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A study on high speed end milling of titanium alloy

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Abstract

Titanium alloys are widely used in aerospace industries, due to its high strength to weight ratio and light weight. This paper investigates high speed end milling of titanium alloy (Ti–6% Al–4% V) using carbide insert based end mill cutter. Effects of cutting forces during high speed machining of titanium alloys have got higher attention in selecting the optimal cutting conditions to improve the production and tool life. Due to Titanium alloy's low thermal conductivity, more heat concentration takes place on cutting tool during rough machining. The heat generated increases the temperature of the cutting tool and affect the surface integrity of the workpiece and also cause tool wear. In this study experiments have been carried out under dry cutting conditions. The cutting speeds selected for the experiments are 120, 150 and180 m/min. The depth of cuts and feed rate were selected to suit finish machining. For conducting the experiments single insert based cutting tool is used. Experiments were conducted based on the Taguchi's design of experiments, in order to analyse the effect of cutting parameters on cutting force, temperature and surface roughness. From this study it is found that depth of cut and feed rate have higher effect on cutting forces when compared to cutting speed whereas the effect of cutting speed has higher effect on temperature.

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Keywords: High speed milling, Titanium alloy, Forces, Temperature & Surface roughness.

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1. Introduction

Among the most effective and efficient modern manufacturing technologies, high speed machining (HSM) is employed to increase the productivity while simultaneously improving product quality and reducing manufacturing costs. Depending on work and tool materials as well as tool life requirements, the cutting speed used in HSM is often 2–50 times higher than those employed in conventional machining. Due to its high material removal rate and short process time, HSM has received growing applications in recent years in many industrial sectors, such as defense, aerospace, aircraft, automotive, and die- and mould making [1]. Certain characteristics of the work materials such as low thermal conductivity, strong chemical reactivity with the cutting tool materials at high temperatures, and relatively low elastic modulus, make Titanium alloy as one of the difficult-to-cut materials [2]. High-speed machining technology offers many advantages over conventional machining such as higher material removal rate, increased machining accuracy and better surface finish, etc [3]. Surface integrity of the work material is influenced by the milling speed in end milling of Ti-6Al-4V, while the experimental milling speed varies from 50 to 110 m/min [4]. To produce better surface roughness in milling titanium alloy Ti-6242S, milling speed of 100 to 125 m/min is appropriate [5]. Increasing the cutting speed during machining of Ti alloy is one of the objectives of the aerospace and defense industry. In this paper cutting speeds of 120-180 m/min have been selected to study the machinability aspects of Ti alloy.

2. Experimentation

2.1. Materials and Methods

The work materials used for the experimentation of the end milling process are Ti-6Al-4V (grade 5) plate of dimension 200 × 50 × 10 mm (l × b × t). The end milling process are carried out on a CNC vertical milling centre using a carbide tipped end mill (Kennametal 12A01R020A16ED10) of diameter 12 mm. Fig 1 & 2 shows the cutter body. Table 1 presents the cutter geometry used for the present study.

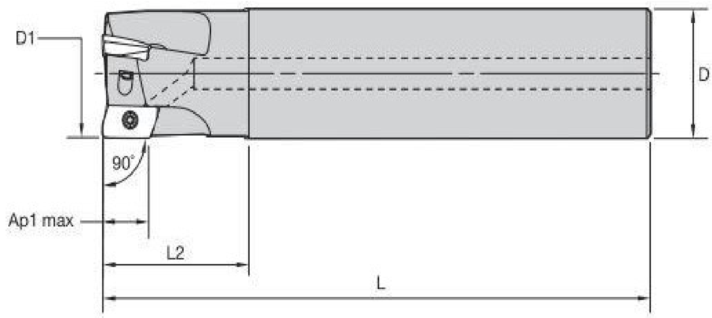

Fig.1. Cutting tool dimensions

Fig.2. Cutting tool

Table.1. Tool Dimensions

Dimensions	D1	D	L	L2	Ap1 max	Axial rake angle	Radial rake angle
Value	12	16	90	20	10.3	8	20

A total of three factors namely cutting speed (m/min), feed/tooth (mm) and depth of cut (mm) were considered for the experimental design. Experiments have been conducted using Taguchi orthogonal array with the various combinations of parameters. The various factors and their levels are listed in Table 2.

