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# Effect of Machining Process on Surface Microhardness of Titanium Carbide Reinforced Aluminium LM6 Composite

Muhammad Yusuf[1,2, a], M.K.A. Ariffin[1,3,b], N. Ismail[1,c] and S. Sulaiman[1,d]
[1]Department of Mechanical and Manufacturing Engineering,
Universiti Putra Malaysia 43400 Serdang, Selangor, Malaysia.
[2]Jurusan Teknik Mesin Universitas Malikussaleh Lhokseumawe, Aceh, Indonesia.
[3]Laboratory of Technology Biocomposite, Institute of Tropical Forestry and Forest Products (INTROP), Putra Infoport, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia..
[a]m_yusoef@yahoo.com, [b]khairol@eng.upm.edu.my, [c]napsiah@eng.upm.edu.my,
[d]suddin@eng.upm.edu.my

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**Abstract.** Due to the fact that material is being removed from the bulk material, all machining operations have some impact on the resulting surface integrity of the machined components. This paper presents an investigation on surface microhardness on machining of TiC reinforced aluminium LM6 alloy composite using uncoated carbide tool under dry cutting condition. The experiments that were carried out consisted of different cutting parameters based on combination of cutting speed, feed and depth of cut as the parameters of cutting process. The microhardness of machined surface at a range of cutting speed, feed and depth of cut were measured. The results show that the microhardness was generally found to be higher near the machined surface layer than the hardness of the matrix in the bulk material during machining for all cutting condition. Microhardness increases beyond the bulk hardness of material occurred 50 μm below machined surface, and then microhardness starts to decrease and reaches the bulk hardness. The microhardness values increases with increased the feed and depth of cut. The highest microhardness recorded was 68 $HV_{0.5}$ when machining at a lower cutting speed of 100 m $min^{-1}$, feed of 0.2 mm $rev^{-1}$ and depth of cut of 1.0 mm.

## Introduction

Metal matrix composites (MMCs) are the new class of materials and rapidly replacing conventional materials in various engineering applications, especially in the automobile and aerospace industries. Aluminium alloy is light metal commonly used in the MMCs as matrix phase reinforced with particles reinforcement such as silicon carbide, titanium carbide, graphite and alumina [1]. Aluminium MMCs have low density, excellent wear resistance, high specific strength and high specific modulus over conventional materials.

Although MMCs are often fabricated with near-net shape processing techniques, a number of secondary machining operations are always necessary. The machinability of MMCs is comparatively poor because the tool wear rate is high and quality of surface finish is on the lower side. Hard ceramic reinforcing components in MMCs make these materials difficult to machine. Muthukrishnan and Davim found that the wear on the cutting tool was caused by the abrasive nature of the hard particles present in the workpiece material [2]. The rapid tool wear and chipping at the cutting tool has resulted in poor surface finish of the machined component. It has caused not only higher surface roughness values but also higher hardness values and severe microstructure alteration in the subsurface layer. Che-Haron and Jawaid report that the wear on the cutting tool edge affects the microstructure, the greatest surface hardening was found to take place when machining was carried out with worn tools [3].

Turning, like any other machining process, is greatly influenced by cutting process parameters such as cutting speed, feed and depth of cut [4]. These cutting parameters are also believed to have significant effects on the machined surface quality. Hence an appropriate selection of cutting parameters will be optimised the surface quality and integrity of the products [5].

Surface integrity represents the nature of surface condition of a workpiece after machining processes. Surface roughness, residual stress and hardness are three important measures to describe integrity of a machined surface. It is well recognised that the surface quality depends on cutting parameters and workpiece material properties [6].MMCs are generally used for a component in engineering applications, which requires the greatest reliability and service life, and therefore the surface integrity must be maintained. A number of researchers have studied in the surface quality and integrity during machining of aluminium matrix composites with different particulate reinforcements. El-Gallab and Sklad investigated the effect of the various cutting parameters on the surface quality and the extent of the sub-surface damage during turning of aluminium with 20% SiC particles MMCs. They found that microhardness depth profiles indicate that the sub-surface damage is confined to the top 60–100 µm [7]. Quan and Ye investigated the hardness and residual stress of SiC/Al composites in the surface layer affected by machining. The experiments were carried out with varying reinforcement particles size. The results indicate that the surface hardness of machined composites may not be lower than that of the interior material, there is remarkable effect of work-hardening in the subsurface of machined composites. The average hardening is more remarkable for composites reinforced by fine particles [8]. Kannan and Kishawy, the effect of particulate volume fraction and size reinforcement on the microhardness variations of the aluminium matrix beneath the machined surface was investigated. Orthogonal cutting tests were carried out on different aluminium matrix composites reinforced with varying volume fractions and average sizes of alumina particulates. They found that particle volume fraction and average size profoundly affect the extent of plastic deformation of the matrix material. The lower the volume fraction and coarser the particles, the higher will be the microhardness variations beneath the machined surface [9].

