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The Influence of Milling Parameters on Surface Integrity under Different Processing Methods

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ABSTRACT

Ultrasonic assisted milling technology has shown significant effects in improving the quality of machined surfaces, but its specific mechanism of action on the surface and near surface of the workpiece when applied to SLM forming TA15 titanium alloy still needs to be further explored. Under the premise of keeping other cutting conditions constant, as the feed rate of each tooth increases, the machining area covered by the tool expands accordingly, which has a direct impact on the formation of surface microstructure. Based on the above reasons, different microstructures of the machined surface can be obtained by changing the feed rate of each tooth. This article mainly uses surface morphology, roughness, and hardness as key indicators to evaluate the integrity of the machined surface. It systematically analyzes the trend and law of the influence of each tooth feed rate on surface morphology, roughness, and surface hardness during ultrasonic vibration milling of SLM formed TA15 titanium alloy.

KEYWORDS

Selective Laser Melting; TA15; Feed Per Tooth.

1. INTRODUCTION

Titanium alloys are increasingly used in industries such as aviation, aerospace, marine, and automotive due to their special material properties, such as high strength, excellent corrosion resistance, and thermal capabilities [1-2]. However, the production of titanium alloys presents challenges due to their low thermal conductivity [3], tendency to undergo active chemical reactions with oxygen [4], and susceptibility to strain hardening [5,6]. Traditional methods, such as powder metallurgy[7,8], rolling, casting, and bulk raw material forging, can be used to manufacture titanium alloy products[9]. However, these methods have disadvantages such as complex manufacturing processes, numerous processing steps, long production cycles, high material removal rates, and high manufacturing costs.

Compared with traditional production methods, selective laser melting (SLM) has the advantages of fewer production steps, higher material efficiency, higher yield, and flexibility. Due to these advantages, SLM technology has been successfully applied in the processing of various titanium alloy products. So far, there has been little research on the surface integrity of TA15 alloy manufactured by SLM. Therefore, it is crucial to study the influence of cutting parameters on the surface integrity of TA15 alloy manufactured by SLM. This article mainly uses surface morphology, roughness, and hardness as key indicators to evaluate the integrity of the machined surface. It systematically analyzes the trend and law of the influence of each tooth feed rate on surface morphology, roughness, and surface hardness during ultrasonic vibration milling of SLM formed TA15 titanium alloy.

2. EXPERIMENTAL DESIGN

The milling parameters are shown in Table 1

Table 1. Single factor experiment table for feed rate per tooth

Cutting Speed(rpm)	Feed per Tooth(mm/z)	Cutting Width(mm)	Cutting Depth(mm)	Ultrasonic amplitude（μm）
2000	0.02,0.03,0.04,0.05,0.06	0.3	2	3

