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PERFORMANCE OF CARBIDE TOOL IN HIGH SPEED TURNING OF TI-6AL-4V ELI UNDER CONVENTIONAL COOLANT AND MINIMAL QUANTITY LUBRICATION

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ABSTRACT

The purpose of the study is to evaluate the tool life performance of uncoated carbide and the quality of machined surface, focusing on roughness surface values in high speed turning of titanium alloy, Ti-6Al-4V extra low interstitial (ELI), under minimal quantity lubrication (MQL) and conventional coolant. The cutting parameters were arranged using the Box-Behnken design of experiment. Meanwhile the cutting parameters; cutting speed, vc (120, 170, and 220 m/min), feed rate, f (0.1, 0.15, and 0.2 mm/rev), and depth of cut, ap (0.4, 0.5, and 0.6 mm) were applied. The effects of two types of coolant were observed and the results shown that the cutting tool turned under MQL has a longer tool life (25%) and leads to reduce surface roughness of machined surface (30%) compared with that turned under the conventional coolant condition. It was proven that the MQL condition is a good alternative in replacing the conventional coolant.

Keywords: high speed turning, Ti-6Al-4V ELI, minimum quantity lubrication, conventional coolant, uncoated carbide.

INTRODUCTION

In high speed turning of titanium alloy, heat generation at the tool tip is a serious issue which needs to consider in machining process. This high temperature can affect the quality of the machined surface, dimensional inaccuracy, and tool failure due to abrasion and thermal shock on the tool. Thus the application of coolant or lubrication in machining titanium alloy is needed [Deiab *et al.* 2014]. Nevertheless from the previous studies indicated that flooded cutting fluid application causes less penetration to the chip-tool interface, and thus fails to remove the generated heat effectively [Dhar *et al.* 2006]. Therefore, effective heat removal is necessary when machining titanium alloy due to the material's poor thermal conductivity, which causes high cutting temperature and high chemical reaction [Abdel *et al.* 2009]. Most tool failures are due to adhesion and diffusion wear mechanisms on the rake face, as well as attrition wear mechanisms on the flank face. Hence, using cutting fluid is essential to remove the heat and chips produced during machining. However, flooded cutting fluids in high-speed machining are ineffective in penetrating the chip-tool interface; these fluids cannot remove generated heat [Dhar 2006]. In addition, inappropriate handling of cutting fluid may pollute water resources and damage the soil [Sreejith 2008; Sreejith and Ngoi 2000]. Several cutting fluids used in metal cutting have detrimental effects for the health, causes air pollution, and can also cause lung and skin diseases to the machine operator. The negative effects mentioned above have led to the use of minimal quantity lubrication (MQL) as an alternative technique for reducing the amount of cutting fluid during machining. MQL is a near-dry lubrication where cutting fluids are used in small amounts [Klocke and Eisenblatter 1997; MaClure 2001; Kamata & Obikawa 2007; Liu *et al.* 2013], the flow rate range is about 10 ml/h to 100 ml/h. A small quantity of biodegradable synthetic mineral is mixed with air to form an aerosol, which is sprayed to the tool tip during the process. This type of cooling technique can also produce desirable performance in dimensional accuracy and of the machined surface, compared with the flooded cooling method. In addition, manufacturing costs will decrease considerably because the high costs for the preparation and removal of emulsion can be avoided altogether. The costly health and environmental problems associated with the use of coolant lubricants are avoided as well. Through experiments, the current study investigates the role of MQL and flooded coolant on tool life performance of uncoated carbide during the high-speed turning of titanium alloy, Ti-6Al-4V extra low interstitial (ELI), at different values for speed, feed, and depth of cut. Tool life is mostly influenced by the temperature generated and force exerted at the cutting edge of the tool. Changing the values of cutting speed, feed rate, and depth of cut will directly affect the cutting force and the temperature generated toward tool life [Gusri *et al.* 2008; Ezugwu *et al.* 2003; Ibrahim 2009; Ezugwu 2005; Sulaiman *et al.* 2012].

