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Study on Dimensional Inconsistency of Titanium Alloy (Grade 5) During Machining

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Abstract

Machining is the process of removing material from a work piece, in the form of chips, to obtain the final part in its desired shape and size. Various aerospace materials such as aluminum, steel, and titanium etc. can be mainly shaped through machining process. Titanium alloys also find larger adoption in areas like bio-medical and automotive mainly because of their inherent high specific strength and consistent corrosion resistance. Machining Ti-6Al-4V-grade 5 has been difficult due to a number of its characteristics like poor conductivity of heat, strong and undesirable chemical reactivity with cutting tool materials at operating/ cutting temperature, its work hardening characteristics and very low modulus of elasticity. Due to low modulus of elasticity, the dimensional inconsistency of thin-walled titanium grade 5 parts that occur after machining is an important topic/issue to be addressed since it has greater effect on the work piece surface quality, cutting tool wear and the cutting forces involved. While milling the thin-walled parts numerous cutting parameters like cutting speed, feed rate, depth of cut, cutting tool materials and cutting fluids were used and the resulting output variables like cutting force, surface finish and the change in flatness levels were observed and discussed.

Keyword: *Dimensional Inconsistency of Titatanium, Numerous Cutting Parameters, Deflecting/Flatness Values*

1.0 Introduction

Ti-6Al-4V titanium alloy is an important material in the aerospace sector due to its high strength to weight ratio. It finds major applications in jet engine and airframe components that can be subjected up to temperature of 600°C. Also, it exhibits enhanced toughness, exceptional corrosion resistance, creep resistance and very good bio compatibility. They also find greater usage in automotive and biomedical sectors. Based on the different crystal structures, titanium alloys are categorized into three categories (α, α+β and β alloys). The most commonly used titanium alloy in the aircraft building is Ti6Al4V, which belongs to the α+β alloy group[1].

Titanium alloys are found to be difficult to machine due to material characteristics like high temperature hardness, poor thermal conductivity, strong chemical affinity and comparatively low modulus of elasticity (100 to 120GPa). The combination of high hardness and low modulus of elasticity is responsible for the phenomenon of elastic recuperation or spring back observed in titanium machining. Not much literature is found on elastic recuperation and its effects during milling of titanium alloy. Because of low modulus of elasticity, the work piece deflects away from the cutting tool (Figure 1) leading to chatter and vibration[2].

Also, the surface quality of the component is affected and with increased cutting temperature and cutting speed the Young's modulus decreases further increasing the elastic recovery[3]. There is a research need to evaluate the process of titanium alloy cutting and the subsequent challenges faces like low thermal conductivity, higher tool wear rate, poor machined surface quality etc. The elastic recuperation significantly increases the cutting forces and hence the

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overall power consumed.

According to Friedrich and Kulkarni the spring back (s) and the normal contact stress (σ_f) are given by,

$$s = k_1 \, r \, \frac{H}{E} \quad \text{... (1)}$$

$$\sigma = k_2 H \sqrt{\frac{H}{E}} \quad \text{... (2)}$$

where k_1 and k_2 are constant related to a particular material, H is hardness of the work piece material and E is Young's modulus of elasticity of the work piece[4]. Spring back is assumed to be linear function of tool edge radius and ratio of work piece hardness and its elastic modulus.

The article attempts to show that spring back is influenced by cutting speed when Ti-6Al-4V plates are milled using CNC machine. The plate used in the experiment having a dimension of 200mm × 150mm × 5mm.

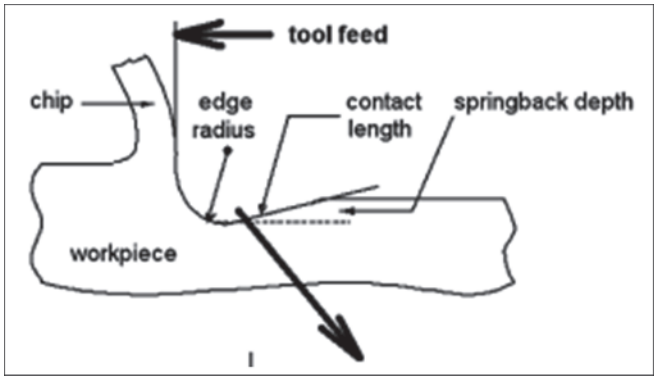

Figure 1: Spring back in machining process [4]

2.0 Methodology

In milling process, the cutting speed influences elastic recovery, followed by feed and then by depth of cut[5]. In this process, an alteration of cutting speed (v_c) means an alteration of feed per tooth (f_z), when the speed of the table or feed velocity (v_f) is kept constant, as shown in the following equation[5]:

$$V_f = f_z.z.n = \frac{f_z.z.1000.v_c}{\pi.D} \quad \text{... (3)}$$

where v_f is feed velocity, f_z is change of feed per tooth, z is number of cutting edges (tooth) of the tool, D is mill diameter and n is rpm of tool.

