Materials Science Forum Vols. 773-774 (2014) pp 894-901
Online available since 2013/Nov/15 at www.scientific.net

doi:10.4028/www.scientific.net/MSF.773-774.894

Surface Quality and Chip Formation in Turning of LM6 Aluminium Alloy and Particulate Reinforced Metal Matrix Composite

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Keywords: Turning process, Aluminium LM6, Metal Matrix Composite, Surface quality, Chip formation

Abstract. Majority of the components of aerospace and automotive vehicles need different machining operations, mainly for the assembly requirements. The components have to present both high dimensional precision and surface quality. This present work is concerned with the effect of cutting parameters (cutting speed, feed rate and depth of cut) on the surface roughness and the chip formation in turning process. The machining results are compared with LM6 aluminium alloy and TiC reinforced metal matrix composite under the same cutting conditions and tool geometry. The cutting condition models designed based on the Design of Experiments Response Surface Methodology. The objective of this research is to obtaining the optimum cutting parameters to get a better surface quality and also the chip formation and furthermore does not hazardous to the worker and the machined products quality. Results shows that Surface roughness values of LM6-TiC composite are higher as compared LM6 alloy at similar cutting condition. With increasing in cutting speed improves the surface quality. The surface quality increases with decrease of the feed rate and the depth of cut. There are difference chip forms for LM6 aluminium alloy and Al-TiC composite for a similar of cutting condition. Generally, chip formations of both materials are acceptable and favourable for the worker as well as the products and the tools.

Introduction

Aluminium alloys have been found extensive application in manufacturing aerospace and automotive structures which is well recognised today. This is due to some superior properties of these materials such as high strength-to-weight ratio, excellent low temperature performance, exceptional corrosion resistance, high machinability index and comparatively low cost [1, 2]. Nevertheless, aluminium alloys cannot meet all engineering in the advanced fields of science and technology. Their main weaknesses are poor high-temperature performance and low wear resistance. To overcome these problems, new engineering materials have been developed by reinforcing aluminium alloys with ceramic particles or whiskers, which are known as metal matrix composites (MMCs). Various properties of MMCs, such as strength-to-weight ratio, thermal stability, wear and corrosion resistance, are superior to those of their constituents [3]. Nevertheless, the incorporation of the hard particles makes the machining of MMCs more difficult than the conventional materials [4, 5].

A lot of components are machined to produce specific geometry and surface finish because they have features such as bearing, locking, or gasketing surfaces which require a consistent surface finish. Majority of the components of aerospace and automotive vehicles need different machining operations to present both a high dimensional precision and a high surface quality, mainly for the assembly requirements.

In machining operations, the surface finish requirement restricts the range of cutting parameters and tool geometries which can be used, especially finishing operations. Surface finish is a factor of great importance in the evaluation of machining accuracy. A lot of factors affect the surface condition of machined part. However, machining parameters such as cutting speed, feed rate and depth of cut have a significant influence on surface quality.

The machinabilty of aluminium matrix composites reinforced particulate has investigated by several researchers. However, not much of published research work seems to be available in the area of machinability of composite materials reinforced TiC.

LM6 reinforced with 5 and 10 wt.% SiC particles was machined. The effect of SiCp reinforcement on the machinability and the effects of machining parameters such as cutting speed and depth of cut at constant feed rate on surface roughness and the cutting forces has been investigated. The experiment was conducted on a conventional lathe machine using HSS cutting tool without use of coolant. The results show that higher weight percentage of SiC reinforcement produced a higher surface roughness. At constant feed rate and different cutting speed, the cutting forces are increases on increasing the depth of cut, it is indicated that the power consumption increases on increasing the depth of cut. The surface roughness increases on increasing the depth of cut and decreases on increasing the cutting speed at constant feed rate [6].

LM6Mg15SiC composite as casted with average particle size 23 μm was machined. The experiment was conducted on combination turret lathe machine using uncoated tungsten carbide (WC; HW-K10) cutting tool without use of coolant. Results indicated that cutting speed, feed rate, and depth of cut are having equal influence on the surface roughness. High speed, low feed rate, and low depth of cut was recommended for achieving better surface finish during turning of Al/SiC-MMC using tungsten carbide insert [7].