EXPERIMENTAL SETUP

Cutting tool

A carbide insert with International Standards Organization (ISO) designation CNGG 120408-SGF-H13A was used in the machining experiments. The cutting tools used were uncoated straight tungsten carbide tools with a rhombic shape and chip breaker. The insert consisted of 82.6 wt.% tungsten carbide, WC with 16.4 wt.% cobalt, and Co as the binder. Straight tungsten

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carbide (WC/Co) cutting tools have proven their superiority in almost all machining processes of titanium alloys [Ezugwu and Wang, 1997; Che Haron, 2001].

Machining

All machining experiments were carried out on a Tornado T4 CNC lathe, with GE Fanuc Series 21i-TB as a controller. The cutting speeds were set at 120m/min, 170m/min, and 220m/min; whereas the feed rates were 0.1mm/rev, 0.15mm/rev, and 0.2 mm/rev. The depths of cut values were 0.4mm, 0.5mm, and 0.6mm. These values involved parameters, and their levels were arranged through design of experiment (DOE) (Tables-1 and 3). The experiments were performed with MQL and flooded coolant condition using a water-based mineral-oil. The MQL was applied at rate of 50 ml/h with high velocity stream of MQL aerosol projected along the auxiliary cutting edge of the insert show in Figure-1 to ensure that the aerosol mist reaches as close to the chip-tool and work-tool interfaces as possible. Figure-1 also show the arrangement of MQL hoses that applied in the experiment.

Figure-1. MQL nozzle direction in turning process.

Workpiece

The workpiece material used in the experiments was a cylinder bar of an alpha-beta titanium alloy Ti-6Al-4V ELI, which has an equiaxed α phase and is surrounded by β in the grain boundary, as shown in Figure-2. The diameter of the cylinder bar is 100 mm, and its length is 150 mm. The nominal compositions of the alloys (in weight %) are provided in Table-1. The workpiece has a microstructure, which consists of an elongated α phase surrounded by fine, dark etching of β matrix. This material offers high strength and depth hardening ability (317 HV). At least 3 mm of material at the top surface of the workpiece was removed to eliminate any surface defects and residual stress that can adversely affect the machining result [Kalpakjian and Rchmid, 2001].

Figure-2. Microstructure of Ti-6Al-4V ELI and its dimensions.

Table 1. Chemical compositions of Ti-6Al-4V ELI (in % wt). The alloy is a higher purity grade of ATI Ti-6Al-4V alloy. This grade has lower oxygen, carbon, and iron content.

Composition	C	Si	Fe	Ti	Al	N	V	S	O	H
Weight, %	0.08	0.03	0.22	Bal.	6.1	0.006	3.8	0.003	0.12	0.0031

Table-2. Factors and levels used in the experiment. Three factors with their values were used in the experiment as cutting parameters.

Level	-1	0	1
Cutting speed, Vc	120	170	220
Feed rate, f	0.1	0.15	0.2
Depth of cut, ap	0.4	0.5	0.6

Measurement wear and tool life

In this experiment, cutting parameters were selected in the high-speed turning range especially for finishing titanium alloy. A 3mm precut entry was made for every new pass of cutting to avoid concentrated impact load that could trigger chipping when the machining starts. Subsequently, a tested insert was used according to the combination in Table-3 after creating the precut. The cutting operation was stopped at subsequent 20mm lengths, and the insert was then dismounted from the tool holder. Afterward, tool wear was measured. The

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experiment for the particular insert was completed when the average flank wear, VBB, reached 0.3mm. These steps were repeated for all combinations and for both coolant conditions. Flank wear (VB) was measured using a 3D optical microscope Perthometer; data on flank wear gained through the experiment were analyzed. In this study followed the (ISO: 3685, 1993) suggests a standard for tool life testing. The following criteria were used as the basis for rejecting an insert: (i) when the average flank wear reached 0.3mm or the maximum flank wear reached 0.6mm; (ii) when the notch at the depth of cut reached 1.00mm; (iii) when the crater wear depth reached 0.14mm; (iv) when the surface finish on the work material exceeded 6mm of the center line average, and (v) when flaking or fracture occurred. Based on these criteria, the cutting process was stopped when any of the above occurred. Cutting was abandoned, and the tools were discarded as well when catastrophic fracture of the edge was observed. However, in this experiment, the average flank wear, VBB, of 0.3mm was set as tool-life criterion for all tested inserts.