Table 2. Design of Experiments with Various Process Parameters

F(mm/tooth)	CS(m/min)	DOC(mm)
0.05	120	0.5
0.05	150	0.75
0.05	180	1
0.075	120	0.75
0.075	150	1
0.075	180	0.5
0.1	120	1
0.1	150	0.5
0.1	180	0.75

3. Computation of average cutting force

Cutting forces have been measured during the end milling operation on Ti-6Al-4V using the carbide tip end milling cutter for the selected parameters. Fig 3 & Fig 4 shows the experimental setup for measuring cutting forces. The cutting force induced during end milling operation can be resolved into three components, namely F_X (feed force), F_Y (tangential force) and F_Z (Thrust force). These three cutting force components are measured using the mill tool dynamometer (Kistler Type 9257B) and were logged with respect to time. Finally the average value of cutting force is computed. The averaged amplitudes of feed, tangential and axial forces, namely $F_{x(amp)}$, $F_{y(amp)}$, and $F_{z(amp)}$ thus obtained are listed in Table 3.

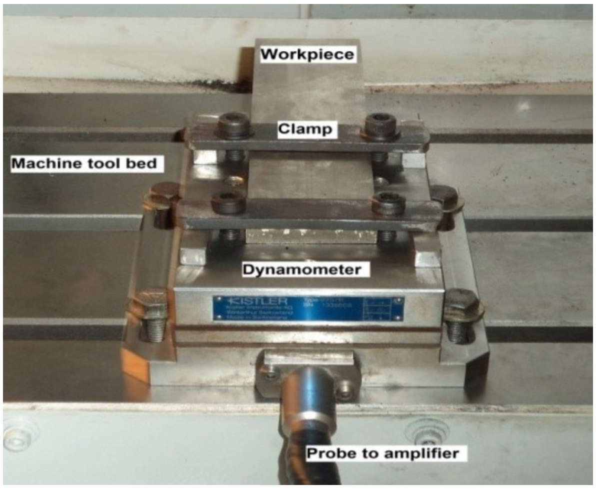

Fig.3.Workpiece and Dynamometer setup

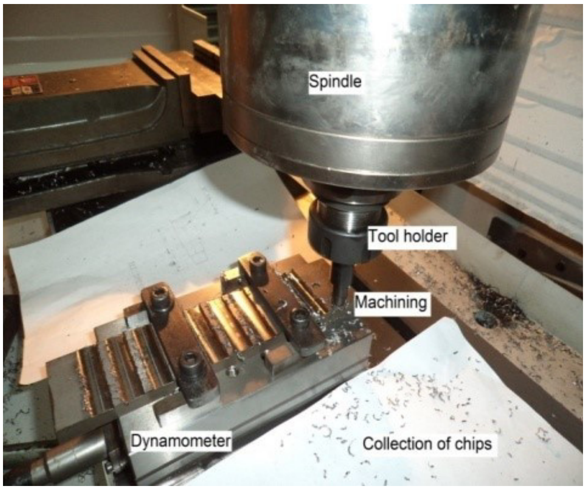

Fig.4. During machining

Table 3. Average force values from experiment

Feed/tooth (mm)	C.Speed (m/min)	DOC (mm)	Feed force(Fx) (N)	Tangential Force(Fy) (N)	Axial Force(Fz) (N)
0.05	120	0.5	144.9	170.4	91.5
0.05	150	0.75	209.4	251.9	90.1
0.05	180	1	236.2	306.3	164.3
0.075	120	0.75	293.9	327.1	129.4
0.075	150	1	342	443.12	129.78
0.075	180	0.5	220.74	267.56	138.42
0.1	120	1	417.14	452.26	144.2
0.1	150	0.5	220.01	261.82	132.76
0.1	180	0.75	328.95	377.51	164.85

