European Journal of Scientific Research
ISSN 1450-216X Vol.27 No.3 (2009), pp.384-391

http://www.eurojournals.com/ejsr.htm

Improved Tool Life in End Milling Ti-6Al-4V Through Workpiece Preheating

Turnad L. Ginta
Department of Manufacturing and Material Engineering
IIUM, Malaysia
E-mail: turnad70@yahoo.co.id

A.K.M. Nurul Amin
Department of Manufacturing and Material Engineering
IIUM, Malaysia

Mohd Amri Lajis
Faculty of Mechanical and Manufacturing Engineering
UTHM, Malaysia

A.N. Mustafizul Karim
Department of Manufacturing and Material Engineering
IIUM, Malaysia

H.C.D. Mohd Radzi
Department of Manufacturing and Material Engineering
IIUM, Malaysia

Abstract

This paper presents the investigation of tool life improvement in end-milling of Titanium Alloy Ti-6Al-4V through workpiece preheating. End milling tests were conducted on Vertical Machining Centre with full immersion cutting. Induction heating was utilized during end milling for preheating. The titanium alloy Ti-6Al-4V bar was used as the workpiece. Machining was performed with a 20 mm diameter end-mill tool holder fitted with one PCD inserts. All of the experiments were run under room temperature and preheating condition at 315, 450, and 650ºC. Flank wear has been considered as the criterion for tool failure and the wear was measured using a Hisomet II Toolmaker's microscope. Tests were conducted until an insert was rejected when an average flank wear greater than 0.30 mm was recorded. Cutting force and torque measurements were conducted using the Kistler Rotating Cutting Force Dynamometer. Vibration during cutting was captured using an online vibration monitoring system. Scanning electron microscope (SEM) was also used to investigate the wear morphology. The results led to conclusions that workpiece preheating significantly increases the tool life of PCD inserts in end-milling of Titanium Alloy Ti-6Al-4V.

Keywords: Tool life, PCD, Ti-6Al-4V, Preheating.

1. Introduction

Titanium alloys are known as difficult-to-machine materials, especially at higher cutting speeds, due to their several inherent properties. These alloys are widely used in the turbine industry due to their superior mechanical, chemical and high temperature properties. Titanium alloys are generally used for structural applications, such as cases and impellers. For these alloys, machining productivity is limited by intensive tool wear which indirectly represents a significant portion of the machining. However, by properly selecting the tool material and cutting conditions an acceptable rate of tool wear may be achieved and thus lowering the total machining cost [H.A. Kishawya, et al, 2004] The performance of a cutting tool is normally assessed in terms of its life. Different wear criteria are usually used in assessing tool life. Mostly, flank wear is considered, since it largely affects the stability of the cutting wedge and consequently the dimensional tolerance of the machined work surface [Turnad L. Ginta,et al, 2007].

Machining of titanium alloys was the subject of interest for many years. Ginta et al [Turnad L. Ginta et al, 2007] developed the surface roughness models in end milling Ti-6Al-4V using uncoated WC-Co and PCD inserts. They found that feed has the most significant influence on surface roughness, followed by cutting speed and axial depth of cut. Jawaid et al [1999] studied the tool wear characteristic in turning titanium alloy Ti-6246. It was found that inserts with fine grain size and a honed edge have a longer tool life. At higher cutting speeds the tool failure was due to maximum flank face wear and excessive chipping on the flank edge. Ribeiro et al [2003] studied the optimization aspect of titanium alloy Ti-6Al-4V machining. These studies reveal that it is possible to work in more severe conditions than the manufacturer’s conservative conditions.