Table-3. The combinations of cutting parameters were arranged by DOE. There are seventeen numbers of experiments were arranged by Box-Behnken.

Run	Factor 1 A:Vc m/min	Factor 2 B:F mm/rev	Factor 3 C:Doc mm
1	1	0	-1
2	0	1	1
3	1	0	1
4	-1	-1	0
5	0	0	0
6	1	-1	0
7	-1	0	-1
8	0	0	0
9	0	-1	-1
10	0	-1	1
11	1	1	0
12	0	1	-1
13	-1	1	0
14	0	0	0
15	-1	0	1
16	0	0	0
17	0	0	0

RESULT AND DISCUSSIONS

The results reported in Figures-3, 4, 5, and 6 were obtained as mean values of the tool life during machining the Ti-6Al-4V ELI alloy with uncoated carbide tools under MQL and flooded coolant condition. Based on these results, MQL condition produced longer tool lives compare to flood coolant. Zheng *et al.* 2013 claimed that MQL significantly improves the tool life especially the flank wear as flank wear has great influence on surface quality. In all combinations of cutting parameters, the flank wear rate for MQL were determined as slow, thereby increasing the capability of cutting titanium alloy. This happened caused the MQL mist aerosol to penetrate into the chip-tool interface, which is the zone with the highest temperature generated during machining. Therefore, the heat was removed quickly, and the progressions of the wear mechanisms, such as plastic deformation and dissolution-diffusion, were slowed. Claimed by Dhar *et al.* 2006, reduction in the cutting zone temperature when applied mql cooling. A shorter contact area at the chip-tool interface was observed in high-speed cutting, causing a concentration of high temperature to be close to the cutting edge. Increased cutting speed or feed rate caused a greater increase in cutting temperature at the cutting edge of the tools. This increment of temperature caused the tools to lose their strength and to undergo plastic deformation, thereby weakening the cutting tool material. Moreover, high depth of cut directly influences the cutting force due to the large contact area between the cutting tool and the workpiece, directly causing the wear progression to increase rapidly. Figure-6 shows the progressions of the typical average flank wear obtained when machining Ti-6Al-4V ELI under MQL and flooded coolant conditions. The results show that the flank wear rates for these experiments decreased under MQL, compared with those conducted using the flooded coolant. This result may be due to the fact that the high temperature generated at the flank area was reduced rapidly via the MQL technique.

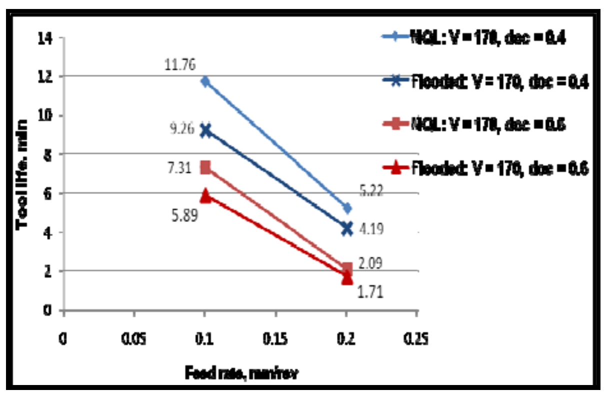

Figure-3. Tool life for several depths of cuts and cutting speeds.

The cause behind reduction in V_B *(flank area)* observed may reasonably be attributed to reduction in the flank temperature by MQL [Dhar *et al.* 2006]. In addition, MQL reduced the chip-tool interface temperature effectively because the mist fluid could easily penetrate into that area in different degrees even for various cutting parameters. Meanwhile in Figure-7 shows the tool life values for all experiments were obviously different between MQL and flooded coolant. The MQL produced tool lives longer than those under flooded coolant by about 25%. [Zheng *et al.* 2013] also found MQL method in micro-milling will significantly improve tool life and reduce material adhesion.