Al-TiC composite produced by the in situ technique was used for experimentation. The machining was conducted on a shaper machine using HSS cutting tool in dry cutting condition. It was concluded that there was improvement in the quality of the machined surface with increased amount of TiC particles in the composite. Cutting force was less in machining (shaping) of Al–TiC composites as compared to those for Al–$TiAl_3$, Al–Si and pure Aluminium [8].

The present work is concerned with the effect of cutting parameters (cutting speed, feed rate and depth of cut) on the surface roughness and the chip formation in turning process LM6 aluminium alloy and LM6 reinforced with 2 wt% of TiC (Titanium Carbide) particles composite. Machining results are compared with those under the same cutting conditions and tool geometry. The cutting condition models designed based on the Design of Experiments Response Surface Methodology. The objective of this research is to obtaining the optimum cutting parameters to get a better surface quality and also the chip formation does not be hazardous to the worker and the machined products quality.

Experimental Setup

Material: Experiments were carried out on 50 mm diameter and 300 mm length round bar of LM6 aluminium alloy and LM6 reinforced with 2 wt% of TiC (Titanium Carbide) particles composite was prepared by stir casting technique. Al-TiC composite was casted using sand moulds with vibration technique [9]. The chemical compositions of LM6 aluminium as the matrix in percentage of mass have been included in Table 1.

Machine and cutting insert: The machining was carried out in dry cutting conditions using Mazak SQT 200MY CNC lathe machine. The specification of the machine used for the machining test is presented in Table 2. The machine used for performing the machining operation is presented in Fig. 1. Insert uncoated carbide cutting tool was used in the experiment. The inserts were manufactured by Taegutec. Details of insert and tool holder are given in Table 3. The surface roughness was measured using portable MarSurf PS1 to measure of average surface roughness (Ra).

Fig. 1. Machine used for experiment

Table 1. Chemical composition of LM6 aluminium as the matrix

Elements	Si	Fe	Cu	Mn	Mg	Ni	Zn	Pb	Sn	Ti	Other	Al
Wet %	10-13	0.6	0.1	0.5	0.1	0.1	0.1	0.1	0.05	0.2	0.15	Rest

Table 2. CNC lathe machine specifications

Parameter	Specifications
Distance between centers	530 mm
Maximum cutting diameter	350 mm
Spindle range	35-5000 rpm
Main motor	5.5 KW

Table 3. Turning cutting tool used in experiment

Details	Specifications
Type of insert	VCGT
Clearance angle	7^o
Back rake angle	20^o
Nose radius	0.8 mm
Cutting speed	200 – 600 m min^{-1}
Feed rate	0.1 – 0.4 mm rev^{-1}
Depth of cut	Max 3.5 mm
Tool holder	SVJCR 2525 M16

Cutting parameters: The combination of cutting parameters: cutting speed (v), feed rate (f) and depth of cut (a_p) were selected as the control parameters of the machining. The cutting condition models designed based on the Design of Experiments (DOE) Response Surface Methodology represent Box-Behnken design [10]. The cutting parameters and levels each parameter were set as given in Table 4. The machining results are compared with those LM6 aluminium alloy and Al-TiC composite under the same cutting conditions and tool geometry.

Table 4. The cutting parameters and level used in the experiment

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

Results and Discussion

Surface roughness: Surface roughness plays an important role in engineering applications and is used to evaluate the machining accuracy. The ideal surface roughness is defined as the best finishing surface which can be obtained with the best machining feed rate and required tool geometry. This is possible if there are not any built up edge and self-existed vibrations together with precise set up of machine movement elements.

The popular model to estimate the ideal surface roughness in turning with a tool having nonzero nose radius, is

$$Ra = \frac{f^2}{32 \,.\, r} \tag{1}$$

where Ra is the average surface roughness (μm), f is the feed rate (mm rev^{-1}), r is the cutting tool nose radius (mm) [11]. This model shows that the surface roughness is primarily dependent on the feed rate and the tool nose radius.

Although many factors affect the surface roughness of machined part such as feed rate, tool geometry, and productivity of machine tool. However, optimize of machining parameters such as cutting speed, feed rate, and depth of cut are extremely important task to determine of surface quality of machined parts [12].

