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Experimental Investigations in the Dry Milling of Titanium Super Alloys

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Abstract — *Getting the desired surface quality in machining of aerospace super alloys where cutting temperature is very high, coolant or lubricant may be used. Due to adverse effects of cutting fluids on operator's health and environments sustainability, an application of such cutting fluids are restricted. In order to avoid such adverse effects and to support demand of environment friendly machining techniques, the dry milling concept is adopted in this study. The higher cutting temperature, rapid wear of the tool and machined surface and subsurface deformation are challenges in the machining of titanium alloys. To achieve reliable performance and long service life of machinery used, its components are required to be machined with higher surface finish along with high dimensional and geometrical accuracy. Surface integrity impacts on fatigue strength, wear resistance, corrosion resistance of the components. In this paper, the experiments have conducted for the dry milling of titanium alloys on micro EDM machine. The experiments have been planned with the combination of the cutting parameters such as cutting speed and feed rate. The aim is to characterize surface roughness and surface defects by various milling conditions. The maximum of 43% increment in the surface roughness was recorded at the feed rate of 20 mm/min and at the constant spindle speed of 1000 RPM. The visual surface defects such as feed marks, adhered materials are found in the experimental results.*

Keywords- *Milling, Titanium alloys, Surface roughness, Surface defects*

I. INTRODUCTION

Titanium alloy is an advance engineering material and its application is growing in various industries due to its superior properties like higher strength-to-weight ratio, excellent corrosion resistance, high fatigue strength in air and sea water and toughness [1]. Milling of titanium alloy Ti-6Al-4V has an application in aerospace, automotive, biomedical, space components and process industries. For getting better machined surface quality, it is expected to have better surface integrity. Surface topography is one of the main characteristics [2]. To characterize surface topography, the effective parameters like cutting speed, feed rate, tool wear, cutting tool material and geometry are to be taken into account. Some techniques are existing to characterize surface topography measurement and analysis. Yang et al. [3] reported that up to the cutting speed of 50 m/min, the Ra increased with the cutting speed and then decreased. In general, the Ra value was measured about 0.62 μm with almost no change. Further feed also linearly increased with the cutting speed increment and equivalent Ra was about 0.03 mm/z. It was also recorded that with increased depth of cut in the feed direction, the Ra was found to be increased. The maximum difference of Ra in both the directions was 0.68 μm. Sun et al. [4] experimentally evidenced that the variation ranges of surface roughness values in both directions were within 0.6–1.0 m. Rao et al. [5] demonstrated the surface roughness of 0.4 μm with using carbide tool for face milling of titanium alloys. Honghua et al. [6] measured Ra value below 0.3 μm with PCD/PCBN tools initially. With reference to depth, the micro hardness value was small. Further there was no evidence of surface defects with PCD/PCBN tools. Krishnaraj et al. [7] measured surface roughness and stated that the average surface roughness was in the range of 0.27 to 0.45 μm with anisotropic nature in their experiment on high speed milling of titanium alloys.

II. EXPERIMENTATION

2.1 Work-piece, tools and cutting conditions

The work material used for the experiments of the milling process was Ti-6Al-4V plate having dimension 65 x 45 x 3 mm. The carbide tool ϕ 4 mm was used for the dry milling process. Cutting conditions are described in Table 1.

Table 1. Cutting conditions of dry milling of Ti-6Al-4V

Machine tool	Hybrid micro EDM multipurpose machine tool
Work piece	Titanium alloy, grade-5 plate having 65 x 45 x 3 mm size
Tool	Carbide drill having 4 mm diameter
Spindle speed	800,1000 and 1200 RPM
Feed rate	10, 20 and 30 mm/min

2.2 Experimental procedure

The integrated multi-process micro-machining tool was used for experiments, see Fig. 1(a). The experiments were designed with possible 9 combinations of spindle speed and feed rate. Fig. 1(b) shows machined work-piece with nine possible combinations of cutting conditions. Fig. 2 demonstrates work and tool holding fixture with control unit. The Zeta optical non-contact type profilometer was used for measurement of surface roughness and to observe surface defects as shown in Fig. 3. Table 2 shows number of experiments with speed, feed rate and output response Ra.

Table 2. Experimental design and output response

Experiment No	Spindle speed RPM	Feed-rate mm/min	Surface roughness (R_a)
1	800	10	1.021
2	800	20	1.128
3	800	30	1.094
4	1000	10	0.8248
5	1000	20	1.183
6	1000	30	1.299
7	1200	10	1.221
8	1200	20	0.8163
9	1200	30	1.026

(a) (b)

