STUDY ON EFFECT OF EVAPORATIVE COOLED TURNING TOOL WITH WATER SOAKED BANANA FIBER FOR MACHINING TI–6AL-4V ALLOY

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Abstract: *The application of Ti–6Al-4V alloy in the fields of biomedical and aerospace industries attracts the manufacturing engineers to understand the behavior of alloy during machining. Ti–6Al-4V alloy posses high specific strength and corrosion resistance and besides its advantages they poses challenges in machining due its low thermal conductivity nature. The heat generated during machining is dissipated through cooling medium and cutting tool. Considering the situation detailed experiments are planned for turning of Ti–6Al-4V alloy with varies cutting speed, feed rate and depth of cut. The cutting tool is cooled with the process of evaporative cooling technique by using the water soaked banana fiber pad along with fan and flooded coolant. This method dissipates 39.51% of heat generated during cutting operation at parameter combination of 1200 rpm cutting speed, 1.5mm/rev feed rate and 0.6 mm depth of cut. The lowest average surface roughness (R_a) is recorded at parametric combination of 1200 rpm cutting speed, 0.25mm/rev feed rate and 0.6 mm depth of cut for banana fiber cooled tool. The use of banana fiber resulted in lesser R_a of 0.42µm. Further studies with multi-pad evaporative cooling facilitate for increased tool heat dissipation.*

Keywords: *Banana Fiber, Evaporative Cooling, Ti-6A1-4V Alloy, Surface Roughness, Cutting Temperature.*

1. INTRODUCTION

The machining of titanium and its alloys is generally difficult task due to several intrinsic properties of the material. But the application of titanium based alloys has expanded to various fields such as biomedical, food processing, automotive and marine. In-spite of the growing demand, it pose assorted machining issues such as tendency to weld to the cutting tool during machining thus, leading to early tool failure, low thermal conductivity and maintaining of high strength at elevated temperature. Most problems encountered during machining of titanium alloys are heat generation and friction at the tool–chip and tool–workpiece interfaces [1]. Several strategies have been used with some success in the development of machinability of titanium alloys. Sartori et al. [2] studied the effect of solid lubricant -assisted minimum quantity cooling (MQC) /lubrication in finish turning of Ti6Al4V alloy. The use of graphite particles as lubricant in the MQC technique contributes for the best machinability results. The use of minimum quantity lubrication (MQL) with lower cutting speed and lower feed rate resulted in good roughness value [3-4]. Bagherzadeh and Budak [5] proposed new cooling technique to enhance machining performance of hard-to-cut materials. Based on the experiments, the combination of minimum quantity carbon dioxide and oil is the most favorable cooling method for tool wear and surface finish. Gariani et al [6] developed a new cutting fluid spray system for supplying a precise quantity of cutting fluid into machining zones through coherent nozzles. This new spraying system shows significant reduction up to 42% in cutting fluid consumption and reduces the average surface roughness and burr height.

Pervaiz et al. [7] optimized the convective heat transfer coefficient for cutting of Ti-6Al-4V alloy. This study provides the model to predict the machining process of titanium alloy. Pervaiz et al. [8] used metal working fluid to mitigate the temperature and friction on the tool and workpiece interface. Raza et al. [9] proposed various techniques like dry/cryogenic machining, MQL and MQCL. The study reveals that the use of vegetable oil in MQL and MQCL and cryogenic machining produces best results at different speed and feed. Moura et al. [10] studied the use of solid lubricant during the turning operation of Ti-6Al-4V. The study revealed that, suitable application of solid lubricants results in reduction in tool wear and surface roughness.