The experiment results of surface roughness values in turning of LM6 alloy and LM6-TiC composite at various of cutting models based on DOE Response Surface Methodology represent Box-Behnken design as given in Table 5. The result is compared to the ideal surface roughness (theoretical) according to model equation (1) is shown in Fig. 2. From Fig. 2, it is observed that there is a large deviation between theoretical and actual surface roughness. The theoretical roughness values are lower than experimental values for both materials. The difference between theory and actual surface roughness may be caused by the factors such as workpiece material, built-up edge formation, chip formation, tool wear, tool vibration, workpiece vibration.

The effect of cutting parameters such as cutting speed, feed rate, and depth of cut on surface roughness in turning of LM6 alloy and LM6-TiC composite are shown Fig. 3 to 5. From the figures shows that surface roughness values of LM6-TiC composite are higher as compared LM6 alloy at similar cutting condition. This indicates that the surface roughness also depending on the structures and constituents of the workpiece materials.

According to Fig. 3, increasing in cutting speed improves the surface quality. Fig. 4 shows that the surface roughness values decreases with the feed rate. Actually it is commonly expected, due to agreeable with a popular model equation (1). The surface roughness values also decreases with the depth of cut as shown in Fig. 5.

Fig. 6 shows the machined surface in turning of LM6-TiC composite at different cutting parameters. It shows that the feed marks are not noticeable on surface texture at lower feed rate (0.05 mm rev^{-1}). On the other hand, feed marks are very clear on higher feed rate (0.2 mm rev^{-1}).

Table 5. Values of surface roughness of the workpiece machined

Cutting model	Cutting parameters			Average surface roughness, *Ra* (µm)	
	v (m min^{-1})	f (mm rev^{-1})	a_p (mm)	LM6 alloy	LM6-2 wt.% TiC
1	100	0.05	1	6.309	7.512
2	250	0.05	1	3.955	4.122
3	100	0.2	1	6.618	7.890
4	250	0.2	1	3.797	3.155
5	100	0.125	0.5	6.391	4.321
6	250	0.125	0.5	3.431	3.991
7	100	0.125	1.5	6.440	5.985
8	250	0.125	1.5	3.835	3.664
9	175	0.05	0.5	3.990	4.503
10	175	0.2	0.5	4.351	5.067
11	175	0.05	1.5	3.610	5.190
12	175	0.2	1.5	4.675	5.835
13	175	0.125	1	4.310	4.759
14	175	0.125	1	4.266	4.778
15	175	0.125	1	4.272	4.725

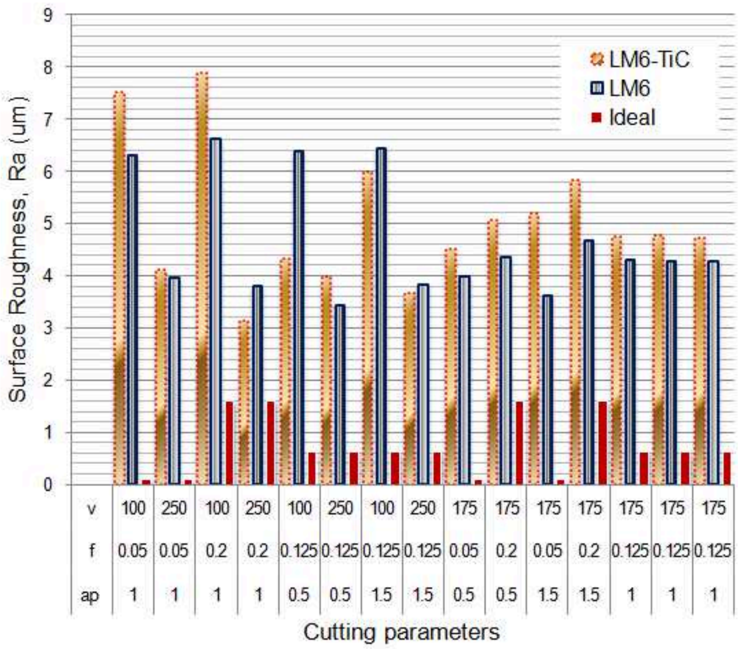

Fig. 2. Ideal surface roughness estimation in turning of LM6 alloy and LM6-2 wt% TiC composite

