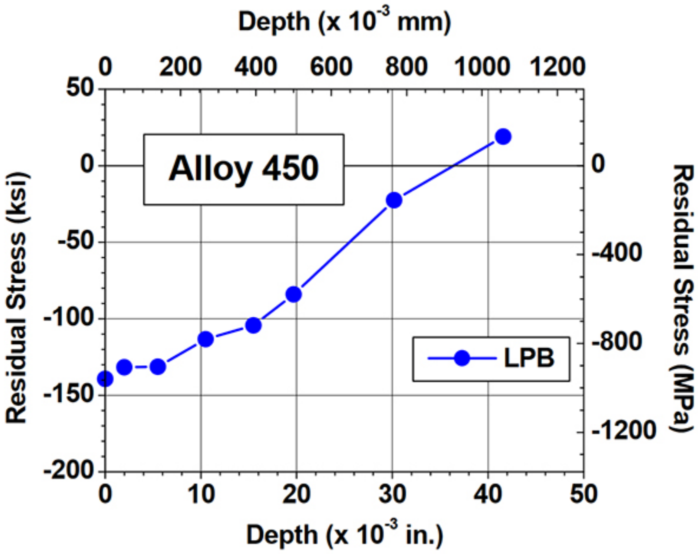

Figure 2

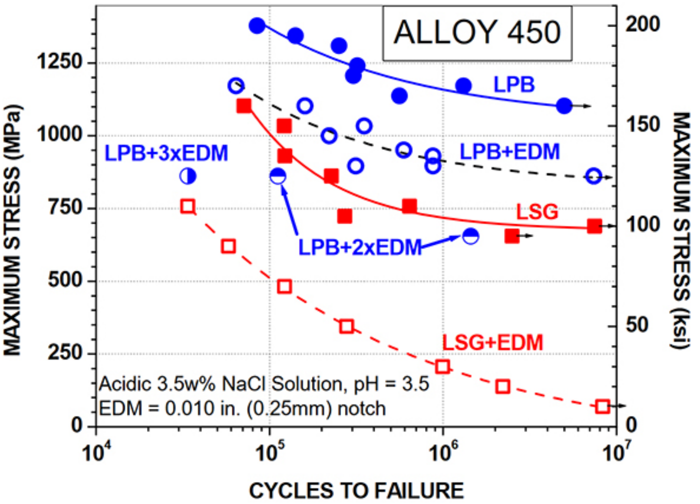

Figure 3

To read the full paper, which also includes alloy 17-4PH, click here.