4. Results and Discussions

4.1. Effect of process parameters on cutting force

From the experimental results it is found that depth of cut has higher significance followed by feed rate. Effect of cutting speed has no significance on tangential and feed force. When the depth of cut and feed rate was increased the cutting forces also increased because of the increase in volume of material removal. While the cutting speed was increased no effect was observed on the tangential and feed forces, whereas there was a marginal increase in axial cutting force. It is observed from the experimental results that there is a strong correlation between the cutting force and depth of cut and moderate correlation exists between cutting force and feed rate. Higher the feed rate and the depth of cut result in higher cutting force hence more energy is required to remove higher volume of materials at shorter time. Fig.5 shows the typical form of cutting force captured during the experiment using Kistler 3 component dynamometer. The period or the frequency depends on the rotational speed of the cutting tool and feed rate. Single peck at every single cycle was observed due to only one insert that was used in this experiment. One cutting process occurred in one rotation of the cutting tool.

Figure 6 shows the effect of cutting speed versus depth of cut for a constant feed rate of 0.075mm/rev. The surface plot has been developed based on the regression model developed using the experimental data. It is understood from the surface plot that the increase in cutting speed at lower depth of cut increase the cutting force more than two times. Whereas at higher depths of cuts (in this cast at 1 mm) the cutting force stabilizes and even reduce because of stable cutting and also higher cutting temperature. The characteristic decrease of the cutting forces has been reported by many researchers. Depth of cut has higher influence on cutting force than feed rate. But the high thermal stress appears to be problematic when comes to tool life. Various researchers reported the sensitivity of the process to the machining parameters.

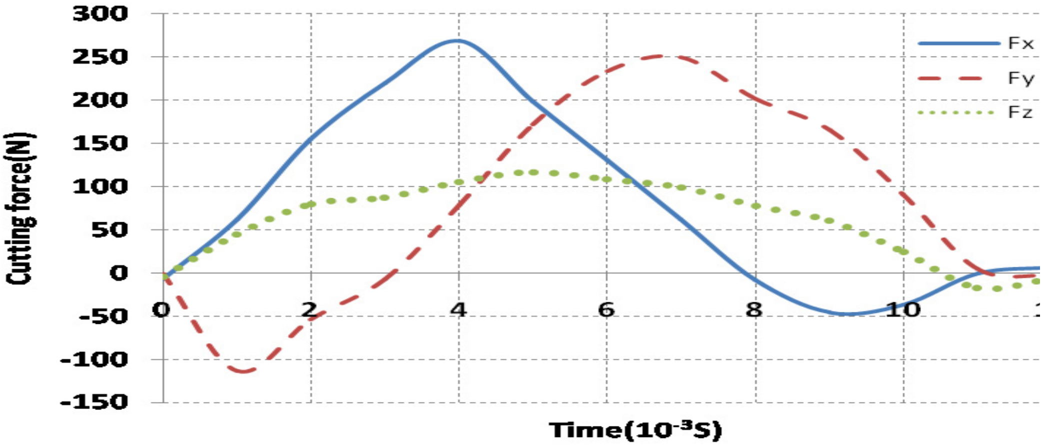

Fig .5. Cutting force Vs Time (120m/min, 0.075mm/rev feed)

