Materials Science Forum Vols. 773-774 (2014) pp 339-347
© (2014) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/MSF.773-774.339

Experimental Investigation on Surface Roughness and Tool Wear in Dry Machining of TiC 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 D.E. 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 UPM Serdang

[a]m_yusoef@yahoo.com, [b]khairol@eng.upm.edu.my, [c]napsiah@eng.upm.edu.my, [d]suddin@eng.upm.edu.my

Keywords: Dry turning, Surface roughness, Tool wear, Aluminium composites

Abstract. With increasing quantities of applications of Metal Matrix Composites (MMCs), the machinablity of these materials has become important for investigation. This paper presents an investigation of surface roughness and tool wear in dry machining of aluminium LM6-TiC composite using uncoated carbide tool. The experiments carried out consisted of different cutting models based on combination of cutting speed, feed rate and depth of cut as the parameters of cutting process. The cutting models designed based on the Design of Experiment Response Surface Methodology. The objective of this research is finding the optimum cutting parameters based on workpiece surface roughness and cutting tool wear. The results indicated that the optimum workpiece surface roughness was found at high cutting speed of 250 m min^{-1} with various feed rate within range of 0.05 to 0.2 mm rev^{-1}, and depth of cut within range of 0.5 to 1.5 mm. Turning operation at high cutting speed of 250 m min^{-1} produced faster tool wear as compared to low cutting speed of 175 m min^{-1} and 100 m min^{-1}. The wear minimum (VB = 42 μm) was found at cutting speed of 100 m min^{-1}, feet rate of 0.2 mm rev^{-1}, and depth of cut of 1.0 mm until the length of cut reached 4050 mm. Based on the results of the workpiece surface roughness and the tool flank wear, recommended that turning of LM6 aluminium with 2 wt % TiC composite using uncoated carbide tool should be carried out at cutting speed higher than 175 m min^{-1} but at feed rate of less than 0.05 mm rev^{-1} and depth of cut less than 1.0 mm.

Introduction

Composite materials are engineered from two or more distinct materials. There are three main types of engineered composites are prevalent in industry, including polymer matrix, ceramic matrix and metal matrix composite. Metal matrix composites (MMCs) are made of continuous metallic matrix and one or more discontinuous reinforcing phases. The reinforcing phase may be in the form of fibers, whiskers or particles. Now a day's 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 SiC, TiC, SiO_2 and Al_2O_3 [1, 2]. Aluminium MMCs have low density, excellent wear resistance, high specific strength and high specific modulus over conventional materials.

Particulate metal matrix composites are most commonly manufactured by a stir-casting technique or metallurgy technique. Stir-casting is the simplest and commercial technique because of producing better matrix-particle bonding, easier control of matrix structure, simplicity, higher production rate and low cost. The machining process of these materials is more difficult than the conventional materials, due to the addition of reinforcing materials which are harder and stiffer than the matrix [3, 4, 5, 6].

In machining process, friction between tool and workpiece generates heat which affect the dimensional accuracy, surface finish, chip flow and hence will determined the quality of finish product. Cutting fluids are used in machining process to remove the heat, reducing friction, reduce cutting force and power requirements, improve dimensional accuracy, and improve surface finish [7]. Meanwhile, the used of cutting fluids can be dangerous to health workers and the environment. Besides, the great social preoccupation about the environmental conservation has made necessary to develop cleaner production technologies. The dry machining is a simplest method consists on eliminating the cutting fluids. However, the total suppression of these cutting fluids involved to work under very aggressive conditions.

Although efforts have been made to produce near-net shape MMCs products by casting process, the machining process always necessary to resulting the good surface finish and dimension accuracy of the products. Machinability is understood as a property of a material that allows for machined under given conditions. It is must always be considered in conjunction with the machining method, the cutting tool, and the machining parameters. Three main machining characteristics become evident in machining process such as better surface finish produced, tool life is increased, and lower power consumption required for machine.

Machinability of a particular material have evaluated by assessing any one of the following parameters: tool life or wear, surface finish, cutting force, power consumption, and cutting temperature. Therefore, in the investigation of machiability, the cutting speed, the feed rate, and depth of cut are important parameters. Machinability of MMCs has received considerable attention because of the high tool wear during machining process [8].

Several researchers have conducted experiments on machining MMCs reinforced with vary of ceramic particles. 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 [9]. 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 [10]. Machinability of Aluminium 2024 reinforced Al_2O_3 particle composite was investigated by turning with TiN coated and HX uncoated carbide tool without coolant. The test results showed that tool life decreased with increasing cutting speed for both cutting tools and the tool life of TiN tool was significantly longer than that of HX tool. The surface roughness was mostly affected by cutting speed [11].