The use of workpiece preheating (hot machining) as a technique for improving machining operations has been under consideration since the late 19th century. This was informed by understanding that metals tend to deform more easily when heated, thus enhancing machinability. The principle behind hot machining is increasing difference in hardness of the cutting tool and workpiece, leading to reduction in the component forces, improved surface finish and longer tool life [E. J. Krabacher and M.E. Merchant, 1951]. Amin and Talantov [1986] studied the influence of the furnace method of preheating of workpiece on machinability of titanium alloy BT6 (Russian Standard) and found that all the vertical cutting force component decreases with the increase in the preheating temperature but the radial and the axial components sharply increase to their peak values at a particular temperature. This temperature was termed as the optimum preheating temperature for the investigated titanium alloy. It was observed that the length of chip-tool contact was very small (0.5 mm) compared to that of steels during room temperature machining, but under preheated condition the length of contact increased to 1.0 mm at the optimum temperature. The tool wear rate was also found to be the minimum at this temperature. Expected tool life for an average flank wear of 0.3 mm was calculated for the optimum preheating temperature from the slope of the corresponding curve and was found to be about 3000 sec against 160 sec at room temperature.

Ozler et al [2000] carried out hot-machining operation using austenitic manganese steel as work-piece material using gas flame heating. Leshock et al [2001] used numerical and experimental analysis of plasma enhanced machining (PEM) of Inconel 718. They evaluated that peak temperatures must be known so that thermal damage is prevented or minimized in the workpiece surface. They also found that the ability to predict the temperature distribution is the first step in optimizing thermally enhanced machining.

The main objective of this paper is to investigate the effect of workpiece preheating using induction heating method on improvement of tool life of PCD inserts during end milling Ti-6Al-4V. Tool wear morphology and cutting force were investigated during the experiments.

2. Experimental Procedure

The workpiece material used in all experiments was alpha-beta titanium alloy Ti-6Al4V. The microstructure consists of both coaxial and columnar alpha phase and inter-granular beta phase.

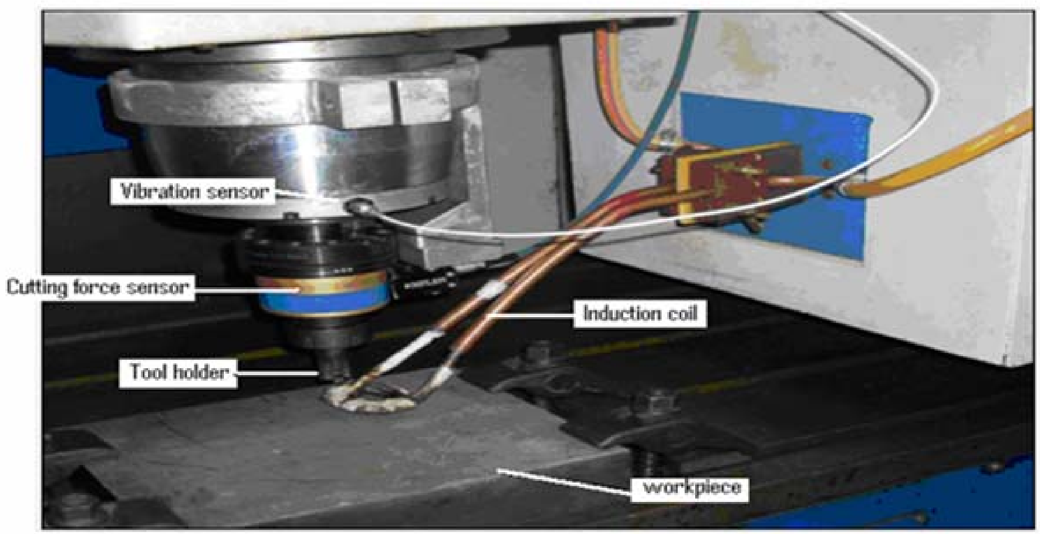
Sandvick polycrystalline diamond (PCD) inserts were used in the experiments. One insert has only one cutting edge.

End milling tests were conducted on Vertical Machining Centre (VMC ZPS, Model: MLR 542 with full immersion cutting. Titanium alloy Ti–6Al–4V bar was used as the work-piece. Machining was performed with a 20 mm diameter end-mill tool holder fitted with one insert. All of the experiments were run at room temperature and with preheating. High frequency induction heating was utilized to run the preheated machining. Selected cutting conditions for the experimentation are presented in Table 1.

