LAMBDA Technologies Group

Diffraction Notes

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FATIGUE LIFE IMPROVEMENT OF ADDITIVELY MANUFACTURED SUPERALLOY COMPONENTS

INTRODUCTION

Additive manufacturing (AM) has allowed for the creation of complex geometries of which were prohibitively expensive, if not impossible, to create using conventional manufacturing methods. Advances in powder metallurgy for AM feedstock material is creating a wider selection of superalloy powders. Additive manufacturing of Ni-base superalloys has gained much interest given the difficulties in machining this family of alloys using conventional methods as well as the aforementioned possibility to create complex geometries. However, forged material properties are difficult to achieve using the AM methods. In this Diffraction Notes the use of compressive residual stress to improve fatigue properties of AM Inconel 718 is studied.

TECHNIQUE

Fatigue Specimen Manufacturing

Test samples were manufactured using a laser powder bed fusion (LPBF) AM process. LPBF is a well-established AM process that involves building a geometry sequentially layer-by-layer using a laser heat source in a powder bed. The samples were built on a plate using a raster build pattern and later removed from the build plate via wire EDM. Test samples were then subjected to a solution heat treatment and age hardening per AMS 2774.

Surface Treatment

It is well known that mechanical surface treatments that impart compressive residual stresses have a significant beneficial impact on the fatigue properties of metal alloys. Two surface treatment processes, shot peening and low plasticity burnishing (LPB), were investigated in this study. Surface treatment parameters along with heat treat and material property data are listed below.

Condition	Surface Parameters	0.2% YS	UTS
Baseline (AM)	N/A	173 ksi (1190 MPa)	208 ksi (1434 MPa)
Shot Peen (AM)	CCW14, 7A intensity, 150% coverage	173 ksi (1190 MPa)	208 ksi (1434 MPa)
LPB (AM)	Proprietary parameters chosen to impart ~0.025 in. (0.64 mm) depth of compression	173 ksi (1190 MPa)	208 ksi (1434 MPa)
Electropolished (Forged)	Electropolished to remove machining related residual stress and cold working	156 ksi (1080 MPa)	204 ksi (1407 MPa)

Surface Roughness

Surface roughness measurements were made on the active surface of a fatigue sample of each condition. Results of the surface roughness evaluation are shown in the table below. Shot peening reduced the surface roughness slightly while the LPB treatment reduced the roughness to nominally half of the baseline value.

Condition	Average Surface Roughness, Ra μin. (μm)
Baseline	255 (6.5)
Shot Peened	204 (5.2)
LPB	132 (3.4)

RESULTS

Residual Stress Measurement

Residual stress and cold work measurements are shown in Figure 1. Measurements collected at nominally mid-gage on the top face reveal relatively low residual stress and cold working for the baseline sample condition. Shot peening introduced a layer of compression to a nominal depth of 0.007 in. (180 μm) with peak compression of about -200 ksi (-1400 MPa) and cold working exceeding 30% at the surface. LPB produced compression to a depth of nominally 0.025 in. (640 μm) with maximum compression of about -185 ksi (-1280 MPa) and less than 5% cold working at the surface.

High Cycle Fatigue

High cycle fatigue tests were performed at room temperature under constant amplitude. The stress vs. life (S-N) results for the fatigue tests are shown in Figure 2. Data are shown in a semi-log plot of maximum stress vs. cycles to failure. Arrows indicate a run-out condition in which the specimen did not fail. Fatigue results collected in an earlier program on electropolished (no residual stress) conventionally forged Inconel 718 are shown for comparison.

At a maximum applied stress of 120 ksi (830 MPa), the baseline (AM) condition exhibited a fatigue life of roughly 1/10th of the conventionally forged and electropolished life. Both the LPB and shot peen processes significantly improved the fatigue life of the AM material, achieving a fatigue life at 120 ksi (830 MPa) approaching that of the conventionally forged and electropolished material. Fractographic analysis revealed all initiations occurred at the gauge surface of the AM fatigue samples.

SUMMARY

- Baseline (post heat treated) residual stress distributions indicated near zero residual stress below the surface with low magnitude surface compression
- Both shot peen and LPB introduced compression with peak compression on the order of -200 ksi (-1400 MPa)
- LPB introduced a depth of compression nominally 3X that of shot peening
- Surface treatments increased life of AM material roughly 10X over baseline condition
- LPB produced slightly higher fatigue life than shot peening indicating the deeper compression may provide greater benefit
- Fatigue lives for surface treated AM material approached that of untreated forged material

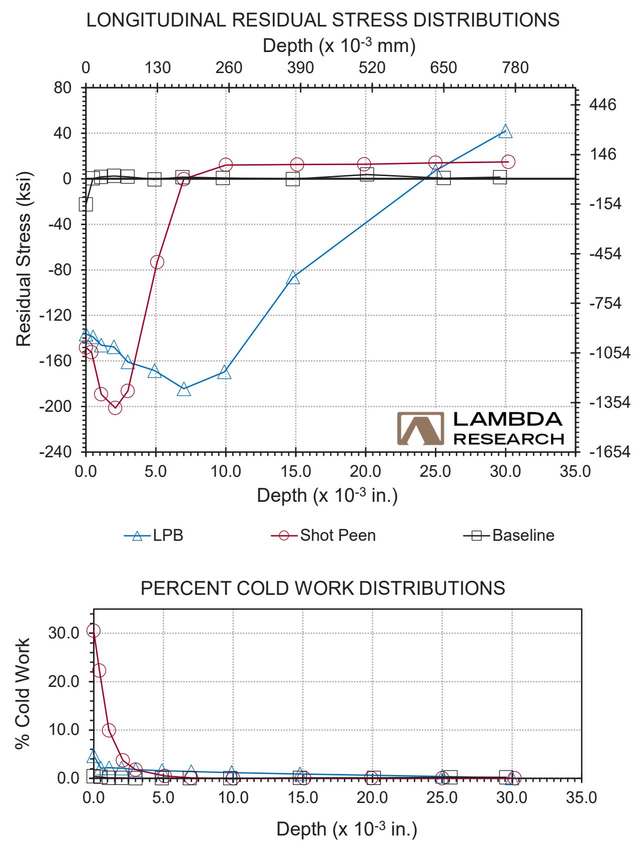

Figure 1: RS vs Depth in Gauge Region

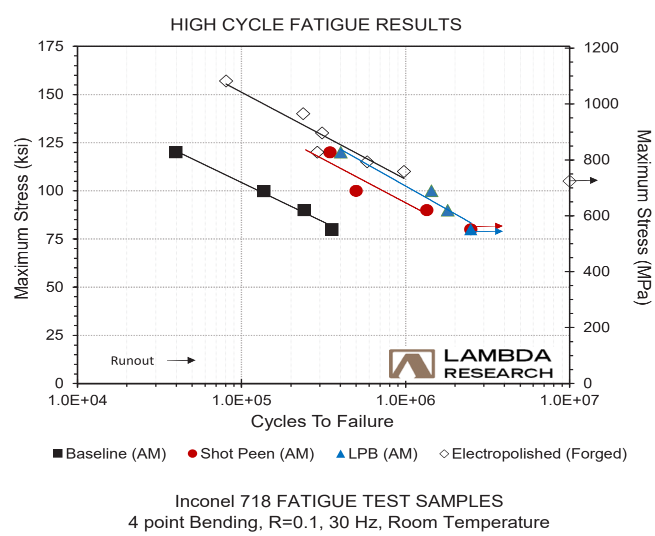

Figure 2: High Cycle Fatigue Results