Hence it is clear from the above literature that research on machining of titanium alloy aims to mitigate the tool and workpiece interface temperature. Although, assorted methods are proposed for reducing the cutting temperature, each methods has its own advantages and disadvantages. In general the heat generate in machining is not effectively conducted through workpiece and chips due to its poor conductivity. The only means the heat can be dissipated is through the tool and coolant. Hence in this research a new method of cooling of cutting tool is proposed. Banana fiber is having the property of holding the moisture content for longer duration of time, hence the banana fiber pad is used beneath the tool in the view of reducing the temperature and correspondingly improving the average surface roughness (R_a). The experiments are conducted with and without banana fiber pad and significant improvement of surface roughness is achieved.

2. EXPERIMENTAL SETUP

The CNC turning center is considered for the turning of Ti-4Al-6V alloy. The chemical composition of Ti-4Al-6V alloy is presented in the table 1. The workpiece of diameter 9.9mm is turned using PDJNL1616H11 carbide turning insert. The Table 2 presents the experimental combination for turning experiments. The experiments are planned based on the method, varying one parameter at a time keeping other parameters constant. The input parameters such as cutting speed, feed and depth of cut are considered for turning experiment and average cutting temperature and average surface quality is measured. In the perspective of reducing the tool and workpiece interface temperature, the banana fiber pad is fixed on the tool holder. The turning tool fixed on the banana fiber experience low heat contributes for good surface quality. The banana fiber used for the experiments are soaked in the water for 36 hours before fixing it in the tool holder. The banana fiber is wetted periodically with water and fan is used to aid the evaporative cooling. Fig. 1 shows the schematic of banana fiber inserted tool post. The cutting temperature is measured with infra red non-contact thermometer whose measuring range varies between -50 to 500 ºC. Surface roughness of the workpiece machined with and without banana fiber was measured using Surftest211, Mitutoyo surface roughness tester. Before measuring the specimen it is properly cleaned with ethanol and each measurement was taken three times and the average of arithmetic medium values (R_a) of the surface specimen was determined. Fig. 2 a & b. shows the turned workpiece and tool used for the turning.

3. RESULT AND DISCUSSIONS

3.1 Theory of Evaporative Cooling for Banana Fiber

The use of water soaked banana fiber reduces the temperature of a tool due to cooling effect through the process of evaporative cooling. The ambient temperature of the tool gets decreased due to conversion of sensible heat to latent heat as water gets evaporated resulting in useful cooling. Moreover the water evaporating into air from the tool depends on the wet-bulb temperature of banana fiber and air's dry-bulb

Table 1. Chemical Composition of Ti-4Al-6V alloy

Weight %	Ti	C	Fe	N	Al	O	V
Ti-6Al-4V	bal	0.08	0.03	0.05	5.5-6.75	0.20	3.5-4.5

Table 2. Experimental Combination for Turning Experiments

Expt No	Before using banana fiber			Average tool temperature 1 (ºC)	Average Surface roughness (R_a)	After using banana fiber			Average tool temperature 2 (ºC)	Average Surface roughness (R_a*)
	Cutting Speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)			Cutting Speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)		
1	800	1.25	0.6	33.3	0.60	800	1.25	0.6	32.3	0.56
2	900	1.25	0.6	36.5	0.62	900	1.25	0.6	34.5	0.58
3	1000	1.25	0.6	40.5	0.63	1000	1.25	0.6	36.5	0.60
4	1100	1.25	0.6	45.3	0.83	1100	1.25	0.6	38	0.82
5	1200	1.25	0.6	46.2	0.92	1200	1.25	0.6	39.6	0.90
6	1200	0.25	0.6	40.6	0.45	1200	0.25	0.6	35.5	0.42
7	1200	0.50	0.6	41.6	0.48	1200	0.50	0.6	37	0.45
8	1200	0.75	0.6	43.4	0.64	1200	0.75	0.6	38.3	0.55
9	1200	1.00	0.6	44.2	0.79	1200	1.00	0.6	39.5	0.77
10	1200	1.25	0.6	46.2	0.92	1200	1.25	0.6	39.6	0.90
11	1200	1.25	0.2	40.2	0.47	1200	1.25	0.2	36.2	0.43
12	1200	1.25	0.3	41.4	0.52	1200	1.25	0.3	36.3	0.48
13	1200	1.25	0.4	43.2	0.66	1200	1.25	0.4	37.3	0.62
14	1200	1.25	0.5	43.9	0.91	1200	1.25	0.5	38.2	0.87
15	1200	1.25	0.6	46.2	0.92	1200	1.25	0.6	39.6	0.89