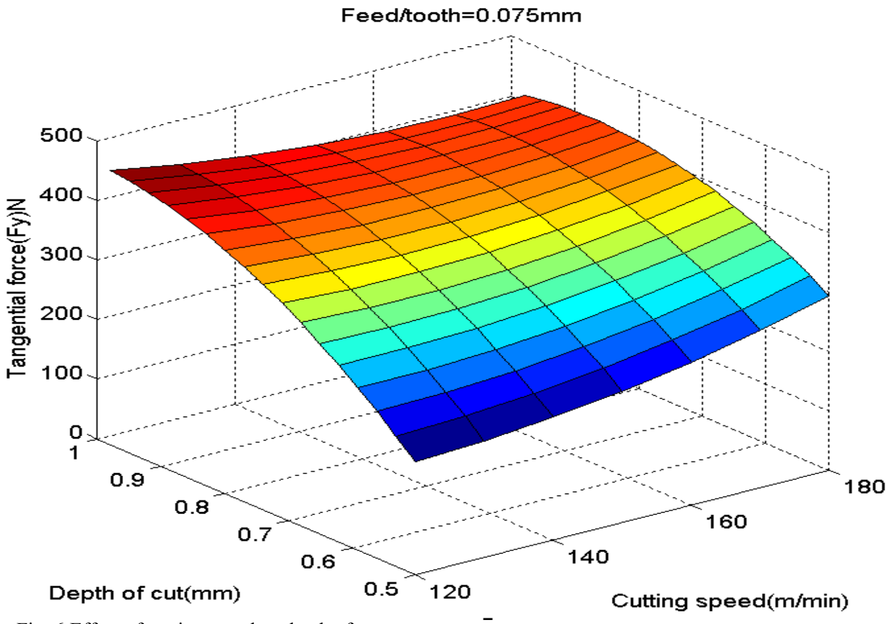

Fig .6.Effect of cutting speed vs depth of cut

4.2. Effect of process parameters on Temperature

During the machining experiments, the temperature encountered while cutting has been recorded by using thermal camera Flir (E60). In this process Flir Tools+ software is used to collect the graphs of temperature with respect to time in seconds. Here the stored thermal videos are converted to pictures at every stage of experiment. These pictures give the temperature of tool and workpiece interface accurately. Fig.7 shows the temperature encountered during end milling of Ti alloy. The red triangle shows the maximum temperature during cutting process. For the entire duration of cutting cycle, the temperature values have been stored with respect to time. Fig 8 presents the maximum temperature recorded during cutting for various cutting speeds and feeds. Cutting speed has higher effect on temperature, with has direct influence on tool life. From the surface plot (Fig 8) it is seen that lower depth of cut of 0.5 mm also encounter higher temperature when compared to 0.75 mm depth of cut. This is because of the ploughing/rubbing action at the lower depth of cut, when the depth of was increased to 0.75 mm, lower temperature at the interface than 0.5 mm depth of cut was encountered.