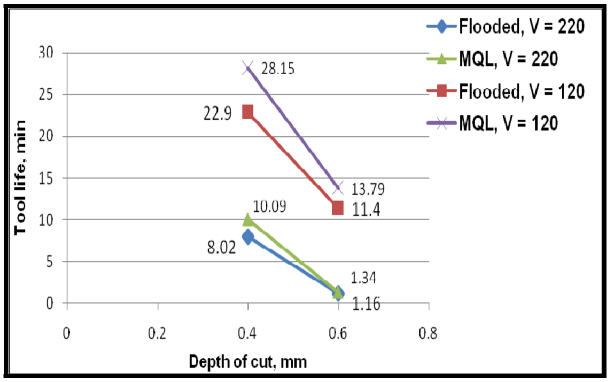

Figure-4. Tool life for several of cutting speeds and feed rate, 0.15 mm/rev.

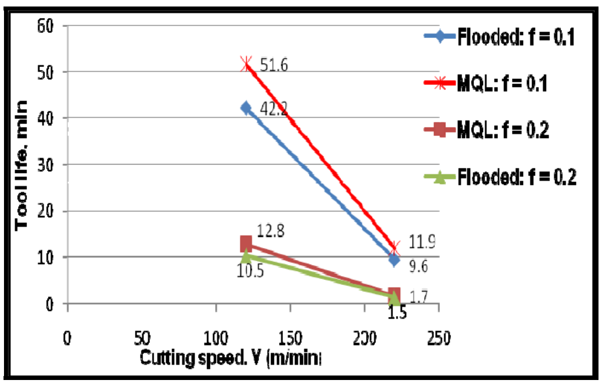

Figure-5. Tool life for several feed rates and depth of cut, 0.5 mm.

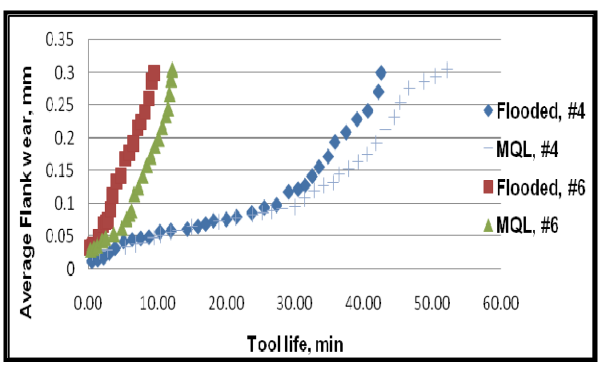

Figure-6. Average flank wears for uncoated carbide tools at experiment number 4 and 6.

CONCLUSIONS

According to the results it can be concluded that besides the cutting speed, the feed rate and depth of cut significantly contributed to the generated temperature, and consequently damaged the cutting edge. Here MQL reduced the cutting temperature, and thereby improved the chip-tool interaction and maintained the sharpness of the cutting edges. In terms of tool life, the cutting performance for MQL is longer than that of the flooded condition by about 25%. Therefore by using the MQL technique during the turning of titanium alloy Ti-6Al-4V ELI provides better performance on uncoated carbide tool compared with flooded coolant.

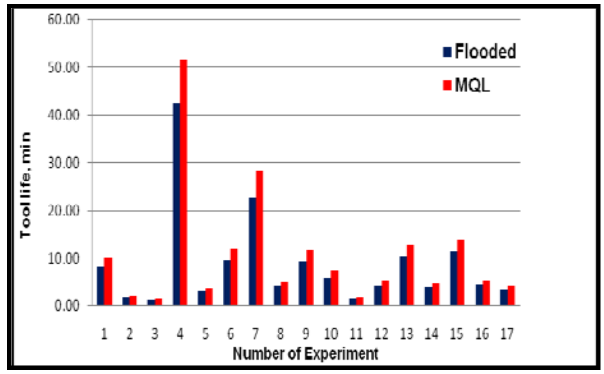

Figure-7. Tool life for MQL and flooded coolant.

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