FATIGUE AND SURFACE TEXTURE OF POST-PROCESSED METAL ADDITIVE TI-6AL-4V

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KEYWORDS

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ABSTRACT

In the present work, the effect of surface roughness on the fatigue behavior of Ti6Al4V specimens manufactured by Laser Powder Bed Fusion (LPBF) with varying surface finishing conditions is investigated. Surface texture was investigated by the use of areal fringe projection measurements.
Height parameters such as the arithmetic mean deviation of the measured profile (Ra / Sa) or its maximum height (Rt / Sz) are, even though highly sensitive to extreme values, still common practice in industrial applications.
In this work, the more robust parameters from the material ratio curve were used to show the correlation of surface texture of post-processed LPBF surfaces and fatigue data. A good fit could be obtained for the core height Sk.

1. INTRODUCTION

Additive manufacturing technologies aid lightweight construction, cut down on material waste and manufacturing time, and ultimately lessen the final product's carbon footprint [1]. Surface quality with regard to fatigue performance is challenging for the part qualification [2], and surface post-processing is still often required, especially when taking into account the high criteria for aerospace applications [1]. Laser powder bed fusion (LPBF) parts characteristically exhibit internal defects [3] and surfaces typically show particle agglomerations and undercuts. These agglomerations also introduce new challenges for measurement methods [4], since the results from the widely applied contact stylus measurement can be compromised by mechanical impact on the instrument tip.
In this work, the effect of post-processing Ti-6Al-4V surfaces from LPBF on surface quality and fatigue behaviour was investigated. Fatigue coupons in four different conditions, including as-built, were considered. The surface topography data were collected by means of optical fringe projection measurements and the surface quality was assessed using alternative areal surface texture parameters from the material ratio curve (ISO 25178) as opposed to the industrially established line parameters (ISO 21920) Ra (mean profile height) and Rt (maximum profile height), as previously shown for different as-built surface conditions [5].
The use of areal parameters offers larger coverage, hence a better statistical representation of the surface than just a single line and is already applied in some academic work [4,6].
The obtained test results are used to identify a purely data based correlation between the fatigue behaviour and the evaluated parameters. In particular, the data points of each post-processing scenario tested at different stress levels were factorised to a common number of cycles by using their respective fatigue curve slope. Finally, a good data fit was obtained for Sk (core height) from the material ratio curve.

2. MATERIALS AND METHODS

2.1 Manufacturing process

Ti6Al4V cylindrical coupons according to DIN EN 6072 [7] (FCE type A, Kt=1.035) were printed on a commercial standard machine. A nominal diameter of 4 mm was adopted, although a slight offset was applied due to the material removal after the application of different post-surface treatments to have the same final dimension between as-built and post-treated ones. All samples were printed at a 70-degree angle from the build plate. To obtain a homogeneous microstructure and to reduce the number of internal defects, all samples were annealed before and subjected to Hot Isostatic Pressing (HIP). In particular, the following treatment conditions were used: stress relief at 720 °C /2h in a vacuum furnace and annealing at 920 °C for 2 hours under a pressure of 1000 bar.

2.2 Surface post-processing

Four different surface conditions were investigated in the present study: as-built, sandblasting, machining, and chemical milling. For as built, no more processing was applied to the coupons after the printing preserving the original surface. In the sandblasting process, hard and angular grits are blown to the surface by compressed air. The jet flow of abrasive grit cleans up the powder adhering to the as-built surface, removes oxidation layers, and mildly improves the surface roughness. In this study, coupons were sand-blasted manually at the pressure of 0.8 MPa with 120 grit made of brown alumina at a distance of approximately 100 mm. Chemical milling was applied following Airbus specifications and therefore details are not here reported. This is a non-conventional process but results showed for some materials competitive alternative to machining. In order to obtain a reference set of values, the machined surface was also investigated since it is widely adopted by industries and is known to provide fine surface finishing.

2.3 Surface texture characterisation

The as-built (AsB), sandblasted (SB) and chemically milled (ChM) surfaces were measured by fringe projection (FP) with the Keyence VR3200 system. The machined samples were measured by laser scanning confocal microscopy (LSCM) on the Keyence VK9700 system.
Table 1 contains specifics on measurement and filtering, in Figure 1, measured locations on the tested fatigue specimens are indicated.

Table 1: Measurement specifics and filtering

	FP	LSCM
Magnification	80x	20x
Field of view	3.78 x 2.84 mm²	0.5 x 0.7 mm²
Lateral resolution	3.7 µm	0.67 µm
S-Filter	8 µm	2.5 µm
L-Filter	0.8 mm	0.8 mm

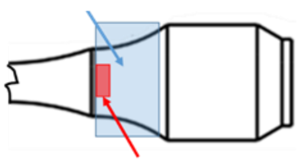


Figure 1: Measured location on tested fatigue specimens

The arithmetic mean height of the areal profile Sa is evaluated for reference as there are more commonly known than the material ratio curve parameters.
The material ratio curve, shown in Figure 2 is derived from the areal profile and represents the accumulated material percentage (x-axis) for each profile height (y-axis). Five parameters can be derived from the curve: Core height Sk, reduced peak height Spk, reduced valley depth Svk, and respective corresponding material ratios Smr1 and Smr2. Sk is the height difference of the intersection with the vertical axes of the main slope tangent line, Spk and Svk are the average sizes of peak and valley portions (outside the core profile).
All of the surface texture parameters used in this work are defined in ISO 25178 [8].