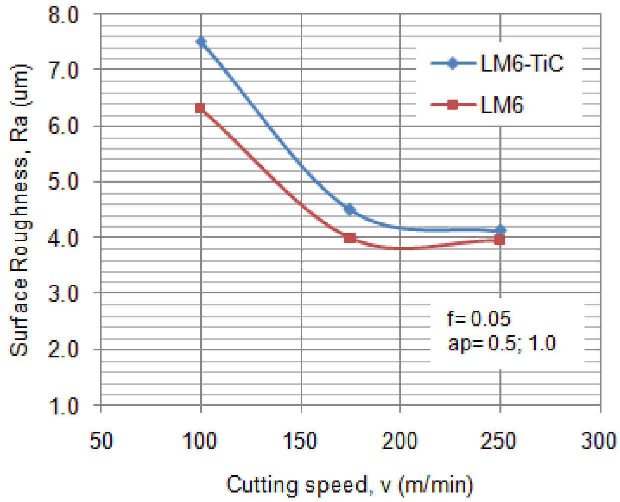

Fig. 3. Effect of the cutting speed parameters on surface

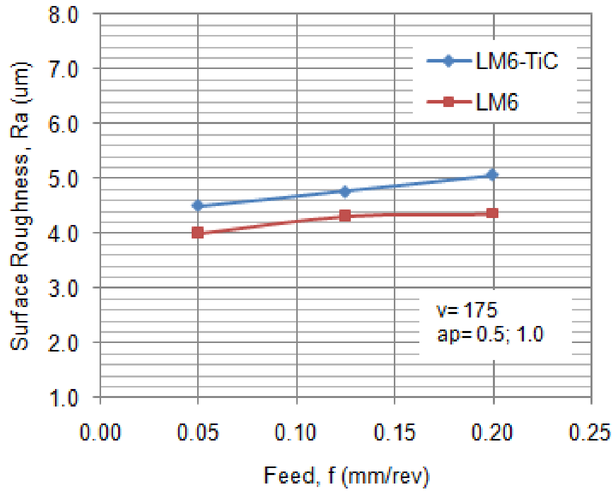

Fig. 4. Effect of the feed rate parameters on surface quality

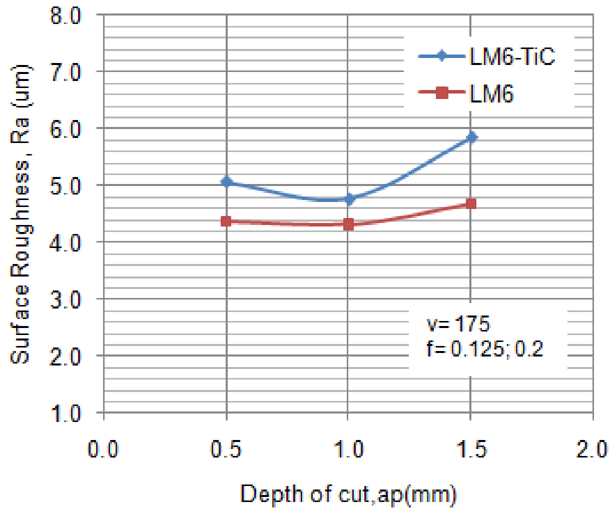

Fig. 5. Effect of the depth of cut parameters on surface quality

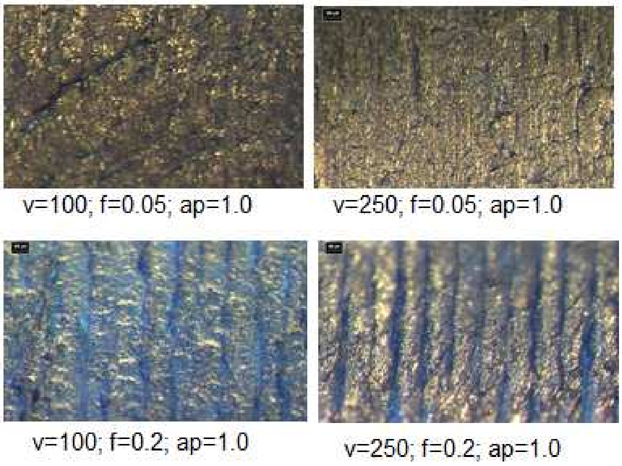

Fig. 6. Machined surface of LM6 reinforced 2 wt.% TiC composite at different cutting parameters