Fig. 1 (a) Micro-EDM machine tool (b) Machined work piece

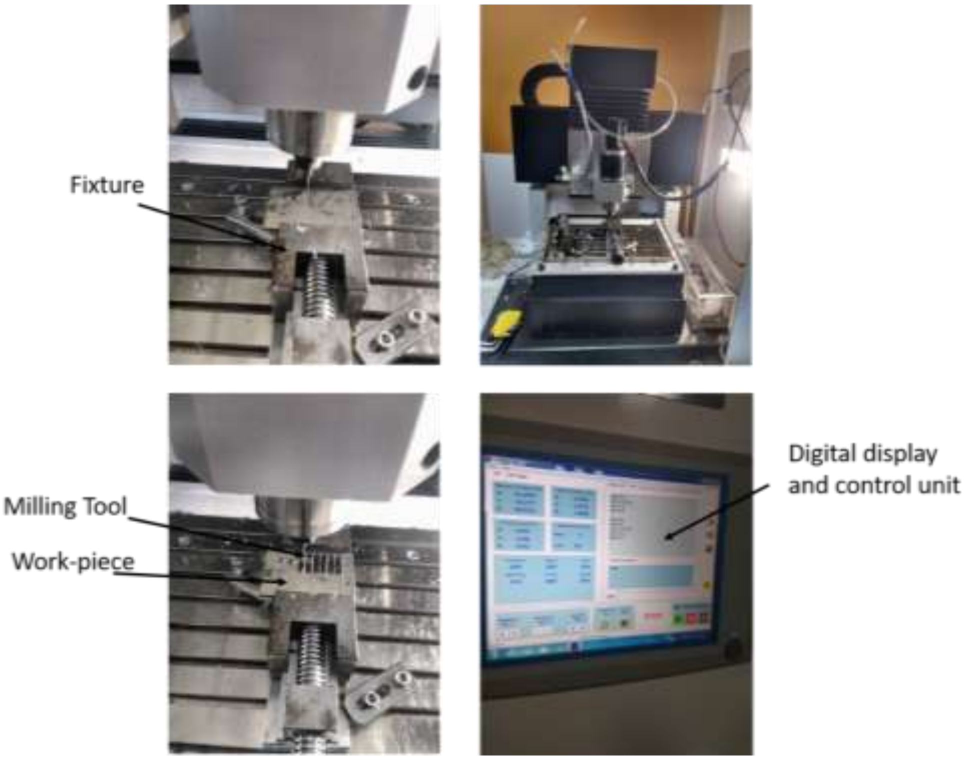

Fig. 2. Fixture assembly, milling tool, work-piece and NC control unit

Fig. 3 Optical profilometer

III. RESULTS AND DISCUSSIONS

3.1 Effect of machining parameters on surface roughness

Surface roughness is measured across the machined slot of titanium alloys and results are plotted in Fig. 4 and 5 to check effectiveness of spindle speed and feed rate. As shown in Fig. 4, it is observed the speed has an impact on surface roughness. The surface roughness reduces by 31% maximum at the spindle speed of 1000 RPM along with constant feed rate of 20 mm/min. Whereas, Fig. 5 shows effect of feed rate on surface roughness. We can conclude that, as feed rate increases, the surface roughness increases significantly. The maximum of 43% increment in the surface roughness is recorded at the feed rate of 20 mm/min and at the constant spindle speed of 1000 RPM. Hence it is certain that the feed has more impact on surface roughness than speed. As the cutting speed increases, the heat generation also increases which makes the work piece material soften, due to which surface quality might be improved.

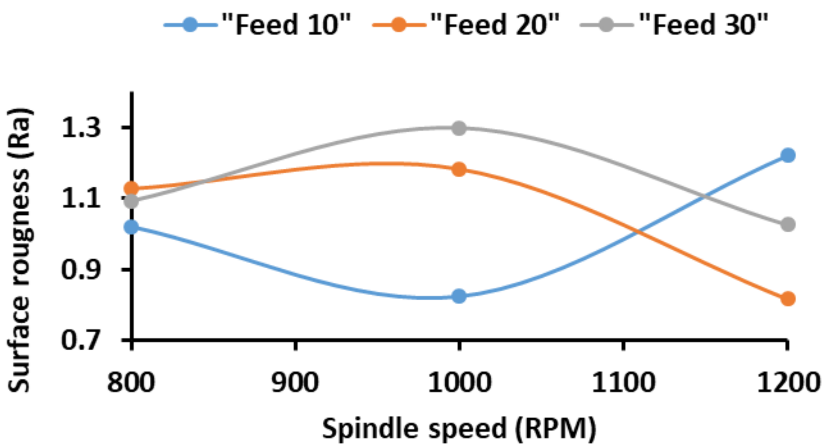

Fig. 4 Effect of on surface roughness (Ra)

3.2 Effect of machining parameters on surface defects

Fig. 6 represents the optical images of the machined surface under different milling parameters. Surface defects such as feed marks, adhered materials are visible on the machined surface which are generated due to milling tool movement and feed direction. The feed marks are found to be in curve form and at the equal distance from each other. The reason behind this phenomenon might be a higher feed rate and machine error. Further it is also found that the adhered materials stick to the machined surface when the cutting speed is higher. The chips particles are stick on the machined surface due to temperature rise.