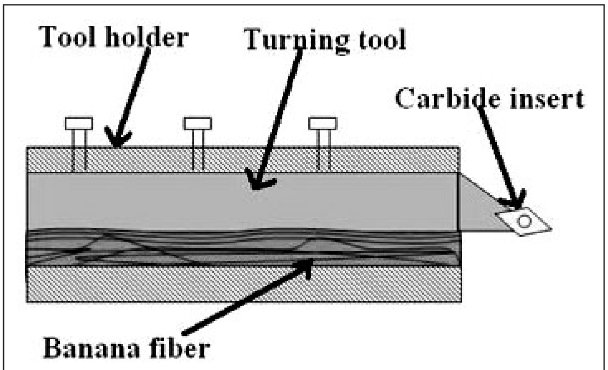

Fig 1. Schematic of Banana Fiber Inserted Tool Post

Fig 2 (a & b). Photograph of Workpiece After Turning and Tool Used for the Machining

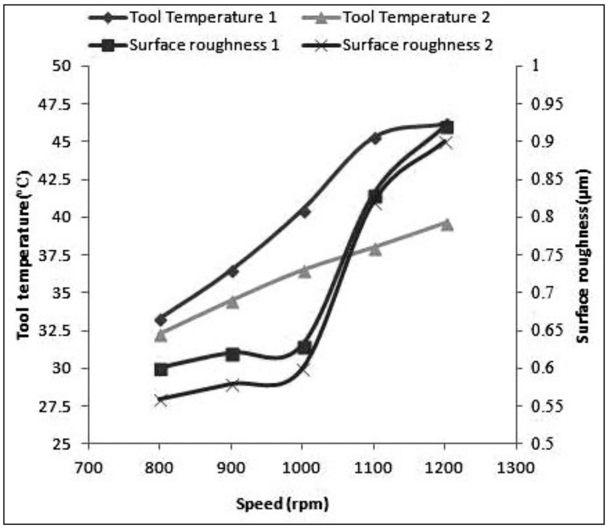

Fig 3.Effect of Cutting Speed on Cutting Temperature and Surface Roughness at 1.5 Feed rate (mm/rev), 0.6 depth of cut (mm)

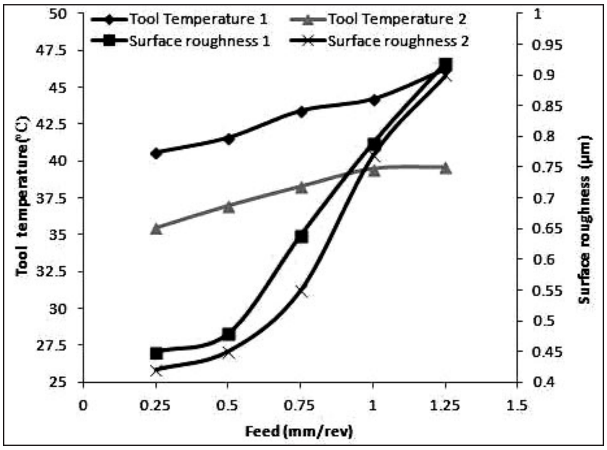

Fig 4. Effect of Feed on Cutting Temperature and Surface Roughness at 1200 rpm Cutting Speed, 0.6 mm Depth of Cut