Chip formation: The types of chips formed during a machining process are related to the workpiece material properties, tool geometry and cutting condition. Generally, there are two groups of chip forms, (1) acceptable chips and (2) unacceptable chips, for convenience of handling. Acceptable chips do not interfere with the work or machine tool and cause no problems of disposal. Unacceptable chips interrupt regular manufacturing operation, as they tend to entangle the tool and workpiece and safety problems to operators. Entangling chips can harm the surface finish and even lead to unexpected tool failure [13].

The typical chips were formed during turning of LM6 aluminium alloy and Al-TiC composite in dry cutting at different cutting conditions are shown in Fig. 7 and 8, respectively. Fig. 9 is the types of chip form produced in turning operations according to the standard ISO 3685 [14]. From the Fig. 7 and 8, it is shows that the chip forms produced in turning of LM6 aluminium alloy and Al-TiC composite at similar of cutting condition was found the different of shape, this is due to the chip forms has depending on the constituent and the properties of the workpiece materials.

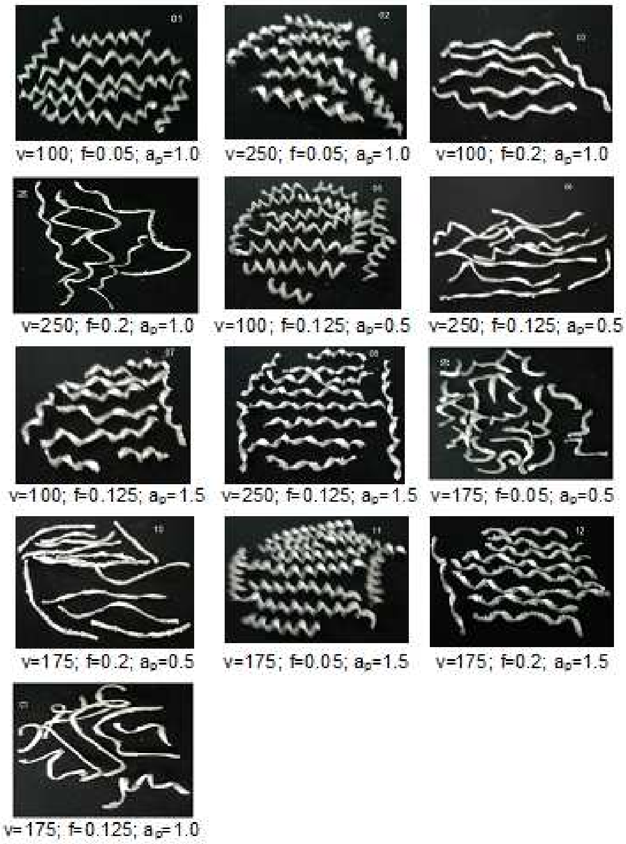

Fig. 7. Chip form of LM6 aluminium alloy at different cutting parameters

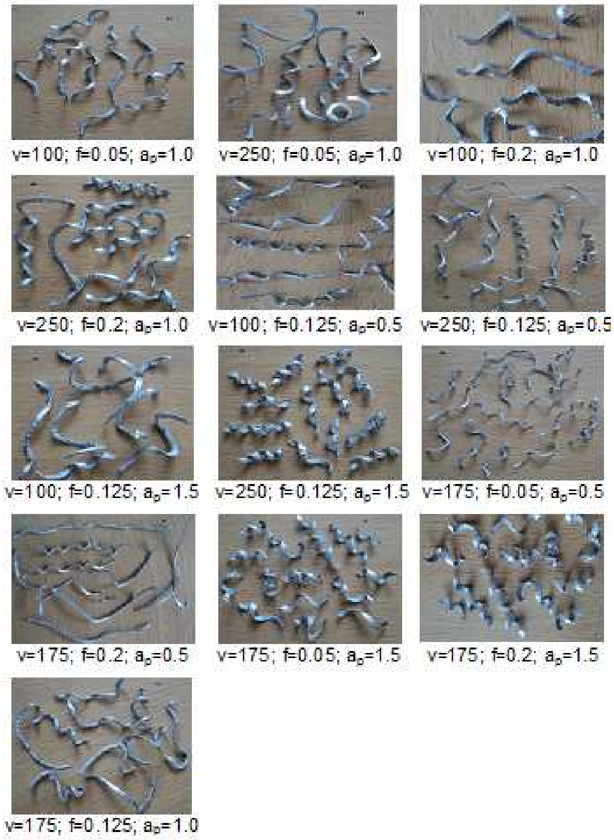

Fig. 8. Chip form of LM6 reinforced 2 wt.% TiC composite at different cutting parameters

The selection of cutting parameter in turning operation can be effecting on the chip form. According to the standard ISO 3685 (Fig. 9), the type of chip formed during turning of LM6 aluminium alloy and Al-TiC composite based on selection of cutting parameters (Fig. 7 and 8) was found noncontinuous chip forms (e.g. similar Long 1.1, Short 1.2, Short 4.2). These chips form are acceptable and favourable for the worker as well as the products and the tools.