3. THE INFLUENCE OF FEED RATE PER TOOTH ON SURFACE INTEGRITY

3.1. Influence of Feed Rate Per Tooth on Surface Morphology

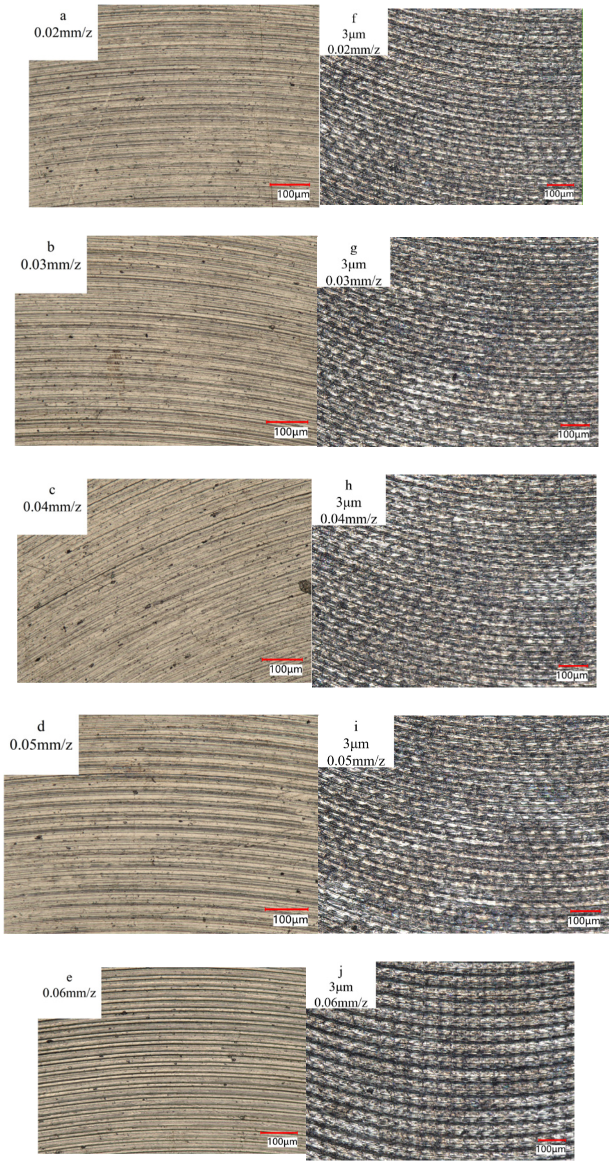

Figure 1. Surface morphology of machined surfaces with different feed rates per tooth: (a) conventional milling, fz=0.02mm/z, (b) conventional milling, fz=0.03mm/z, (c) conventional milling, fz=0.03mm/z, (d) conventional milling, fz=0.05mm/z, (e) conventional milling, fz=0.06mm/z, (f) ultrasonic vibration milling, fz=0.02mm/z, (g) ultrasonic vibration milling, fz=0.03mm/z, (h) ultrasonic vibration milling, fz=0.04mm/z, (i) ultrasonic vibration milling, fz=0.05mm/z, (j) ultrasonic vibration milling, fz=0.06mm/z

Figure 1 shows the surface morphology of conventional milling and ultrasonic vibration milling under different feed rates per tooth.

Figures 1 (a) to (e) show that conventional milling surfaces have circular plowing marks. As the feed rate of each tooth increases, the marks become wider and the height difference is large. Micro chips are attached to the surface, and the tool marks are obvious. The lateral flow of material leads to irregular morphology. Increasing the feed rate improves the material removal rate, but increasing the cutting force exacerbates tool deformation and vibration, resulting in surface damage and increased material extraction.

In contrast, the ultrasonic vibration milling surfaces in Figures 1 (f) to (j) exhibit a "fish scale" microtexture with no microchips or lateral plastic flow. Micro texture makes plowing marks uniform and reduces the width of wave peaks. When the feed rate is small, there are almost no pits or burrs on the surface, and the micro texture distribution is uniform and regular. But as the feed rate increases, the distribution of microtextures becomes uneven, resulting in fine pits and tiny burrs.

3.2. Effect of Feed Rate Per Tooth on Surface Roughness

Each group of samples was measured at three positions, and the average of the three measurement results was taken for analysis. Figure 2 shows the surface roughness of conventional milling and ultrasonic vibration milling under different feed rates per tooth. Figure 3 shows the surface roughness values of ultrasonic vibration milling under different feed rates per tooth.

Figure 3 shows that the surface roughness Sa values of ultrasonic vibration milling and traditional milling both increase with the increase of feed rate per tooth. Under the same feed rate, the Sa value of ultrasonic vibration milling is higher than that of conventional milling. For example, when the feed rate is 0.02mm/z, the Sa value of the conventional milling surface is 0.219 μ m, while the Sa value of the ultrasonic vibration milling surface increases to 0.283 μ m, and the Sa value of ultrasonic vibration milling is 29.22% higher than that of conventional milling; When the feed rate is 0.06mm/z, the Sa value of conventional milling is 0.447 μ m, while the Sa value of ultrasonic vibration milling is 0.480 μ m, which is 7.38% higher. This is because an increase in feed rate leads to an increase in chip thickness and cutting force, exacerbating tool deformation and deteriorating machining conditions. In addition, the micro texture on the surface of ultrasonic vibration milling is also one of the reasons for the high Sa value.

3.3. Effect of Feed Rate Per Tooth on Surface Hardness

Table 2 shows the measured values of surface hardness for conventional milling and ultrasonic vibration milling under different feed rates per tooth, while Figure 4 shows the relationship between surface hardness and feed rate per tooth.

