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Microstructure Alterations of Ti-6Al-4V ELI during Turning by Using Tungsten Carbide Inserts under Dry Cutting Condition

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Abstract— **Titanium alloys possesses a hexagonal close packed (h.c.p) structure, called phase to ambient temperature. This structure changes to body center cubic (b.c.c), called phase to the temperature of 882 C. Machining process that generates high temperature during machining can affect on microstructures of machined surface, which represents as a quality of components. The turning parameters evaluated are cutting speed (55 - 95 m/min), feed rate (0.15 - 0.35 mm/rev), depth of cut (0.10 - 0.20 mm) and tool grade (uncoated, CVD and PVD). The aims of this paper are to investigate the effects of machining process on microstructures of machined surface and chip were machined using tungsten carbide inserts under dry cutting condition. The results show that machining at high cutting speed (95 m/min) affected on the microstructure significantly at the end of machining. The temperature is the most significant factor affected on microstructure of the machined surface and chip at shear zone. The changes of microstructure were also affected by the tool pressure during cutting.**

Keywords— **Ti-6Al-4V ELI; microstructure; alteration; turning; carbide insert**

I. INTRODUCTION

Titanium and titanium alloys have been used widely in the aerospace, chemical, petroleum, sport, automotive and biomedical industry because of their strength-to-weight ratio, superior corrosion resistance and strength at elevated temperature. However, titanium and titanium alloys are considerable problem in manufacturing due to their poor machinability. Titanium alloys have low thermal conductivity, relative low modulus elasticity and high chemical reactivity with many cutting tool materials [1], [2], [3], [4], [5], [6]. The titanium possesses a hexagonal close packed (h.c.p) structure, called phase to ambient temperature. This structure changes to body center cubic (b.c.c), called phase to the temperature of 882 C are shown in Figure. 1. The addition of alfagenics elements (Al. Ga and Sn) increases the temperature of transformation allotropic and the addition of betagenics elements (V, Nb and Ta) reduces the temperature of transformation allotropic [7], [8], [9]. The machining of titanium alloys has been hindered by their high temperature strength, very low thermal conductivity; relatively low modulus of elasticity and chemical reactivity [5]. In addition the susceptibility of titanium to work hardens during machining impair their machinability, hence they are referred to as difficult-to-machine materials [2].

Machined surface characteristics such as surface roughness and form as well as the sub-surface characteristics such as residual stress, granular plastic flow orientation and surface defects are important in determining functional performance of machined component [10]. Some typical metallurgical damages produced during machining Titanium alloy Ti-6Al-4V include micro-cracks, micro-pits, tearing (pick-up), plastic deformation of feed marks, re-deposited etc. [11]. The plastic deformation and change of orientation flow during machining titanium alloys are important phenomenon as revealed that titanium alloys are known to exhibit super-plastic property. The ability of metal to exhibit exceptionally high elongation when pulled in tension of often 100% while maintaining characteristics stable microstructure [12]. Ti-6Al-4V is two-phase alloy and boundary sliding can take place at the grain boundary and the phase boundary currently [13]. The deformation process in forging as explained by Kim et al. [13], in their micro-structural analysis show that in fine-grained Ti-6Al-4V, the deformation in imposed on the phase while the coarse grain microstructure it is on both the and phase.

The microstructures of the machined surface and chip produced when machining titanium alloy Ti-6%Al-4%V with tungsten carbide insert under dry cutting condition was changed orientation. A thin layer of disturbed was formed immediately underneath the machined surface [14]. However, prolonged machining with nearly worm tool also produced deformation of microstructure, severe plastic deformation and thicker disturbed layer on the machined surface. Some the top layer of the machined surface experienced work hardening process, hence the hardness was higher the average hardness of the workpiece material. Generally, the different microstructures are generated by thermo-mechanical treatment. There are considered as a complex sequence of solution heat treatment, deformation, re-crystallization, aging and annealing for stress relief [8].

II. METHODOLOGY

The workpiece material used in the machining trials was a titanium alloy alpha-beta grade Ti-6%Al-4&V Extra Low Interstitial (Ti-6Al-4V ELI) that has a phase diagram as shown in Fig. 1 The microstructure of the Titanium alloy used in this experiment is a plate-like □-phase and surrounded

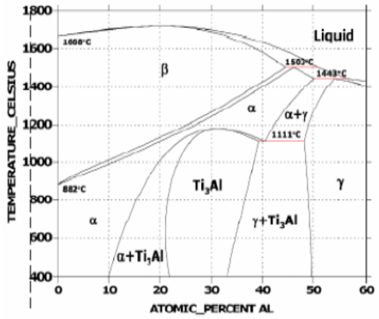

Fig. 1 The Ti-Al phase diagram (Massalski, 1986)

This experiment is carried out in dry cutting condition at high cutting speed using Colchester T4 6000 *CNC* lathe machine. The cutting parameters for turning operation are cutting speed of 55, 75, and 95 m/min; feed rate of 0.15, 0.25 and 0.35 mm/rev; depth of cut of 0.10, 0.15 and 0.20 mm. Tool holder and carbide inserts used are SCLR2020K12 and CCMT120404LF, respectively. Tungsten carbide tools used is Chemical Vapor Deposition (CVD) with coating layer of TiN-Al2O3-TiCN-TiN and thickness of 15.5 µm. The microstructures of the machined surfaces were observed under optical microscope with various magnifications after etching using Kroll Reagan solution (15 mL of HNO3, 5mL of HF and 80 mL of non-mineral water). However, before etching process, the specimens of titanium alloy were grinded by using sand paper with mesh of 240, 400, 600, 800, 1000 and 1200 micron.

