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An investigation of anisotropy on AISI 316L obtained by additive manufacturing (AM) measuring surface roughness after micro-endmilling operations

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Abstract
Hybrid Manufacturing (HMf), using Additive Manufacturing (AM) and Metal Cutting are able to produce parts that could hardly be fabricated by other processes. The material addition by layers can produce complex geometries using a variety of materials (polymers and metals). Stainless steel can be used for micromolds and microfluidic devices. The level of details and surface finishing control by micro-machining processes could introduce a relevant approach to produce microdevices with low roughness and much less geometrical deviations. The present work aims at investigating some aspects related to the anisotropy of AM workpieces using micro-endmilling operation. Stainless steel workpieces produced by Powder Bed Fusion (PBF) process were micro-endmilled with two diferent ball-nose micromills diameters (600 and 800 µm) and ~1.7 µm edge radius. Cutting parameters adopted were 60 m/min cutting speed, 100 µm depth of cut and feed per tooth (f_t) variating from 0.5 to 3 µm performing full slot operations. The machining was carried out changing the tool path direction in specific angles (30°, 90°, 120° and 180°) along the slot length. Roughness parameters R_p, R_v, R_z, R_{sk} and R_{ku} were applied measured in different machined surfaces inside the slot, in an attempt to detect anisotropy. Analysis of Variance (ANOVA) showed the effect of cutting direction and cutting parameters on surface roughness. The results indicates that when reducing endmill diameter anisotropy effects appears on the roughness parameters, independently of f_t values.

Anisotropy. Microchannels Finishing. Stainless Steel. Additive Manufacturing. Micro-endmilling.

1. Introduction

Hybrid manufacturing (HMf) processes can be very competitive to fabricate metallic components for high performance applications. HMf using Additive Manufacturing (AM) and Metal Cutting can produce parts with complex geometry, better dimensional precision and surface finishing, since it uses the best of each fabrication tecnique [1]. The AM allows a variety of types of micro devices and its application has been estimulated by many researches [3]. Micromanufacturing can also take advantage of HMf [2]. However, the material deposition by layers finds a serie of challenges when micro parts and refined microstrutures are required [4]. Microfeatures, such as roughness and microchannel profile, often need post processing by subtractive processes [5]. Micromilling, as a post process can be used to improve the quality of microparts. However, the well known material anisotropy, caused by the layer deposition mechanism, must be considered. The present work intends to evaluate the material anisotropy by means of surface roughness in workpieces made by the Powder Bed Fusion (PBF) process submitted to micro-endmilling operations.

2. Experimental procedure

Stainless steel (316L) workpieces were manufactured by PBF [6] using a Concept Laser Model M2 with 200 W in a "chess board style" selective fusion. Layers were deposited 90° of each other. Micro-endmilling operations were performed in a vertical machining center CNC Kern model D-824118 with maximum 50k rpm spindle rotation. Two carbide ball-nose micromills with 600 and 800 µm diameters were used (edge radius ~1.7 µm). The cutting edge radius and microchannels roughness were measured by Olympus OLS4000 3D Laser Microscope. Cutting speed was 60 m/min. For the 600 µm endmills, 100 µm Doc, and f_t of 0.5 and 1 µm was used. For the 800 µm endmill f_t of 0.5, 1 and 3 µm with the same Doc were used. Channels were micromilled under dry condition and cutting direction was changed with 30°, 90°, 120° and 180°. Figure 1 presents the experimental setup.

Two 3D images of each channel was made and three replicates per cutting condition was performed. Roughness parameters R_z, R_p, R_v, R_{sk} and R_{ku} were measured in up milling and down milling side of the channels. Cutting parameters and cutting direction effects on roughness were evaluated by Analisys of Variance (ANOVA) and statistical significance β less than 5%.

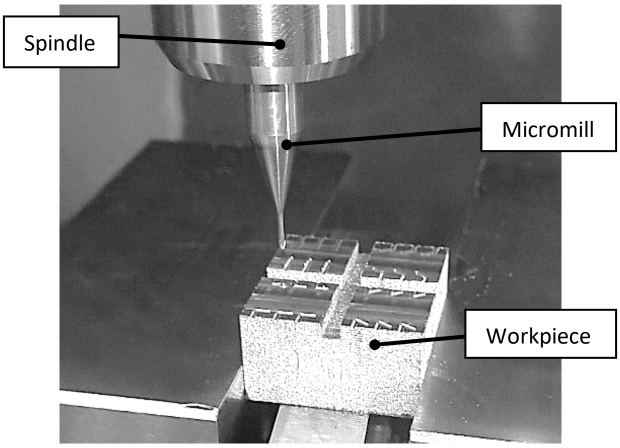

Figure 1. Experimental setup for micromilling of channels in 316L workpiece obtained by PBF process.

3. Results and discussion

Although material microstructure is presented here, optical microscope observations show a very irregular gains formation, similar to welded structures. Figure 2 presents results of roughness R_p, R_v, R_z, R_{sk} and R_{ku} for micro-endmilling with 600 µm endmill, 4 direction changes and 2 f_t values.

