Fatigue performance at 550°C of shot peened and oxidized Inconel 718 additively manufactured by Laser-Powder Bed Fusion (L-PBF)

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Abstract

As-machined, shot peened, oxidized, and shot peened-oxidized samples were fatigue tested at elevated temperature. Shot peening increases fatigue life by 6. Fractographic analyses reveal that cracks mostly initiate on lack of fusion. For the as-machined and oxidized samples, cracks are located at the surface or subsurface within a 120 µm depth range. While for the shot peened samples, cracks are located subsurface at about 850 µm depth. Finally, results show that oxidation does not affect fatigue life even after shot peening.

Keywords

Shot peening, Additive manufacturing, fatigue, high temperature, IN718

Introduction

Metal additive manufacturing is a disruptive technology that is likely to replace some traditional manufacturing processes. However, this process creates undesirable high surface roughness [1], porosity [2], and tensile residual stress [3]. These side effects imply that as-built (AB) test pieces have drastic inferior fatigue life in comparison with that of the conventional counterparts [1,4]. Consequently, additive manufactured parts must undergo surface finish to increase their fatigue life.

Shot peening is a process used to increase fatigue life. Bagherifard et al. [5] showed for the AlSi10Mg alloy that the roughness of the AB parts decreased after shot peening, which consequently increased the fatigue strength by 270% in comparison with the AB condition. However, the effect of shot peening on fatigue life of IN718 additively manufactured is yet to be studied at elevated temperature.

Objectives

The objective of the present study is to evaluate fatigue properties enhancement by shot peening of the IN718 manufactured by Laser-Powder Bed Fusion (L-PBF). In addition, the impact of pre-oxidation on fatigue life before and after shot peening is also studied. This paper presents fatigue results performed on as-machined condition.

Experimental Methods

The studied material was a nickel-based superalloy Inconel 718 elaborated by Laser-Powder Bed Fusion (L-PBF). The L-PBF process conditions cannot be disclosed.

Axial fatigue tests were performed in the built direction on a MTS 318.25 machine under a stress ratio of 0.1 and a maximum stress of 650 MPa, at a temperature of 550°C and a frequency of 10 Hz.

Herein, results for four surface conditions are presented, namely, 1/ as-machined (AM), 2/ as-machined and oxidized (AMO), 3/ as-machined and shot peened (SP), 4/ as-machined, shot peened, and oxidized (SPO). Three samples were fatigue tested per surface condition. All fractured samples were observed under a scanning electron microscope to identify the crack initiation causes.

Samples were shot peened using CW400 media at an intensity Almen of F12 (in millimeter) with a coverage of 150%. Samples were oxidized at 550°C during 1000h in an air environment. Surface roughness profiles of as-machined and shot peened samples were measured to evaluate the effect of shot peening on roughness. Four profiles were measured per surface condition. Finally, microhardness profiles were measured in the plane perpendicular to the built direction at 100 gf.

Experimental Results

Table 1 provides the fatigue results for the studied surface conditions. Shot peening increased fatigue life by 6 when compared to the as-machined condition. Oxidation unaffected the average fatigue life both before and after shot peening. However, oxidation increased fatigue life dispersion both before and after shot peening.

Fractographic failure analyses revealed that most of the cracks initiated at a lack of fusion. Figure 1 shows an example of an observation of a lack of fusion for an as-machined sample. In addition, fractographic analyses of the AM and AMO conditions showed that cracks initiated either at the surface or below the surface at an average depth of 100 µm. Interestingly, surface cracks initiated on lack of fusion located at the surface. These results suggested that surface roughness had a minor impact on crack initiation. Finally, similar analyses performed for the SP and SPO conditions revealed subsurface crack initiations at an average depth of 850 µm.

The roughness parameters of the AM and SP surface conditions are presented in Table 2. Shot peening increased R_a and R_z of the as-machined condition by 10 and 8, respectively.

Finally, microhardness profiles were measured for all the studied conditions. Table 3 provided the microhardness values at the surface and at the end of the zone affected by shot peening. Shot peening hardened the surface within a 200 µm depth. However, oxidation after shot peening did not affect the microhardness peak value. This was surprising, since thermal residual stress relaxation was expected to decrease this value. Finally, the microhardness value of the base material (525 Hv) increased after oxidation to 560 Hv for both the AM and SP conditions. This could result from an additional precipitation of the γ' and γ'' phases.

Table 1. Fatigue results at a temperature of 550°C for a 0.1 stress ratio at a maximum stress of 650 MPa.