Table 2 shows that under the same feed rate per tooth, the surface hardness of the samples milled by ultrasonic vibration is higher than that of conventional milling, with a hardness increase ranging from 9.78% to 18.41%. When the feed rate per tooth is 0.02mm/z, the surface hardness of conventional milling and ultrasonic vibration milling is 308.73HV and 338.91HV, respectively. When the feed rate per tooth is 0.04mm/z, the surface hardness of conventional milling and ultrasonic vibration milling is 316.21HV and 364.36HV, respectively. As the feed rate per tooth increases from 0.02mm/z to 0.06mm/z, the surface hardness of both milling methods increases. This is mainly because the increase in feed rate leads to an increase in cutting force and surface cutting temperature, and under the combined action of mechanical and thermal loads, the surface hardness increases. In ultrasonic vibration milling, the impact and ironing effect of the milling cutter bottom edge further enhance the hardness of the machined surface. Due to the impact and pressure of the milling cutter bottom edge on the machined surface during ultrasonic vibration milling, the hardness of the machined surface is ultimately higher than that of conventional milling.

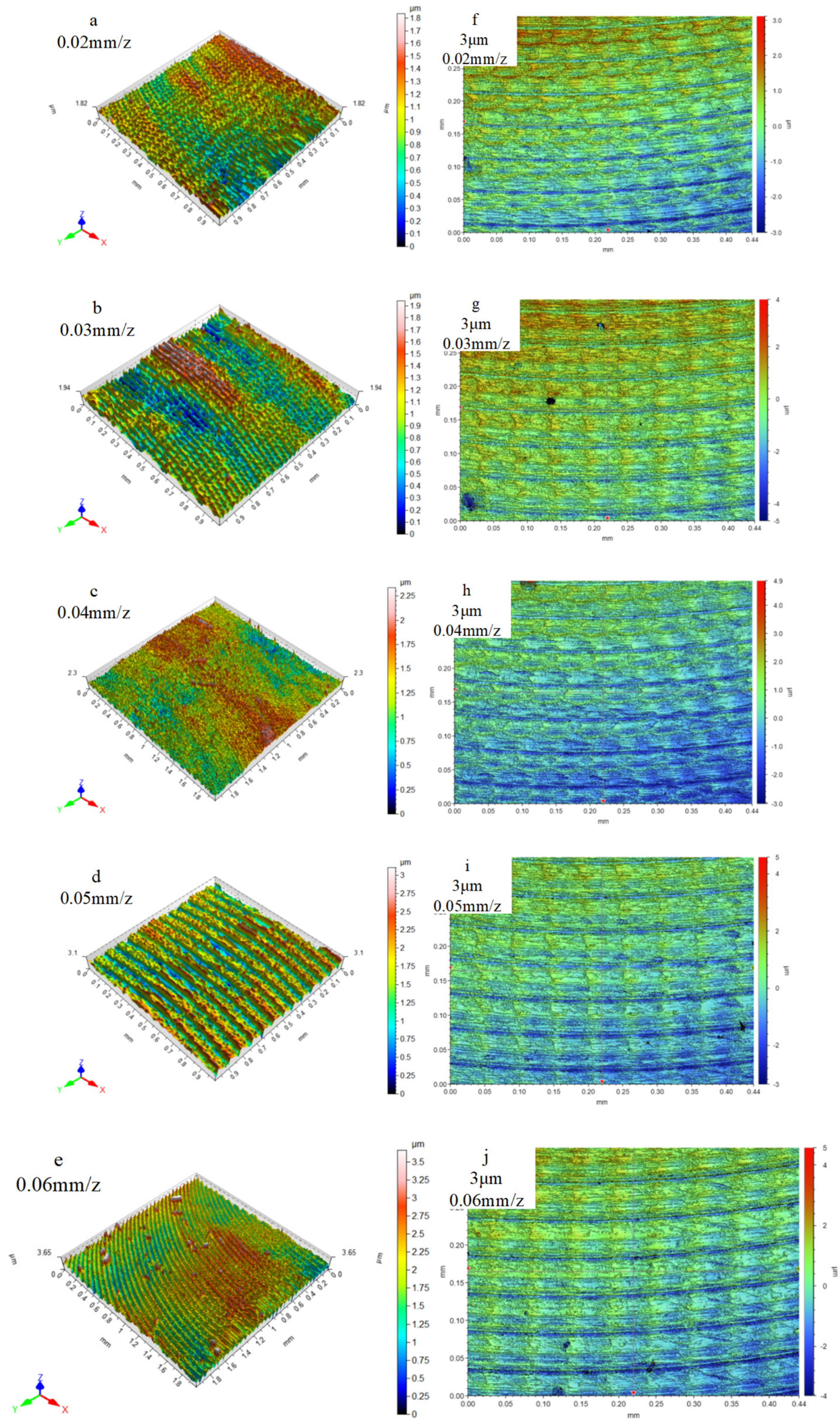