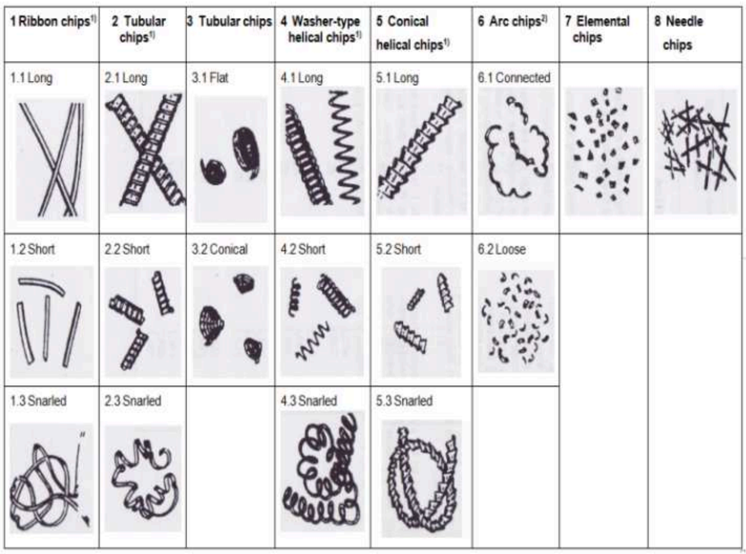

Fig. 9. Chip form produced in turning operations [14].

Summary

In the present investigation, comparative study on surface quality and chip formation in turning of LM6 alloy and LM6 reinforced with 2 wt% of TiC particles has been conducted. The following conclusions are drawn based on the above experimental work:

§ Surface roughness values of LM6-TiC composite are higher as compared LM6 alloy at similar cutting condition. This indicates that the machined surface quality also depending on the structures and constituents of the workpiece materials.
§ With increasing in cutting speed improves the surface quality.
§ The surface quality increases with decrease the feed rate and the depth of cut.
§ The chip form produced in turning of LM6 aluminium alloy and Al-TiC composite at similar of cutting condition was found the different of shape, this is due to the chip forms has depending on the constituent and the properties of the workpiece materials.
§ The type of chip formed during turning of LM6 aluminium alloy and Al-TiC composite based on selection of cutting parameters was found noncontinuous chip forms.
§ Generally, chip formation of both these materials is acceptable and favourable for the worker as well as the products and the tools.

Acknowledgments: The authors thank Mr. Tajul Ariffin, Mr. Ahmad Shaifudin, Mr. Mohd Saiful Azuar and Mr. Muhammad Wildan Ilyas from the Laboratorium of Mechanical and Manufacturing Engineering, Universiti Putra Malaysia for their assistances during the conducting of the experiment.

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Advances in Materials and Processing Technologies XV
10.4028/www.scientific.net/MSF.773-774

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