III. RESULTS AND DISCUSSIONS

A. Machined Surface Alterations.

Fig. 3 shows the comparisons of microstructures to titanium alloy Ti-6Al-4V ELI during machining at cutting speed of 55 m/min, feed rate of 0.15 mm/rev and depth of cut of 0.15 mm between at the initial and end of cutting. The initial cutting is when the edge of cutting tool is still sharp

a).and the end of cutting is when the tool becomes a dull by phase in the grain boundary as shown in Fig. 2. The physical properties of workpiece material Ti-6Al-4V ELI is C=0.11, Si<0.03, Fe=0.18, Ti=balance, Al=0.61, N=0.007, V=4.0, S<0.003, O=0.11, H=0.0031 and Y<0.005 in percentage. Before machining, at least 3 mm of thickness of material at the top surface of workpiece was removed in order to eliminate any surface defects and residual stress that can adversely affect the machining result [15].

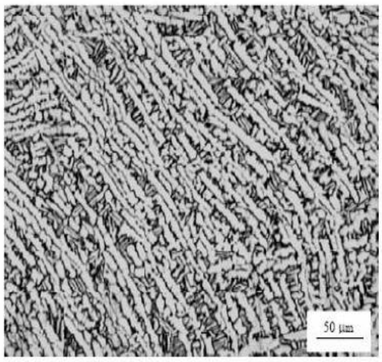

Fig.2. Microstructure of titanium alloy Ti-6Al-4V ELI

b).Generally, there is no significant difference of microstructures on the machined surface between at the initial machining and the end of machining. It is probably due to low cutting speed generates low temperature but it is not enough to change the microstructure significantly. Correspond to previous researcher‟s founding that the changes of microstructure are generated by thermo-mechanical treatments [8]. Based on the phase diagram, to change the microstructure of titanium alloys depends on the treatment temperature [16] and the properties combination of titanium alloys, including microstructure, can be change significantly through processing as well as heat treatment variations [16].

In addition Che Haron and Jawaid [3] said that machining titanium alloy Ti-6%Al-4%V with using carbide inserts in dry cutting condition at high cutting speed and worn tool produced a change of microstructure and surface alterations on the machined surface, also furthermore a thin layer of disturbed or plastically deformed layer was formed immediately. Machining titanium alloy at high cutting speed would generate a high temperature that causes a change of microstructure and surface alterations. Due to low cutting speed when machining operation was not enough the heat to generate microstructures and to change its orientation. It can be concluded that the temperature is the most significant factor affected on the microstructures of titanium alloys in dry machining condition.

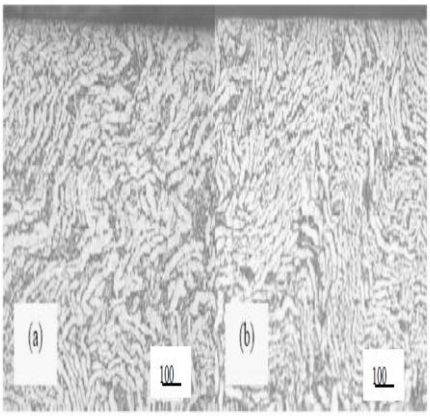

Fig. 3 Microstructure after machining at cutting speed of 55 m/min, feed rate of 0.15 mm/rev, depth of cut of 0.15 mm and CVD tool; (a) initial machining (b) end of machining.

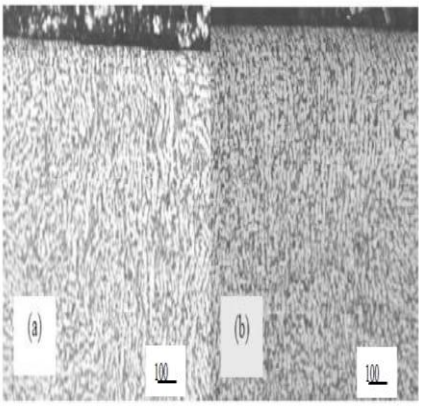

Fig. 4 Microstructure of titanium alloy generated after machining at cutting speed of 95 m/min, feed rate of 0.35 mm/rev., depth of cut of 0.10 mm and CVD tool; (a) initial machining (b) end of machining.