Table 1: Cutting condition for experimental work

Cutting Parameters	**Values**
Cutting speed (m/min)	127
Feed (mm/tooth)	0.088
Axial depth of cut (mm)	1
Radial depth of cut (mm)	20 (full immersion)
Preheating temperature (ºC)	Room temperature, 315, 450, 650

Figure 1: Experimental set-up



The experimental set up for the machining is presented in Fig. 1. Depending on the cutting conditions and wear rate, machining was stopped at various interval of cutting length from 100 mm to 200 mm to record the wear of the inserts. Flank wear has been considered as the criteria for tool failure and the wear was measured under a Hisomet II Toolmaker's microscope. Testing under room temperature condition was stopped when an average flank wear achieved exceeded 0.3 mm. Scanning Electron Microscope (SEM) was employed to investigate tool wear and tool morphology. Due to the limitation of the resources, linear regression was used to find the tool life values for experiment with preheating (because the experiment was stopped when the flank wear reached 0.10 – 0.20 mm), in view of high tool life. Cutting force and torque measurements were conducted using the Kistler Rotating Cutting Force Dynamometer.

3. Result and Discussions

3.1. Tool Life

Fig. 2 shows progression of the typical flank wear of PCD inserts in end milling Ti-6Al-4V at room temperature and with preheating (315, 450 and 650ºC). It appears that tool life was significantly influenced by preheating. Experiment at room temperature resulted in 11.1 min in tool life, but experiment with preheating gives an improvement of tool life by 1.01, 1.5 and 2.7 times at preheating temperature of 315, 450 and 650ºC, respectively, compared to that of experiment at room temperature. Workpiece preheating at 650ºC gives the longest cutting time (30.23 min) before achieving 0.3 mm of flank wear compared to the experiment at room temperature (11.22 min), as illustrated in Fig 3a.

Most appreciable improvement of tool life takes place with an increase of preheating temperature. This is related to the lowering of cutting force with preheating temperature (Fig. 3b), and suppression of chatter during preheated machining. The results show that preheating reduces the cutting force from 338.2 N at room temperature to 265.6 N with preheating at 650ºC. This reduction related to the workpiece softening caused by the preheating. An increase of preheating temperature gives a reduction in cutting force.

Fig. 4 presents the effect of preheating in reducing the amplitude of vibration during machining. Fig. 4a and 4b represent the FFT outputs for room temperature and preheating at 650ºC, respectively. An analysis of the vibration output is shown in Table 2. It may be observed from Fig. 4 that there are four main peaks in the range of 0 – 12,500 Hz. The most significant peaks during room temperature cutting are ranging from 0 to 2,500 Hz with amplitude value of 0.006 mV, from 2,500 to 5,000 Hz with amplitude value of 0.007 mV, from 7,500 – 10,000 Hz with amplitude value of 0.008 mV, and from 10,000 – 12,000 Hz with amplitude value of 0.012 mV. Reduction in amplitude values varies from 28.6 to 66.7 % with preheating temperature at 650ºC.

It is affirmed from above analysis that preheating leads to a reduction in amplitude of vibration and cutting force during cutting. Lower vibration and cutting force will reduce the dynamic loads on the edge which leads to lower tool wear. Softer workpiece reduces the stress acting on the tool, and it has responsible for reducing tool wear and increasing the tool life.

3.2. Tool Wear Morphology

Fig. 5a and 5b shows the SEM micrograph of flank wear after end milling at room temperature and with preheating at 650 ºC. End milling at room temperature condition caused severe tool wear in flank land as shown in Fig. 5a. It can be attributed to the excessive chipping of the cutting edge which was associated with a relatively high dynamic loading on the tool due to small chip-tool contact length, and high amplitude of chatter. Tool wear was also found to be much lower in the case of preheated machining (Fig 5b), which reflects that preheating has effects on reducing the wear. Softening of the workpiece zone just in front of the cutting tool thus decreases the strength of the workpiece layer being removed. A decrease in the strength due to high temperature provides favourable condition for cutting.