This study investigates the integrity of machined surface by analysing the surface microhardness values after machining TiC reinforced LM6 aluminium alloy using uncoated carbide tool under dry cutting condition. The objective of this paper is to determine the effect of cutting parameters on the hardness alteration on the subsurface layer.

## Materials and Methods

**Fabrication of Composites.** MMC of LM6 aluminium alloy (BS 1490-1988 LM6) type was used as the matrix material with 10 wt.%TiC (Titanium Carbide) particles as reinforcement was prepared by liquid metal stir casting technique. The chemical compositions of LM6 aluminium as the matrix in percentage of mass have been included in Table 1. The small ingot of LM6 is melted in crucible using an electrical resistance furnace. The TiC particles were preheated at the temperature of 600$^{o}$C for 1-2 hours before mixed with the LM6 liquid to make their surface oxidized. The melt was mechanically stirred by using a hard steel impeller and then the preheated titanium carbide particles added with the stirred LM6 liquid. The processing of the composite was carried out at the temperature of 720$^{o}$C with the stirring speed of 200-250 rpm for 20 minutes (Fig. 1). The melt composite was poured at the temperature of 690$^{o}$C into the round bar sand mould with the dimension of diameter of 50 mm and length of 300 mm. The vibration technique was used during solidification process by putting sand mould on the vibration table as shown in Fig. 2. This technique has a remarkable effect on the castings properties. Sayuti et al. [10] found that use vibration technique during solidification have been improved to the mechanical properties of aluminium matrix composites. Fig. 3 shows the round bar casting product of LM6 composite.

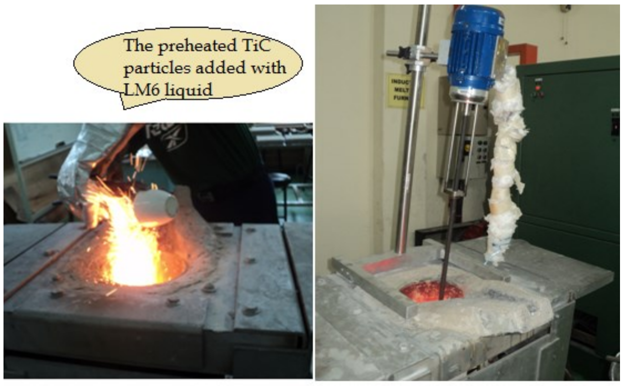
Table 1. Chemical composition of LM6 aluminium alloy

| Elements | Weight [%] |
|---|---|
| Silicon, Si | 10-13 |
| Iron, Fe | 0.6 |
| Copper, Cu | 0.1 |
| Manganese, Mn | 0.5 |
| Magnesium, Mg | 0.1 |
| Nickel, Ni | 0.1 |

| | |
|---|---|
| Zinc, Zn | 0.1 |
| Lead, Pb | 0.1 |
| Tin, Sn | 0.05 |
| Titanium, Ti | 0.2 |
| Other | 0.15 |
| Aluminium, Al | Rest |

Table 2.The cutting parameters and levels used in the experiment

| Cutting parameter | Unit | Levels | | |
|---|---|---|---|---|
| | | Low | Medium | High |
| Cutting speed (v) | m min$^{-1}$ | 100 | 175 | 250 |
| Feed (f) | mm rev$^{-1}$ | 0.05 | 0.125 | 0.2 |
| Depth of cut ($a_p$) | mm | 0.5 | 1.0 | 1.5 |




(a) (b)

Fig.1. (a) Mixing process of preheated TiC particle with LM6 liquid
(b) Mechanically of stirring process of liquid composites