Whereas, Fig. 4 shows the comparisons of microstructures to titanium alloy Ti-6Al-4V ELI during machining at high cutting speed of 95 m/min and feed rate of 0.35 mm/rev between at the initial and the end of cutting. It can be seen clearly at the end of machining, there is an effect of cutting titanium alloy in drying machining on the microstructures of machined surface. At the initial machining, the effect of machining was less but at the end of machining significantly affected on the microstructure. When machining at the worm tool, it will generate a more heat as a result of friction of hard particles. Titanium alloys have a poor conductivity so it‟s also contribute to concentrate the heat as long as a sliding area. According to Che Haron [6] that machining titanium alloy Ti-6Al-4V generated higher stresses and temperature on the cutting edge that caused the chipping process to take place on the cutting edge. However, due to high temperature and stress on the cutting edge also caused a changed orientation of microstructure mainly at top layer machined surface. The changed orientation and the disturbed layer or plastic deformations are as results of thermo-mechanical treatment on the microstructures [8]. In addition, as reported by Ezugwu et al. [10] that the plastic deformation has been formed when machining Ti-6Al-4V with carbide tools at aggressive condition involving feed rates of 0.25 – 0.35 mm/rev.

Temperature generated when machining titanium alloys is more than a 900□ C using tungsten carbide tools at the interface of cutting tool and workpiece material. It is possible to affect on microstructure of titanium alloy. Consider to Ezugwu et al. [10] that the mean temperature measured at the tool-chip interface when turning titanium alloys at cutting speed of 200 m/min and feedrate of 0.1 mm/rev with carbide insert is about 1100□ C under dry cutting condition. Beside of temperature generated during machining, the change of orientation was also affected by the tool depression as a result of cutting speed direction. It can be seen clearly that the orientation of microstructure followed to the cutting speed direction when was looked at under scanning electron magnetic (Fig. 5).

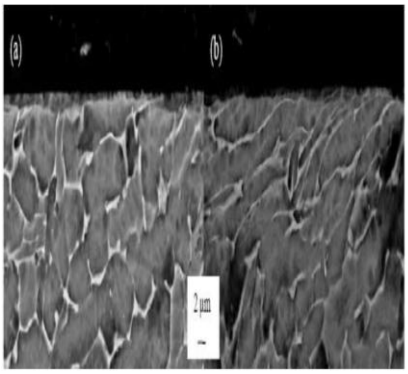

Fig. 5 Microstructure of titanium alloy generated after machining at cutting speed of 95 m/min, feed rate of 0.35 mm/rev., depth of cut of 0.10 mm and CVD tool; (a) initial machining (b) end of machining.

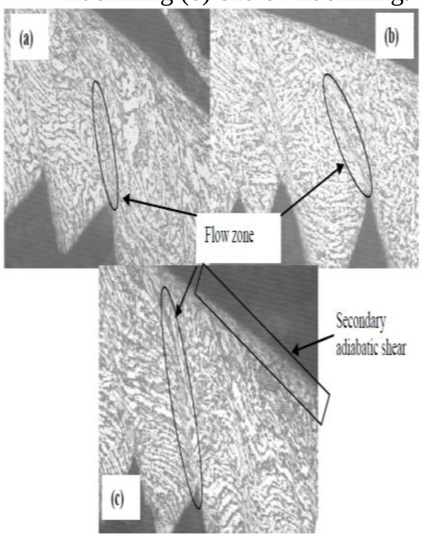

Fig. 6 Chip microstructure of titanium alloy at cutting speed of 75 m/min, feedrate of 0.25 mm/rev and depth of cut of 0.20 mm and CVD coated tool; (a) initial machining, (b) middle machining and (c) end of machining.

B. Chip Alterations.

The changes of microstructures of titanium alloy, which was machined by using coated cemented carbide inserts at high cutting speed, consist of the adiabatic shear band and shear zone of the chip segmentation as shown in Fig. 6 The changed orientation of chip probably due to high heat generated when machining titanium alloy at high cutting speed, even at the shear zone region, the changing in microstructures occurred was due to heat generated and tool pressure. An obvious phase transformed from beta to alpha in the first and second adiabatic shear zone. As characterized by previous research [16] that three characteristics of chip can be observed; (1) the beta phase becomes less and smaller compare in the bulk chip (2) the beta phase was severely deformed and the deformation degree increases with cutting speed (3) the thickness of phase transformed layer increases in cutting speed and (4) phase changes in the bulk chip were not observed. At the initial turning (6a), the number of microstructure changes were smaller compared to the middle turning (6b). This case shows that increase the cutting time produced more heat and more effect on changing microstructures. Further machining will cause a wider both primary adiabatic shear zone and secondary shear zone. Even, fracture occurred at first adiabatic shear of chip.

IV. CONCLUSIONS

Machining Ti-6Al-4V ELI at low cutting speed (55 m/min) did not differ significantly the microstructures on machined surface neither at the initial machining nor at the end of machining. Whereas machining at high cutting speed (95 m/min) significantly affected on the microstructure for both conditions. The temperature is the most significant factor affected on microstructure of the machined surface and chip of titanium alloy under dry cutting condition. The microstructure changes were also influenced by tool pressure, which was same direction with cutting speed during cutting. The increase of cutting time produced more heat that results more effect on changing microstructures of both primary adiabatic shear zone and secondary shear zone. Fracture at first adiabatic shear zone can perform as a result of high shear in this area.

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