ANOVA indicated that changing tool path caused a variation of roughness values detected by R_z, R_p and R_v ($\beta \approx 0\%$), what indicates some anisotropy caused by the AM process. The increase of f_t caused smoother surface, with balance between peaks and valleys formation along the machined surfaces, as detected by R_{sk}. The up milling side of the slot showed higher roughness values(R_z, R_p and R_v), and an indented like surface on the down milling side ($R_{ku}<3$).

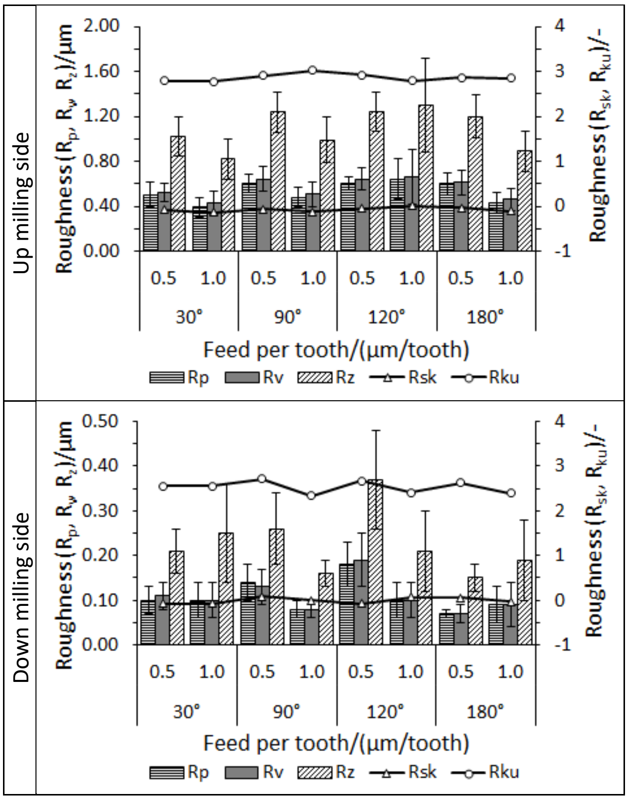

Figure 2. Roughness graphs for micro-endmilling with micromills diameter of 600 µm.

Figure 3 presents graphs of roughness parameters R_p, R_v, R_z, R_{sk} and R_{ku} for endmill 800 µm. For each angle change, 3 f_t values were used. ANOVA revealed no significant effect directionth change upon the roughness ($\beta>5\%$). However, the increase of f_t (mainly from 0.5 to 1.0 µm) and down milling side showed smoother machined surfaces ($\beta \approx 0\%$). Peak formation prevailed in down milling side, while up milling resulted in a balance between peaks and valleys. Kurtosis ($R_{ku} \approx 3$) showed a uniform distribution of surface formation during machining.

The roughness analisis indicated some possible effect of workpiece anisotropy and it was more sensitive when reducing endmill diameter. Therefore, it is important to consider the workpiece orientation to obtain better machined surfaces during micromilling operations. On the other hand, larger endmill diameter showed smoother surface along the microchannels, even when tool path changes direction.

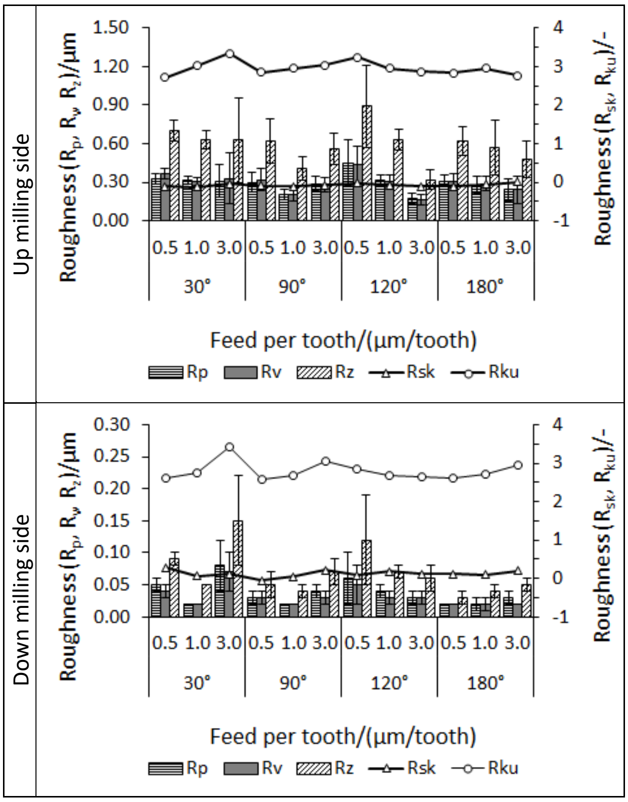

Figure 3. Roughness graphs for micro-endmilling with micromills diameter of 800 µm.

4. Conclusions

Results showed some indications of material anisotropy when tool path changed direction, specially using 600 µm diameter tool in all cutting conditions tested. Increasing tool diameter for 800 mm minimizes that effect, keeping a relative uniformity of roughness values. The down milling side of the slots produced smoother surfaces, while effects of minimum chip thickness caused rough surfaces on the up milling side. In the future a more detailed statistical analysis will further evaluate additional information relating roughness and material anisotropy in workpieces obtained by PBF process.

Achnowledgments

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