In this work, optimise the values of cutting speed, feed rate, and depth of cut to find minimum values of surface roughness (*Ra*) and investigate the wear of the cutting tool (*VB*) during the turning of LM6 aluminium with 2 wt.% TiC composite using uncoated carbide tool in dry cutting condition. Test results are analyzed for achieving better machining performance during machining of Al-TiC composite.

Experimental setup

Preparation of Metal Matrix Composite: MMCs of type LM6 aluminium alloy (BS 1490-1988 LM6) was used as the matrix material with 2 wt.% TiC (Titanium Carbide) particles as reinforcement were 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 minute (Fig. 1). The melt composite was poured at the temperature of 690°C in to 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. Vibrational moulding during solidification process has a remarkable effect on the castings properties of metals, alloys, and composites [12]. Fig. 3 shows the round bar casting product of LM6 composite.

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. Turning cutting tool used in experiment

Details	Specifications
Type of insert	VCGT
Clearance angle	7°
Back rake angle	20°
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

Fig. 1. Stirring process of liquid LM6 with the preheated TiC

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

Fig. 3. The round bar casting product of MMC

Machining Experiment: The machining was done on CNC lathe machine (Mazak SQT 200MY) and insert uncoated carbide cutting tool was used in the experiment. Details of insert and tool holder are given in Table 2. Fig. 4 shows MarSurf PS1 test equipment which is used for the surface roughness (Ra) measuring. The flank wear on the cutting tool was investigated using Leica microscope. 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. This method is an effective approach to optimize the cutting parameters and able to reduce the experiment expenses [13, 14]. The cutting parameters and levels each parameter were set as shown in Table 3. With use of Minitab software based on DOE response surface methodology, found fifteen the cutting condition models represent Box-Behnken design to run the experiment as given in Table 4.

Table 3. 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

Fig. 4. Schematic view of measuring surface roughness

Table 4. The cutting condition models represent Box-Behnken design to run the experiment

Cutting condition model	Cutting parameters		
	v (m min^{-1})	f (mm rev^{-1})	a_p (mm)
1	100	0.05	1.0
2	250	0.05	1.0
3	100	0.2	1.0
4	250	0.2	1.0
5	100	0.125	0.5
6	250	0.125	0.5
7	100	0.125	1.5
8	250	0.125	1.5
9	175	0.05	0.5
10	175	0.2	0.5
11	175	0.05	1.5
12	175	0.2	1.5
13	175	0.125	1.0
14	175	0.125	1.0
15	175	0.125	1.0

Results and Discussion

Surface Roughness: Surface roughness is a factor of great importance in the evaluation of machining accuracy. Many factors affect the surface roughness of a machined part such as properties and constituents of workpiece material, tool geometry, and machine condition. However, cutting parameters such as cutting speed, feed rate and depth of cut have a significant influence on surface roughness. The recorded surface roughness values during machining of aluminium LM6-TiC composite using uncoated carbide tool under dry turning process at cutting speed of 100, 175 and 250 m min^{-1} with different of feed rate and depth of cut are shown in Fig. 5 to 7, respectively. It is clearly observed that in figures, feed rate has biggest effect on surface roughness, high feed rate of 0.2 mm rev^{-1} resulted in high values of surface roughness measured especially at low and medium cutting speed of 100 and 175 m min^{-1}. Actually this case is commonly expected, due to agreeable with a popular model to estimate the surface roughness with a tool having nonzero nose radius, is

$$Ra = \frac{f^2}{32 \, . \, r} \qquad (1)$$

where Ra is the average surface roughness (μm), f is the feed rate (mm rev^{-1}), r is the cutting tool nose radius (mm).[15] This model shows that the surface roughness is primarily dependent on the feed rate and the tool nose radius. According to the ideal surface roughness values will occur when satisfactory cutting conditions are achieved. In this study, low values of surface roughness were found at high cutting speed of 250 m min^{-1} with various feed rate (0.05-0.2 mm rev^{-1}) and depth of cut (0.5-1.5 mm). This was due to the velocity of chips flow that is faster at high cutting speed than low cutting speed. This causes a shorter time for the contact of chips with the newly formed surface of the workpiece [15].

In Fig. 5 to 7 it can be seen that, the curve line of surface roughness values of each different cutting condition is almost similar until the length of cut reached 4050 mm. This is probably during machining of LM6-TiC MMCs without significant change of the flank wear at the tool nose radius during machining until length of cut reached 4050 mm.