3.0 Experimental details

The CNC milling was carried out using TAKUML V12 machine, which had FANUC Series oi-MD system

Figure 2: Picture of Ti-6Al-4V plate used

incorporated in it with a table size of 1350mm × 690mm, spindle speed (gear transmission) of 6000 rpm. The titanium alloy plates of 200mm*150mm*05 mm were face milled. Depth of cut employed was 0.5mm; cutting speed was varied in the experimentation.

The cutting tool used was two flute end mill of 10 mm diameter, 250° helix angle. Cutting tool was tung alloy cutter, cutting fluid used was Swiss grade BLASER coolant. The deflection or change in surface flatness was measured by MITUTOYO dial gauge after the completion of milling operation.

As shown in Figure 3 points A, B, C, D, P, Q, R and S were selected for measuring the flatness/deflections after the face milling operation. Spindle speeds in steps of 500rpm were adopted while keeping the depth of cut constant. The arrow

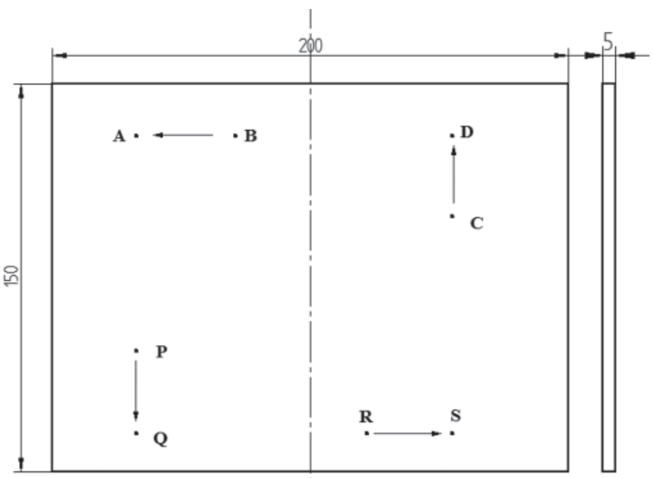

Figure 3: Rectangular plate showing various points where deflection readings were obtained

Table 1: Deflection/flatness values measured at the selected points using dial gauge

	Spindle speed (in rpm)	Feed rate (mm/sec)	Variation in flatness (in microns)				Overall deflection (in microns)
			B to A	C to D	P to Q	R to S	
1	1000	0.1	-20	30	-10	-20	50
	1000	0.2	-15	20	0	-20	40
	1000	0.3	-10	20	-25	15	40
2	1500	0.1	-15	10	0	30	45
	1500	0.2	-20	-5	5	10	30
	1500	0.3	-15	10	0	5	25
3	2000	0.1	-15	20	-10	10	35
	2000	0.2	-10	10	0	5	20
	2000	0.3	-15	-10	5	5	20
4	2500	0.1	5	-5	10	12	17
	2500	0.2	10	-10	15	0	25
	2500	0.3	0	5	-10	0	15
5	3000	0.1	5	15	-5	0	20
	3000	0.2	-10	5	0	5	15
	3000	0.3	-10	0	-5	-5	10
6	3500	0.1	-5	0	5	5	10
	3500	0.2	0	-5	0	3	08
	3500	0.3	5	0	5	0	05

marks show the direction in which the dial gauge was traversed to measure the change in flatness due to the elastic behaviour of titanium alloy while machining. It should be noted that all these variations are observed or obtained after the removal of fixtures and clamping devices.

4.0 Results and Discussion

From the Table 1 the different values of variation in flatness or deflections have been measured using dial gauge. The negative sign indicates the trough or fall in the level or height, whereas positive sign indicates the rise or increase in level or height at that particular point. As the spindle speed is increased the deflection values are found to reduce and they reach a state of stability at a speed of around 3000rpm.

At around 3000rpm spindle speed the deflection is found to be less and it is almost in same range at 3500 rpm. Also, it is observed that at higher feed rates elastic recovery is reduced.