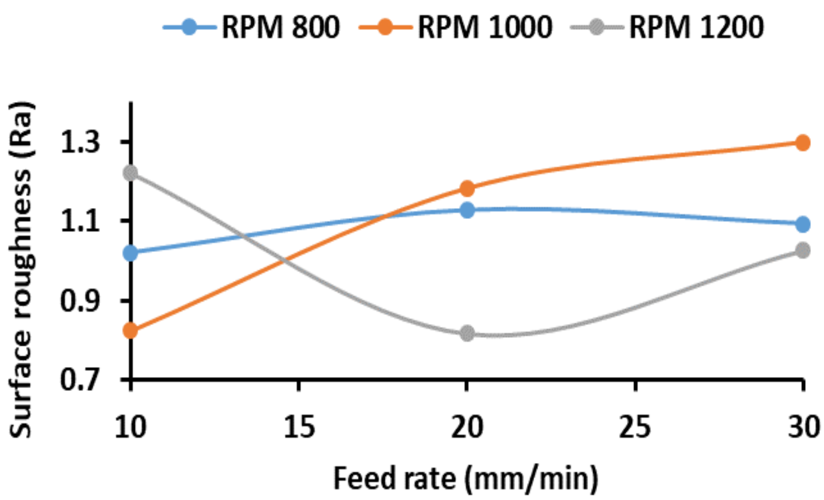

Fig. 5 Effect of feed on surface roughness (Ra)

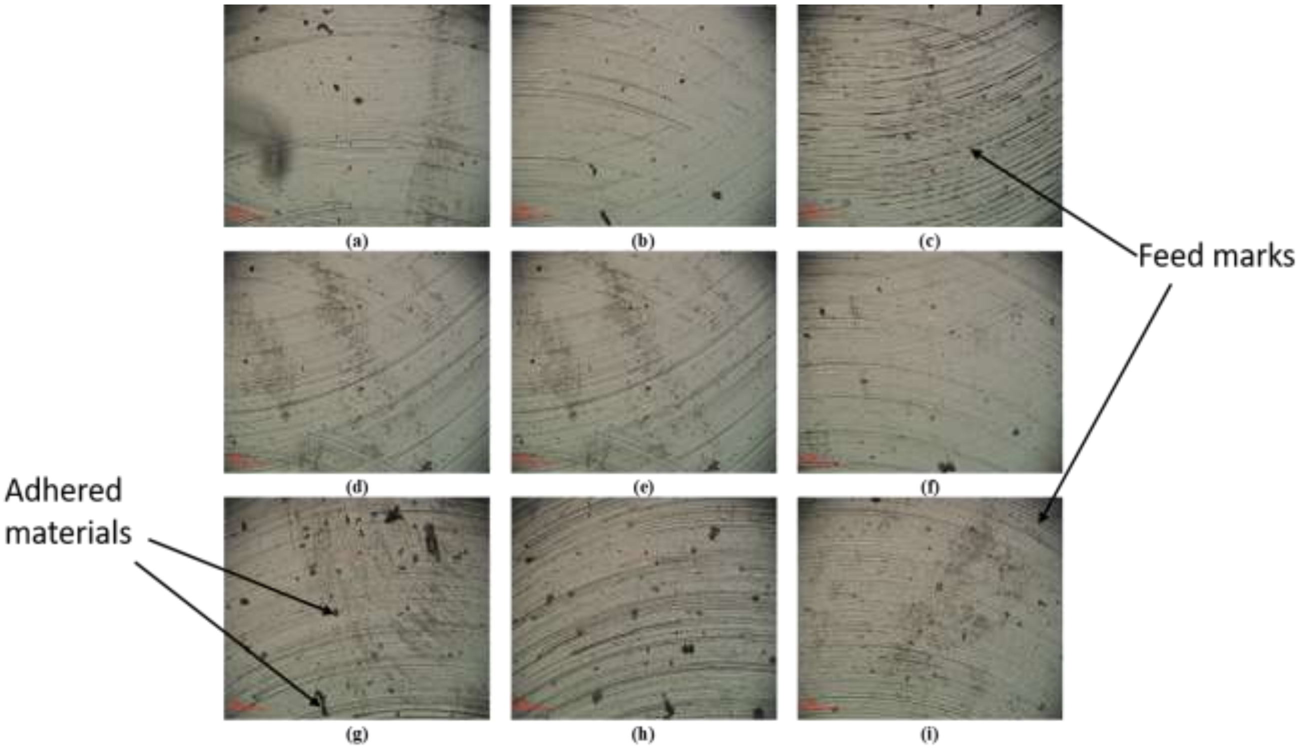

Fig. 6 (a to i). Milled surface of the various combination of cutting parameters

CONCLUSIONS

This paper concentrates on dry milling of titanium alloys and influence of cutting parameters on surface roughness and surface defects. Following are the conclusions derived from the experimental investigations.

- As the cutting speed increases from 800 to 1000 RPM, the surface roughness reduces from 1.183 to 0.8163, which is significant outcome.
- The feed rate has a large influence on surface roughness. The surface roughness increases from 0.8248 to 1.183 at the feed rate of 20 mm/min.
- The surface defects visible at the machined surface in dry milling of Ti-6Al-4V are feed marks and chips particles adhered on the machined surface. The feed marks are having equal distance. The small metal debris are observed on the machine surface at the higher speed.

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