Fig. 6 shows the SEM views of crater wear which were resulted from cutting at room temperature and preheated conditions. Crater wear was formed due to the diffusion wear along the rake face. Chip-tool contact length is found to be significantly increased at 650ºC of preheating, which contributed to lower dynamic loading on the tool and consequently lower tool wear rates. It may be concluded that notching, crater wear, and chipping are the prominent failure mode when machining titanium alloys due to the combination of high temperature, high cutting stresses and the strong chemical reactivity of titanium.

Built-up edge (BUE) was also observed in SEM view of crater zone (Fig. 6 and Fig. 7). BUE occurs both at room temperature and preheated machining due to high reactivity of the material at elevated temperature.

Figure 2: Average flank wear of PCD inserts at different preheating temperature

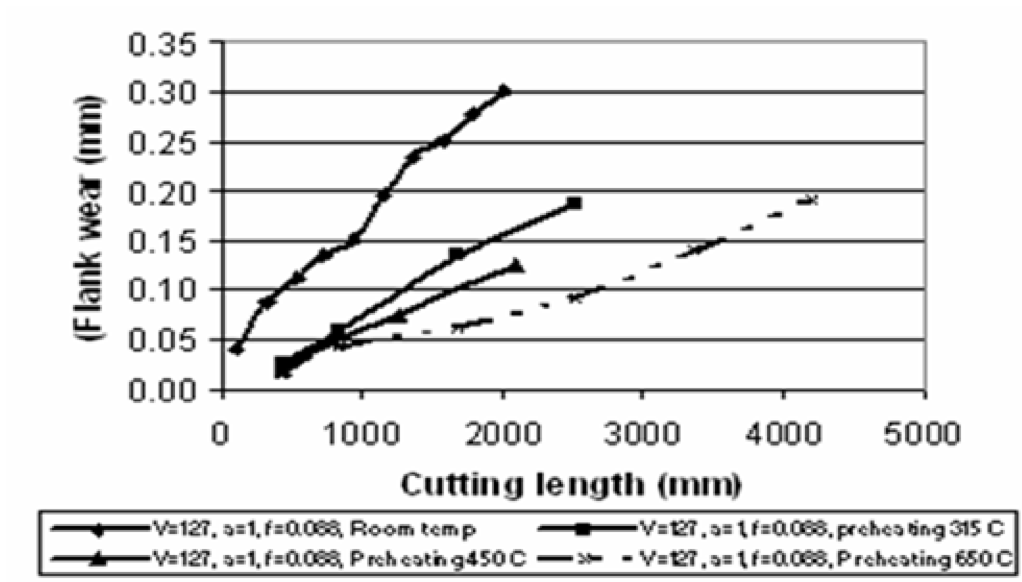


Figure 3: Effects of preheating on: a) Tool life, b) Cutting force.