Figure 2. Surface roughness at different feed rates per tooth: (a) conventional milling, fz=0.02mm/z, (b) conventional milling, fz=0.03mm/z, (c) conventional milling, fz=0.03mm/z, (d) conventional milling, fz=0.05mm/z, (e) conventional milling, fz=0.06mm/z, (f) ultrasonic vibration milling, fz=0.02mm/z, (g) ultrasonic vibration milling, fz=0.03mm/z, (h) ultrasonic vibration milling, fz=0.04mm/z, (i) ultrasonic vibration milling, fz=0.05mm/z, (j) ultrasonic vibration milling, fz=0.06mm/z

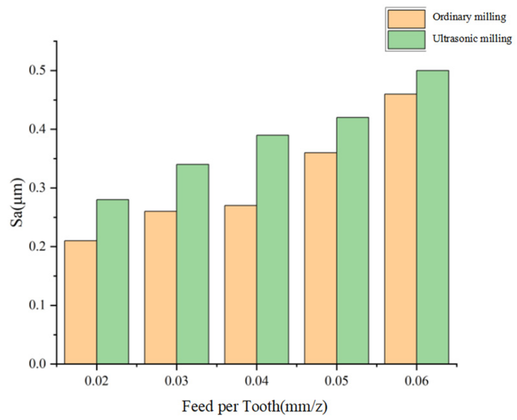

Figure 3. The influence of feed rate per tooth on the Sa value of the machined surface

Table 2. Surface hardness measurements under different ultrasonic amplitudes

Hardness (HV)				
Feed Per Tooth	0.02	0.03	0.04	0.05
Conventional milling	308.73	314.82	316.21	321.08
Ultrasonic milling	338.91	353.23	364.36	372.91

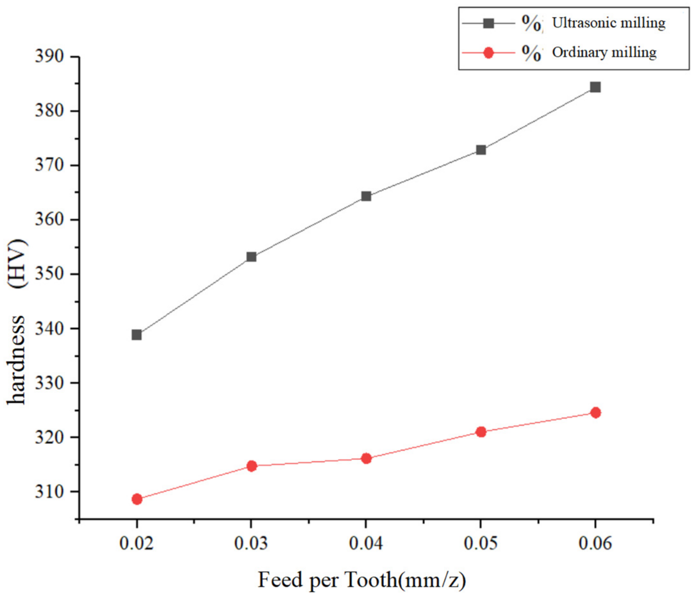

Figure 4. Surface hardness of conventional milling and ultrasonic vibration milling under different feed rates per tooth

4. SUMMARY

At the same feed rate, the surface roughness Sa value of ultrasonic vibration milling is higher than that of conventional milling. For example, when the feed rate is 0.02mm/z, the Sa value of ultrasonic vibration milling is 29.22% higher than that of conventional milling; When the feed rate is 0.06mm/z, it is 7.38% higher.

When the feed per tooth increased from 0.02mm/z to 0.06mm/z, compared with conventional milling, the surface hardness of the sample in ultrasonic vibration milling increased by 9.78%-18.41% under the same feed per tooth.

CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

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