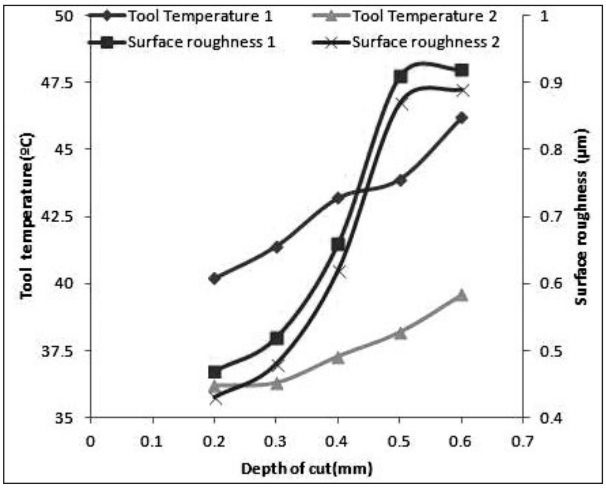

Fig 5. Effect of Depth of Cut on Cutting Temperature and Surface Roughness at 1200 rpm Cutting Speed and 1.5 mm/rev Feed

temperature. The greater the difference between the two temperatures, greater the evaporative cooling effect. The cooling efficiency depends on the following equation (1):

$$\eta_{cooling} = \frac{\Delta T}{T_d - T_w} \quad \text{.............................(1)}$$

where ΔT is the change in actual temperature, Td and Tw are the dry bulb and wet bulb temperatures respectively.

3.2 Effect of Cutting Parameters on Cutting Temperature and Surface Roughness

The Fig. 3 shows the effect of changing parameters of cutting speed on tool temperature and surface roughness with and without banana fiber. Based on the figure it is clear that the tool and workpiece temperature found to increase with cutting speed. It can be seen that the average cutting temperature increases rapidly from 800 rpm to 1100 rpm and less rapidly from 1100 rpm to 1200 rpm. It is due to the fact the cutting temperature normally get stabilized after some duration of cutting time, resulting in equilibrium state between heat generation and heat dissipation. The use of banana fiber b eneath the tool significantly reduces the average cutting temperature by evaporative cooling process. The use of banana fiber contributes for dissipation of 39.51% heat generated during cutting operation at parameter combination of 1200 rpm cutting speed, 1.5mm/rev feed and 0.6mm depth of cut. The Ra increase with cutting speed and it is noticed that at higher cutting speed between 1000 to 1200 rpm the surface roughness increases significantly. The higher value of feed and depth of cut contributes for higher Ra value. The trend of Ra* value improves with the help of banana fiber cooling. The Ra* value improves by 5.82% for higher parametric combination. Based on experimental results, the change in cutting speed and with banana fiber, the tool temperature was found to be lowest at 32.3ºC.

It is clear from the Fig.4 that the change in feed has a significant on surface roughness. The lowest R_a* is recorded at parametric combination of 1200 rpm, 0.25mm/rev feed and 0.6mm depth of cut. The use of banana fiber acts as both cooling and damping medium which prevents the excess heating and tool chatter, thus resulting lesser R_a* of 0.42µm. For different feed the change in temperature is 5.6 ºC. With increase in feed the cyclic force frequency decreases cutting temperature and surface roughness. Fig.5 shows that the change in depth of cut along with the banana fiber evaporative cooling contributes for more heat dissipation from the tool. The cutting temperature shows a remarkable improvement with the use of banana fiber.

4. CONCLUSIONS

1. The experiments are conducted successfully for turning of Ti-4Al-6V alloy with and without water soaked banana fiber.
2. The evaporative cooling technique using water soaked banana fiber yields significant results on reduction of tool temperature and surface roughness.
3. The use of banana fiber contributes for dissipation of 39.51% heat generated during cutting operation at parameter combination of 1200 rpm, 1.5mm/rev feed and 0.6 mm depth of cut.
4. The lowest R_a is recorded at parametric combination of 1200 rpm, 0.25mm/rev feed and 0.6mm depth of cut for banana fiber cooled tool. The use of banana fiber resulted in lesser R_a of 0.42µm.
5. Further studies with multi-pad evaporative cooling facilitate for increased tool heat dissipation.

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