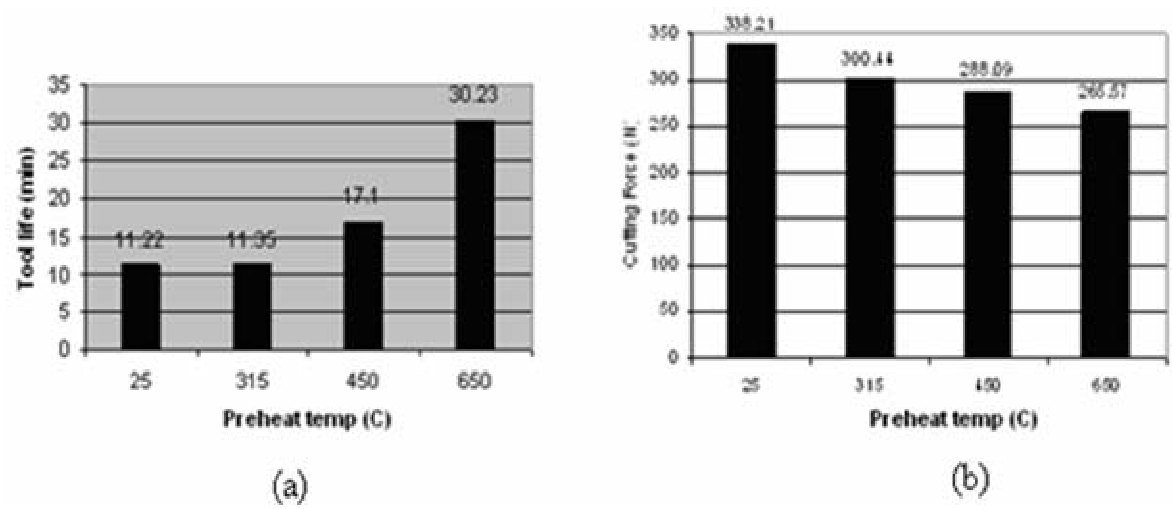


Figure 4: FFT output of end milling Ti-6Al-4V (cutting speed 127 m/min, axial depth of cut 1 mm,feed 0.088 mm/tooth) at: a) Room temperature, b) preheating at 650ºC.

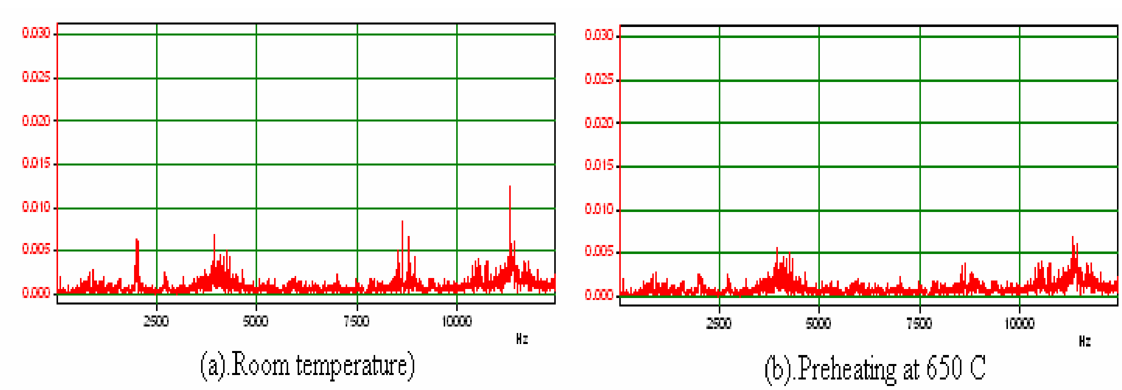
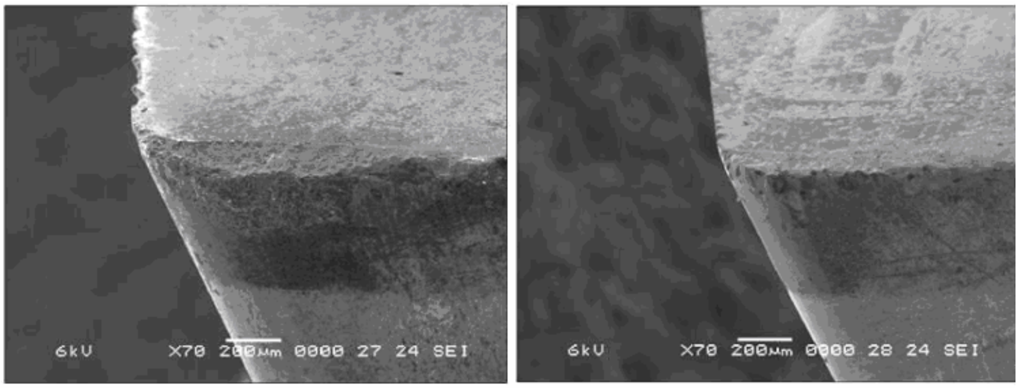