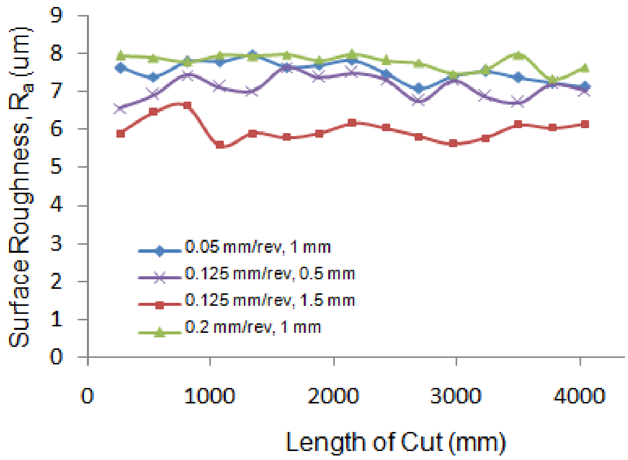

Fig. 5. Surface roughness values at cutting speed of 100 m min^{-1}

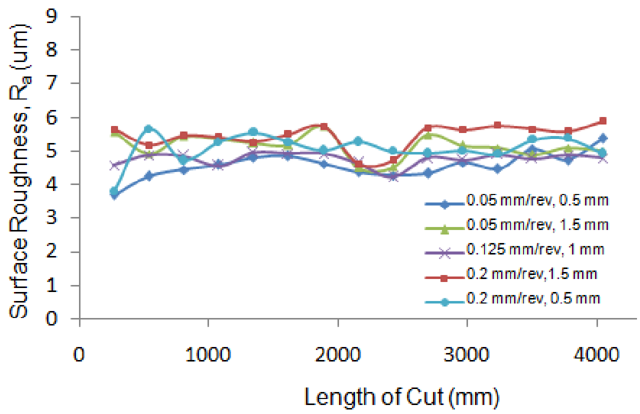

Fig. 6. Surface roughness values at cutting speed of 175 m min^{-1}

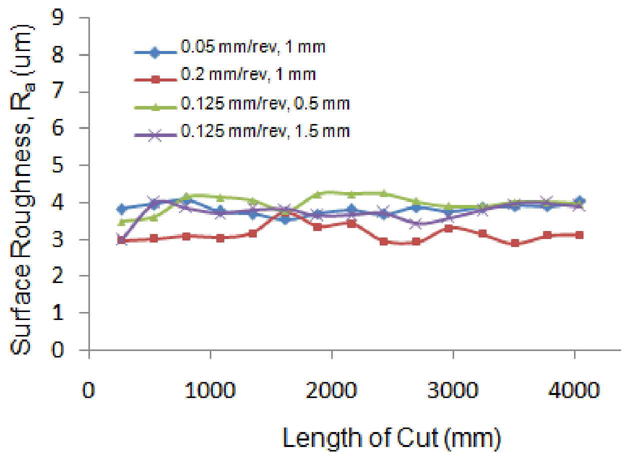

Fig. 7. Surface roughness values at cutting speed of 250 m min^{-1}

Tool Wear: Rapidly tool wear is one of the major concerns during machining of MMCs. Interaction of hard ceramic reinforcement particles with tool appears to be the major factor to tool wear. The wear of uncoated carbide cutting tools during turning of LM6-TiC composite was measured under optical microscope. The tool wear was recorded at every one pass machining until length of cut reached 4050 mm. ISO 3685 was followed for measurement of the tool wear [16]. The progress of tool flank wear versus cutting time at cutting speed of 100, 175 and 250 m min^{-1} with different of feed rate and depth of cut are shown in the Fig. 8 to 10, respectively. Tool wear rate was higher occurred at the initial stage, gradually increased at the second stage and extremely increased at the final stage. At the initial stage, higher tool wear rate was caused by small contact area between the cutting tool and the workpiece, which caused increased in temperature at the cutting edge, thus some material easily removed from the cutting tool [17, 18]. The cutting time decreases with increasing cutting speed. Hence, increasing cutting speed produced faster tool wear when machining of LM6 composite. The flank wear progression increases rapidly at high depth of cut of 1.5 mm and feed rate 0.2 mm rev^{-1}. On the other hand, machining at low depth of cut (0.5 mm) and low of feed rate (0.05 mm) produced slow flank wear progression. This shows that both feed rate and depth of cut significantly influenced the tool flank wear progression. The flank wear minimum (VB = 42 µm) was found at cutting speed of 100 m min^{-1}, feet rate of 0.2 mm rev^{-1}, and depth of cut of 1.0 mm until the length of cut reached 4050 mm as shown in Fig. 8. In Fig. 10 shows that the flank wear maximum (VB = 121 µm) was found at cutting speed of 250 m min^{-1}, feet rate of 0.125 mm rev^{-1}, and depth of cut of 1.5 mm until the length of cut reached 4050 mm. The microscope images of the tool wear minimum and maximum as shown in Fig. 11 and 12, respectively.