Fig.2. Vibration table set up during solidification process of MMC

Fig. 3. The round bar casting product of TiC reinforced LM6 aluminium composite

**Machining experiment.** The machining trials under dry cutting condition were carried out on CNC lathe machine (Mazak SQT 200MY). The combination of cutting parameters which are cutting speed (v), feed(f) and depth of cut ($a_p$) were selected as the control parameters of the machining as shown in Table 2. The round bar casting product of aluminium LM6 with 10 wt.%TiC composite used as the workpiece material in machining trials, its microstructure as shown in Fig. 4. The size of the workpiece was prepared 50 mm in diameter and 300 in length. The cutting tool insert uncoated carbide VCGT 160402 FL K10 with tool holder SVJCR was used in the experiment. Workpiece microhardness of layer beneath the machined surface was tested used a Vickers microhardness tester of WILSON WOLPERT model 401 MVD use the load of 500g ($HV_{0.5}$).

**Results and Discussion**

The microhardness measurements were performed using a Vickers indentor with 500 gram of load on the machined surface of LM6 aluminium alloy reinforced with 10 wt.%TiC. The microhardness is generally found to be higher near the machined surface layer and decreases with the depth of machined subsurface for all cutting condition. The microhardness increases beyond the bulk hardness of the matrix material is a result of remarkable work hardening of the matrix material beneath the surface layer due to very high cutting temperature produced during cutting operation.

The microhardness alterations on the machined surface under each different of cutting condition during turning of LM6-TiC composite can be seen from Fig. 5 to 7. As can be seen from the figures, the microhardness is influenced by the cutting parameters. The microhardness increases with increased the feed and depth of cut for three different levels of cutting speed (100, 175 and 250 m $min^{-1}$). Hence, the increase in cutting temperatures, which leads to thermal deformation in the matrix material, could be one reason behind the hardening in the machined subsurface.

Generally, the higher microhardness occurs from the top layer until 50 µm below machined surface. Moving further away, the microhardness decreases and reaches the hardness of the aluminium matrix of the bulk material. The highest microhardness recorded was 68 $HV_{0.5}$ when machining at a lower cutting speed of 100 m $min^{-1}$, feed of 0.2 mm $rev^{-1}$, and depth of cut of 1.0 mm (Fig. 5). At lower cutting speeds, the temperature generated is lower and higher mechanical stresses are imposed on the surface layer due to higher cutting forces generated. This can cause the loss of strength of the matrix material due to thermal softening. Quan and Ye [8] found that the hardness values of 20 µm beneath the machined surface is about of 75% higher than the hardness of the matrix in the bulk material during machining of aluminium reinforced $Al_2O_3$ at lower cutting speed.

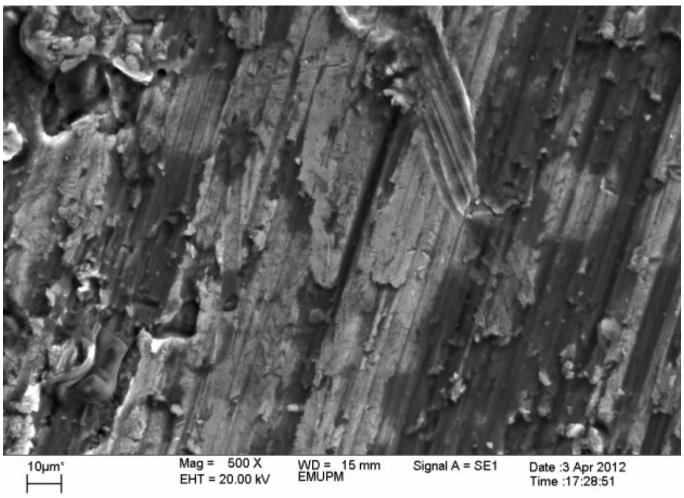



Fig. 4. The microstructure of LM6 aluminium alloy reinforced 10 wt.%TiC composite