Table 2: Acceleration amplitudes of vibration and the percent reduction

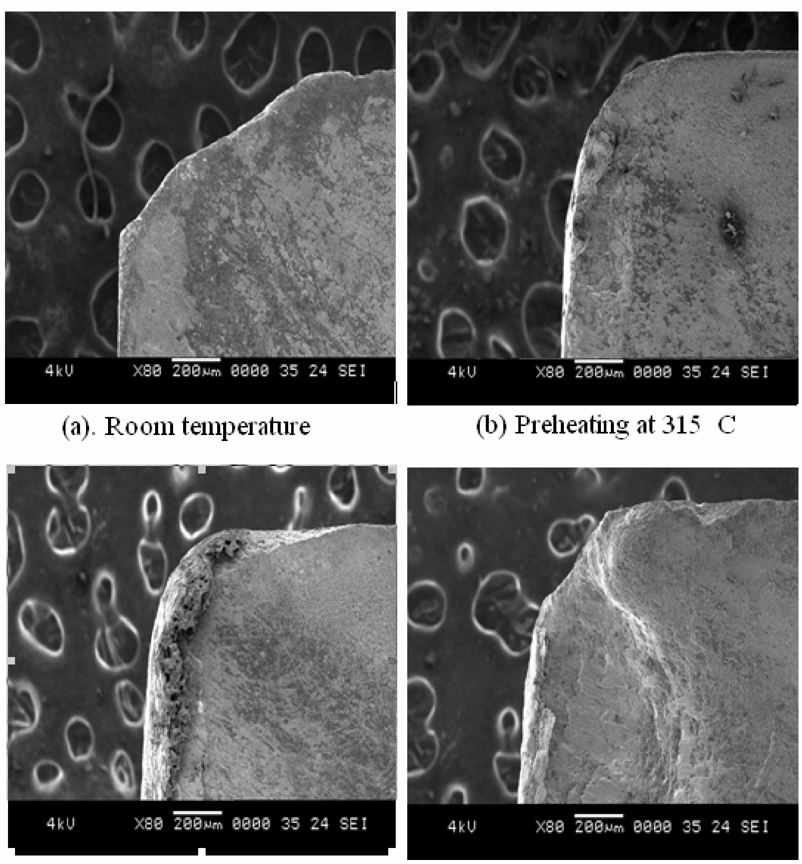
Frequency range (Hz)	Maximum acceleration amplitude (mV)		
	Room temp.	650ºC	Reduction (%)
0 – 2,500	0.006	0.002	66.7
2,500 – 5,000	0.007	0.005	28.6
7,500 – 10,000	0.008	0.003	62.5
10,000 – 12,500	0.012	0.007	41.7

Figure 5: SEM views of flank wear: (a) at room temperature after 1990 mm length of cut, (b) with preheating at 650ºC after 4200 mm length of cut



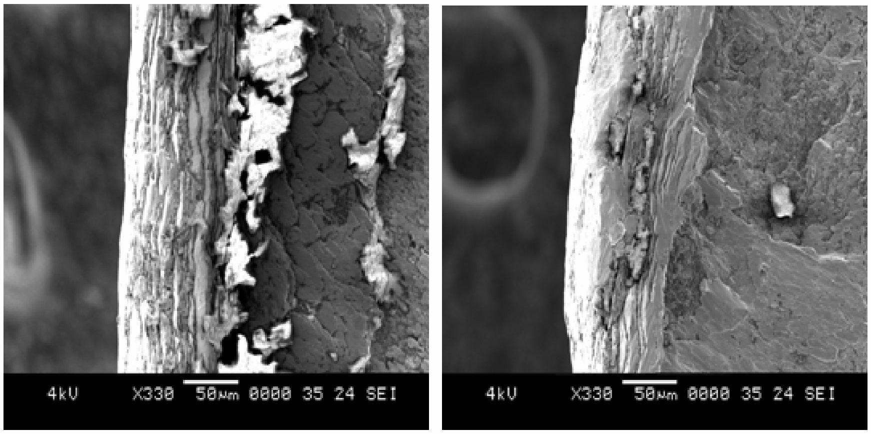
(a). Room temperature (b). Preheating at 650^0C

Figure 6: SEM views of crater wear



(c). Preheating at 450 C (d). Preheating at 650 C

Figure 7: SEM views of built-up edge.