When higher feed rates are adopted the force component causing local compression on the work surface is more pronounced and this in turn inhibits the elastic recovery at that point to significant extent, thereby lowering the deflection values. Also feed velocity is directly connected to ploughing forces which also has impact on elastic recovery.

5.0 Conclusion

In the current attempt to study the influence of cutting speed on elastic recovery, it has been found that in case of slender work piece the defection values generally increase with cutting speed, but it attains a state of stability or it can be inferred that the extent of increase becomes less relevant.

The effect of elastic behaviour is evident on chatter and vibrations, it has significant effect on geometric tolerances while machining. Although clamping and fixture support promise moderate but temporary relief from dimensional inconsistencies, achieving considerable reduction in deflection levels can reduce the cutting temperature and tool wear to a greater extent.

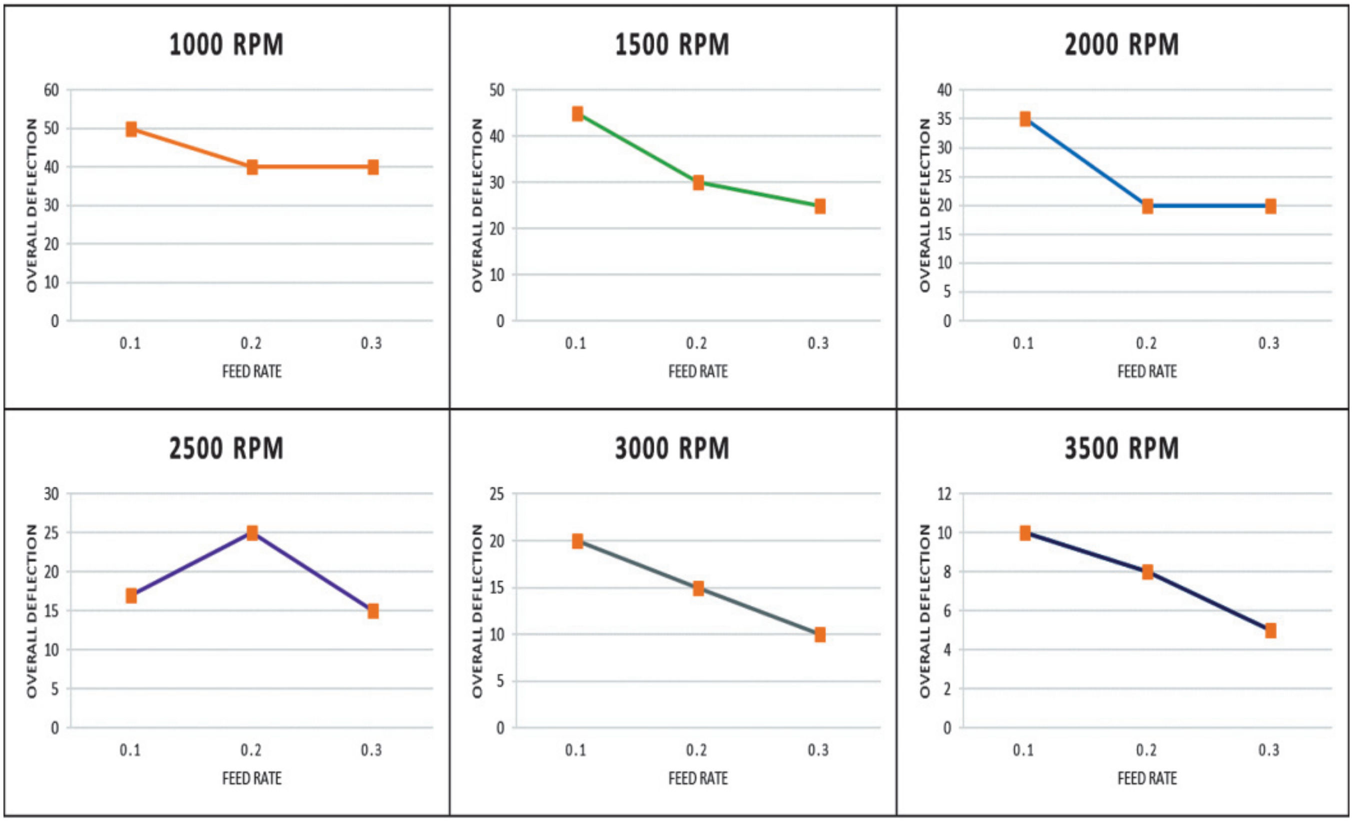

Figure 4: Plots showing behaviour of deflections with feed rate at various rpm

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