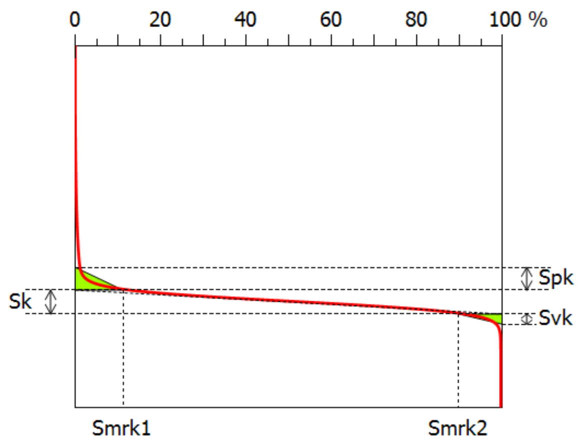


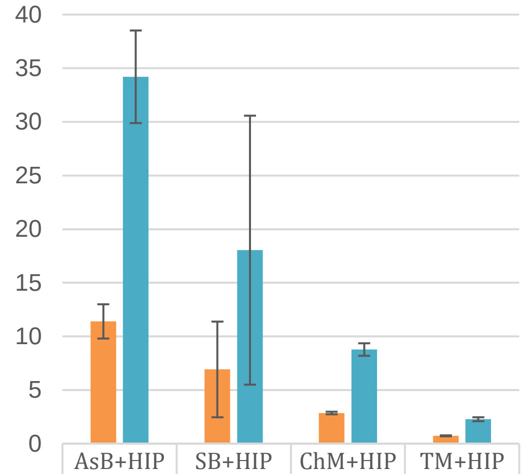
Figure 2: Material ratio curve with Sk, Spk, Svk, Smr1 and Smr2

2.3 Fatigue testing

Uni-axial fatigue tests were carried out on an Instron system machine at room temperature. A stress ratio of $R = s_{min}/s_{max} = 0.1$ was adopted and a frequency of 20 Hz. All tests were performed up to the failure of the sample (a run out of 2x10^6 was set). Stress levels were chosen so to cover the fatigue life range from 10^4 up to 10^6.

3. RESULTS

The evaluated surface texture parameters show the expected differences among the as-built and post-processed surface conditions. From **Figure 1** it can be seen that the variation for the sandblasting condition is very large. This is due to irregularities in the process itself. Within that group, there was one far outlier in particular, which is overall closer to the AsB group. Looking at **Figure 2,** an SB data point is located close to the AsB group, confirming the relation between surface texture and fatigue life.



	AsB+HIP	SB+HIP	ChM+HIP	TM+HIP
Sa / µm	11.40	6.92	2.86	0.73
Sk / µm	34.20	18.04	8.77	2.28

Figure 3: Surface Texture Parameters Sa and Sk, L-Filter 0.8 mm

To finally investigate the relationship between the fatigue results and the evaluated parameters, all data points were factorized to the same fatigue life (10^5). The Basquin's equation was used to fit the different data points of each scenario.

Figure 4 shows the factorized stress as a function of the measured Sk values. It should be noted that in the present investigation, several parameters were evaluated but Sk gave the best fit and therefore is the only parameter here shown.

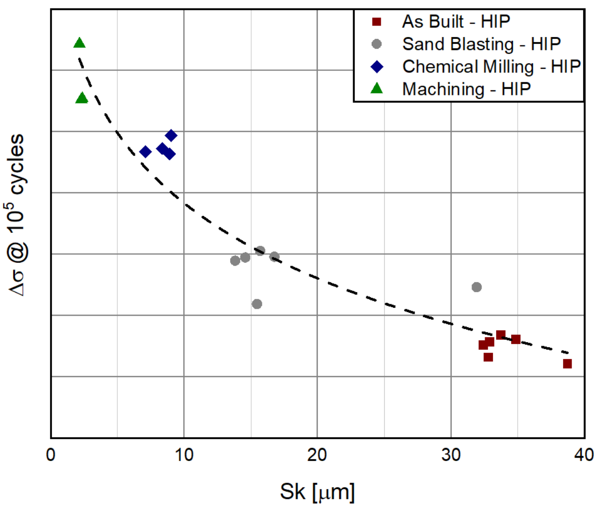


Figure 4: Factorised stress as a function of the measured Sk parameters for the different post-processed surface conditions

As expected, a significantly reduced fatigue behavior was observed in as-built material. The use of sandblasting improved the fatigue properties as a direct consequence of the reduced roughness but it can be still observed a substantial gap compared to the reference machined values. Improved fatigue performances were obtained only after chemical milling; as shown before, lower surface textures were indeed observed compared to as-built and sandblasting.

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