(a). Preheating at 315 C (b). Preheating at 650 C

As the temperature increase, the size of the BUE increases up to a certain temperature. From the views in Fig. 6, it is appeared that preheating at 450ºC rises the BUE size, and then it decreases at preheating temperature of 650ºC. BUE tends to grow until it reaches a critical size and then passes off with the chip. This gives rise to a cyclic variation in size of BUE. BUE represents a major influencing factor on surface roughness when machining Ti-6Al-4V. Fig.7 views the pictures of BUE. An increase in preheating temperature, leads to an increase in chemical reactivity between chips or tool materials and cutting tools, and which leads to the formation of BUE. Fig. 7a and 7b present the evidence of BUE in preheated machining at 315 and 650ºC, respectively.

4. Conclusion

Preheating helps in substantially increasing tool life during end milling Ti-6Al-4V using polycrystalline diamond inserts. Experiment with preheating at 650ºC gives benefit in increasing tool life by 2.7 times compared to the experiment at room temperature. High frequency induction heating was proved as a suitable technique for preheated machining. Preheating helps in appreciable lowering down the cutting force values during cutting and reducing acceleration amplitude of vibration. Experiment with preheating at 650ºC can significantly reduce the magnitude of cutting force and acceleration amplitude of vibration in 21.6 % and 66.7%, respectively. Built up edge is a big problem in cutting Titanium Alloy Ti-6Al-4V. Evidence of built up edge was found in both room temperature and preheating experiments. This is related to the high chemical reactivity between workpiece material and the cutting tools.

5. Acknowledgement

The authors wish to thank Ministry of Science, Technology and Innovation (MOSTI) Malaysia for their financial support to the above project through the e-Science Fund Project (Project No.03-01-08-SF0001) and the Research Management Centre IIUM for overall management of the project.

References

[1] H.A. Kishawya, C.E. Becze, D.G. McIntosh, 2004. "Tool performance and attainable surface quality during the machining of aerospace alloys using self-propelled rotary tools", *Journal of Materials Processing Technology*, 152, 266–271.

[2] Turnad L. Ginta, A.K.M. Nurul Amin, A.N.M. Karim, Agus G. Sutjipto, 2007. "Tool life prediction by response surface methodology for end milling titanium alloy Ti–6Al– 4V using uncoated carbide inserts", *Proc. of ICME 2007, Dhaka.*

[3] Turnad L. Ginta, A.K.M. Nurul Amin, A.N. M Karim, M. H. Ishtiyaq, 2007. "Modeling for Surface Roughness in End-Milling of Titanium Alloy Ti-6Al-4V Using Uncoated WC-Co and PCD Inserts", *Proc. of The 4th International Conference on Leading edge Manufacturing in the 21st Century*, Fukuoka. pp. 23 – 28.

[4] Jawaid, C.H. Che-Haron, A. Abdullah, 1999. "Tool wear characteristics in turning of titanium alloy Ti-6246", *Journal of Materials Processing Technology*, 92-93, pp. 329-334.

[5] M.V. Ribeiro,, M.R.V. Moreira, J.R. Ferreira, 2003. "Optimization of titanium alloy (6Al–4V) machining", *Journal of Materials Processing Technology*, 143–144, pp. 458–463

[6] E. J. Krabacher and M.E. Merchant, 1951 "Basic factors in hot machining of metals", *Trans ASME*, Vol 73.

[7] Amin, A.K.M.N. and Talantov N.V, 1986. "Influence of the Instability of Chip Formation and Preheating of Work on Tool Life in Machining High temperature Resistance steel and Titanium alloy", *Mechanical Eng. Res. Bull*, Vol. 9, pp. 52-62.

[8] Ozler, L., Inan, A., Ozel, C, 2000. "Theoretical and experimental determination of tool life in hot machining of austenitic manganese steel", *Int. J. Mach. Tool Manuf. 41*, pp. 163–172.

[9] Carl E. Leshock, Jin-Nam Kim, Yung C. Shin, 2001. "Plasma enhanced machining of Inconel 718: modeling of workpiece temperature with plasma heating and experimental results", *International Journal of Machine Tools & Manufacture* 41, pp. 877–897.