Surface condition	**Fatigue life**	
	Mean [cycles]	**Coefficient of variation (standard deviation / mean) [%]**
As-machined	44 020	3
As-machined + oxidized	49 660	36
As-machined + shot peened	295 161	31
As-machined + shot peened + oxidized	279 862	49

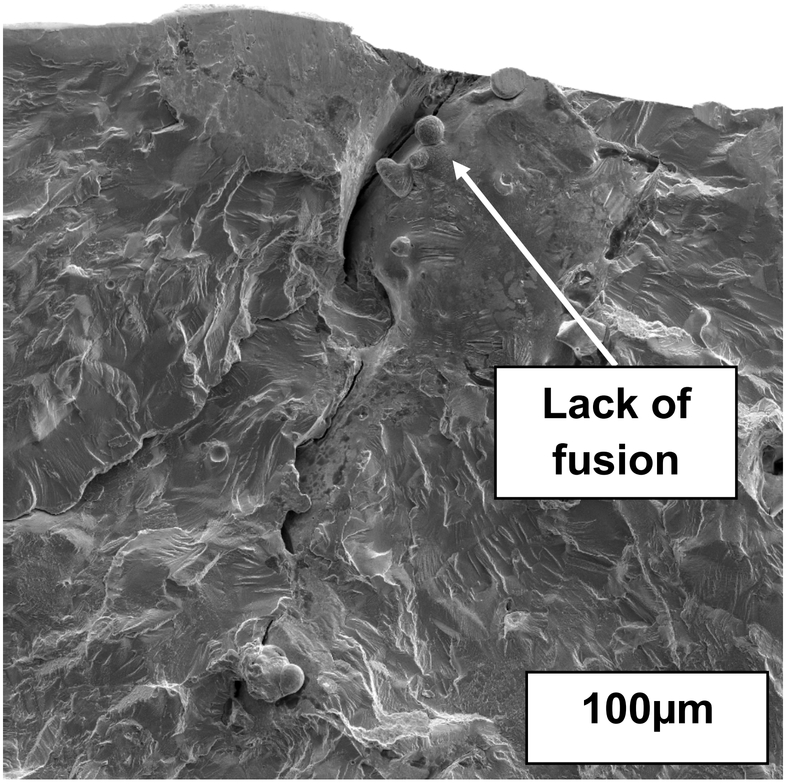

Figure 1. Typical fractographic observation obtained under a scanning electron microscope showing a crack initiation on a lack of fusion.

Table 2. Arithmetic average (R_a) and average maximum peak to valley height (R_z) of the measured roughness profiles.

Surface condition	R_a		R_z	
	Mean [cycles]	Coefficient of variation (standard deviation / mean) [%]	Mean [cycles]	Coefficient of variation (standard deviation / mean) [%]
As-machined	0.1	16	0.8	16
As-machined + shot peened	1.1	5	6.5	12

Table 3. Microhardness measurements

Surface condition	Microhardness, Hv			
	At the surface		At 0.2 mm depth	
	Mean	standard deviation	Mean	standard deviation
As-machined	540	13	525	7
As-machined + oxidized	560	4.5	560	7
As-machined + shot peened	603	7	520	8
As-machined + shot peened + oxidized	601	10	560	10

Discussion and Conclusions

Shot peening increased fatigue life of the as-machined condition by 6. All the cracks that initiated in the AM and AMO samples were contained within the shot peening affected zone, characterized using microhardness measurements. In addition, fractographic analyses of the SP and SPO samples revealed subsurface cracks at a depth of about 850 µm. These results showed that shot peening prevented crack initiation around the surface, which in turn increased fatigue life.

Oxidation increased microhardness values most likely caused by a secondary precipitation of the γ' and γ'' phases.

Oxidation unaffected fatigue life of the AM condition. Oxidizing the material at 550°C during 1000h led to a nanometric oxide layer. Fractographic analyses revealed that cracks initiated either at the surface or below the surface. Moreover, cracks at the surface were initiated by lack of fusion. As a consequence, surface roughness and geometric discontinuity induced by oxidation had no effect on fatigue life.

Oxidation unaffected fatigue life of the shot peened samples. While oxidation barely affected the surface, fatigue life was expected to decrease because of thermal residual stress relaxation that should occur during oxidation. However, the microhardness measurements showed that oxidation unaffected microhardness in the shot peened affected zone. Assuming a correlation between residual stress and microhardness, residual stress did not relax after exposing the material at 550°C during 1000h. This is in opposition with the observations made by Cammett *et al* [6] on a conventional shot peened IN718. In fact, the authors observed that residual stresses decreased by 50% after exposing the material at 525°C during only 10h. Additional work is required to confirm this observation using direct residual stress measurements.

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