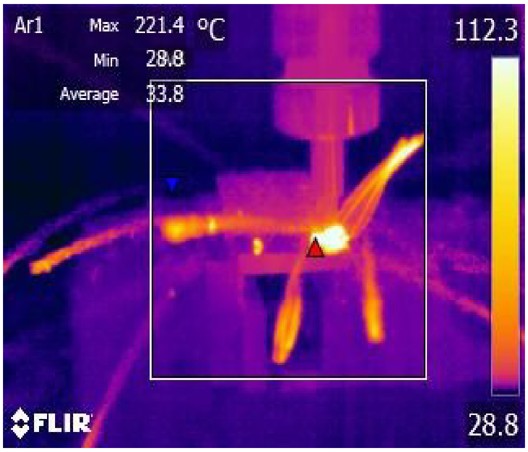

Fig.7. Temperature recorded during cutting

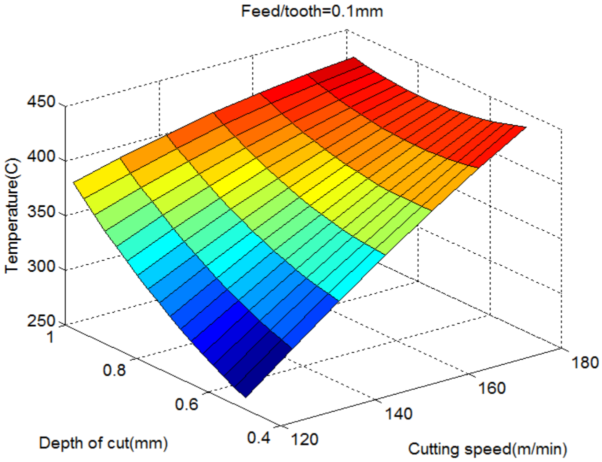

Fig.8. Effect of cutting speed vs depth of cut

4.3. *Effect of process parameters on surface finish*

Surface roughness values have been measured at the bottom surface of the slot machined. Surface roughness depends more on the machine tool rigidity, geometry of the cutting tool and machining parameters [7]. In general feed rate has higher influence on surface roughness. From the experiments it is found that feed rate has less effect on surface roughness since the insert used is having wiper geometry. Cutting speed has higher influence followed by depth of cut. Depth of cut of 0.75 mm gives better finish than lower depth of cut (0.5mm) used in this study. The depth of cut is 1 mm, leads to increase in force and can cause deflection/chatter in the cutting tool. The vibration or chatter occurred during the machining process has significant impact on the surface finish. Hence selection of cutting parameters is very crucial in order to avoid chatter. This experiment had not proved that, higher feed rate results in higher value of surface roughness. The experimental results have shown that the milled surface shows the anisotropic nature with the range of surface roughness values from 0.27 to 0.45µm. Low value of surface roughness obtained during this experiment is due the geometry of the cutting tool used. Surface roughness value reduces with cutting speed, but has much less variation in the feed rate range.

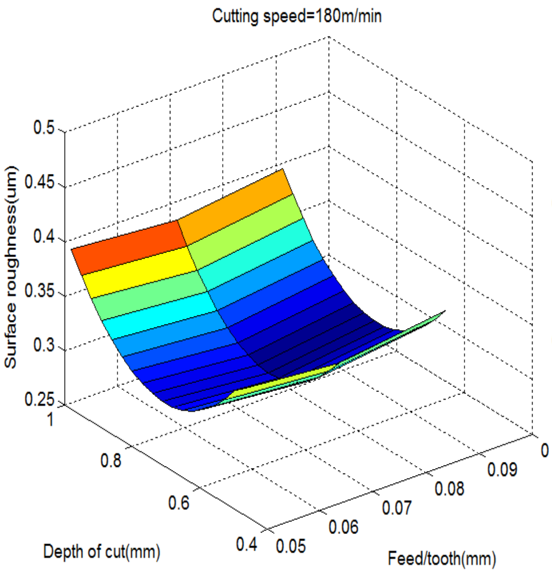

Fig.9. Effect of feed rate vs depth of cut

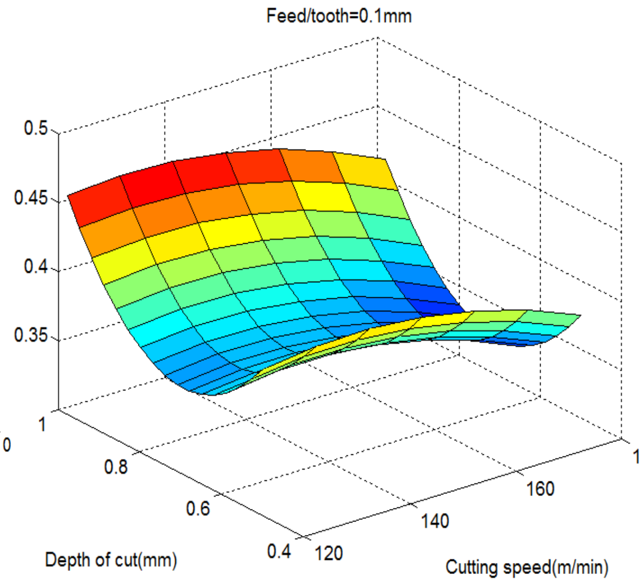

Fig.10. Effect of cutting speed vs depth of cut

5. Conclusions

In this experimental study the following conclusions may be drawn with respect to machining parameters on force, temperature and surface roughness.

- From the cutting force pattern, it is clearly understood how the force values are changing according to the angle of contact of tool with workpiece.
- Cutting speed has less effect on cutting forces; at higher depths of cuts (in this cast at 1 mm) the cutting force stabilizes and even reduces because of stable cutting and temperature. Moreover it is found than depth of cut has higher influence on cutting force than feed rate. From the study it is found that depth of cut 0.75 mm is preferable.
- Cutting speed has higher effect on temperature than depth of cut and feed rate. Within the machining range studied, cutting speed of 150m/min, 0.75 mm depth of cut and feed rate of 0.075 mm/rev is suitable for high speed machining.
- The experimental results have shown that the milled surface shows the anisotropic nature with the range of surface roughness values from 0.27 to 0.45μm and the range values are highly suitable for finish milling of Ti alloy.

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