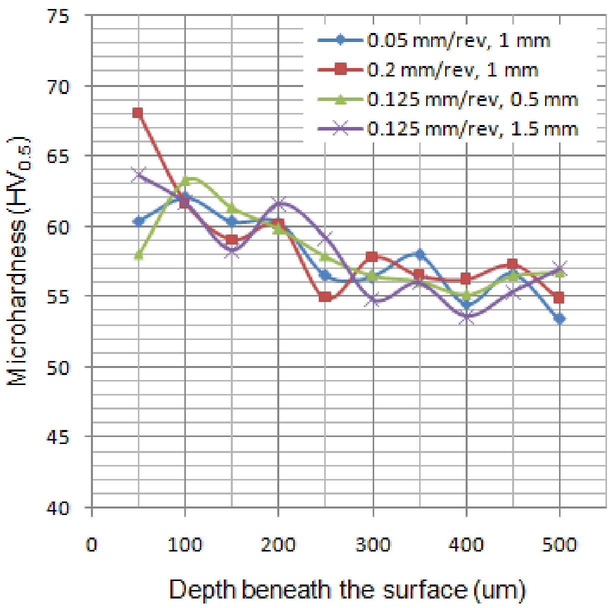



Fig. 5.The microhardness when machining of LM6-TiC composite at cutting speed of 100 m min$^{-1}$

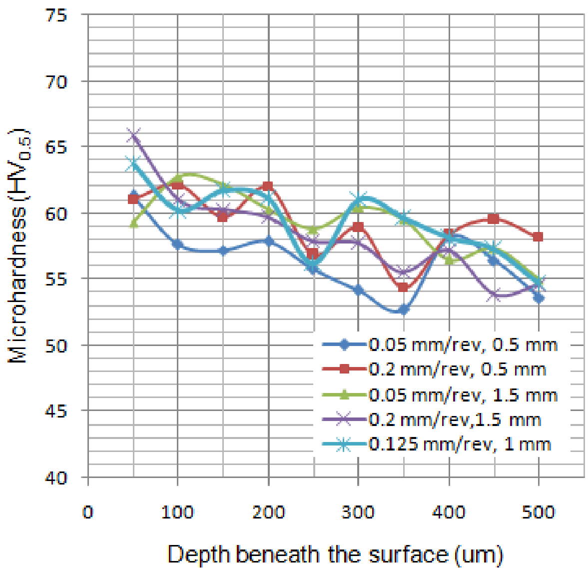



Fig. 6.The microhardness when machining of LM6-TiC composite at cutting speed of 175 m min$^{-1}$

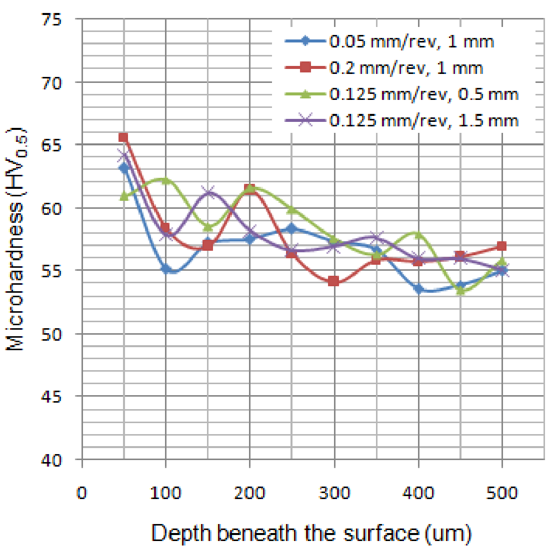



Fig. 7.The microhardness when machining of LM6-TiC composite at cutting speed of 250 m min$^{-1}$

## Summary

In this work, effects of various cutting parameter on microhardness machined surface in turning of TiC reinforced LM6 aluminium alloy matrix composite have been investigated. Based on the results of microhardness measurements the following conclusions can be drawn:

- The microhardness which is nearby the machined surface layer is generally found to be higher than the hardness of the matrix in the bulk material during machining for all cutting condition. This is as a result of remarkable work hardening of the matrix material beneath the surface layer due to very high cutting temperature produced during cutting operation.
- The microhardness is influenced by the cutting parameters. The microhardness increases with increasing the feed and depth of cut.
- Generally, the higher microhardness occurs from the top layer until 50 μm below machined surface. Moving further away, the microhardness decreases and reaches the hardness of the aluminium matrix of the bulk material. The highest microhardness recorded is 68 $HV_{0.5}$ when machining at a lower cutting speed of 100 m $min^{-1}$, feed of 0.2 mm $rev^{-1}$, and depth of cut of 1.0 mm.

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