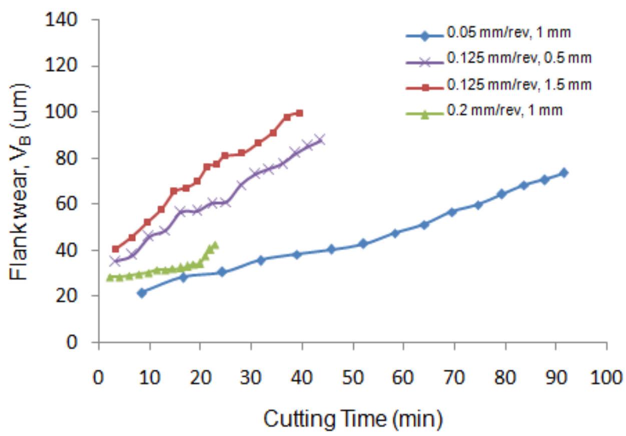

Fig. 8. The flank wear of uncoated carbide tool at cutting speed of 100 m min^{-1}

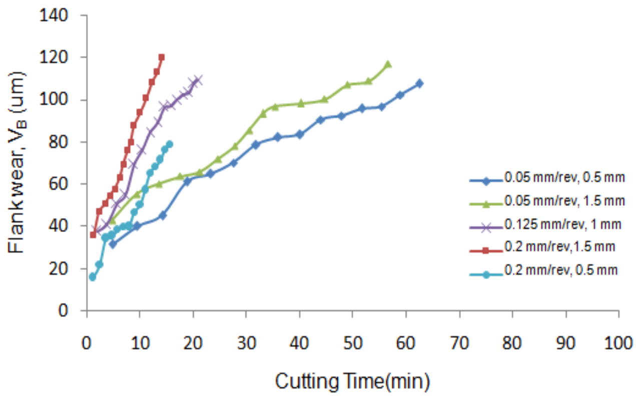

Fig. 9. The flank wear of uncoated carbide tool at cutting speed of 175 m min^{-1}

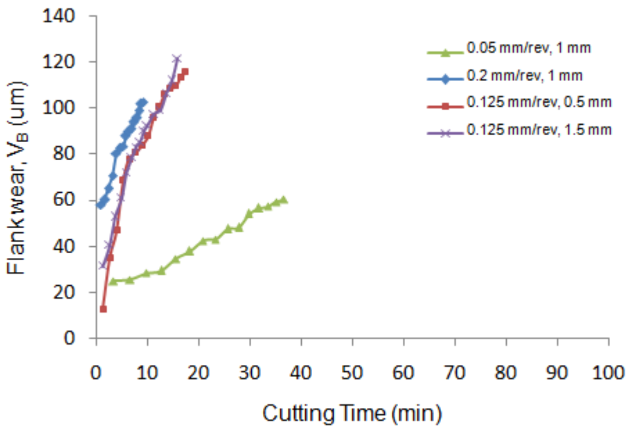

Fig. 10. The flank wear of uncoated carbide tool at cutting speed of 250 m min^{-1}

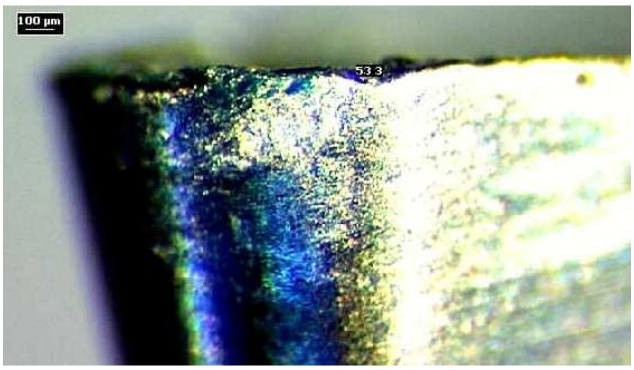

Fig. 11. Tool flank wear appearance (VB = 42 µm) at cutting speed of 100 m min^{-1}, feet rate of 0.2 mm rev^{-1} and depth of cut of 1.0 mm when length of cut reached 4050 mm

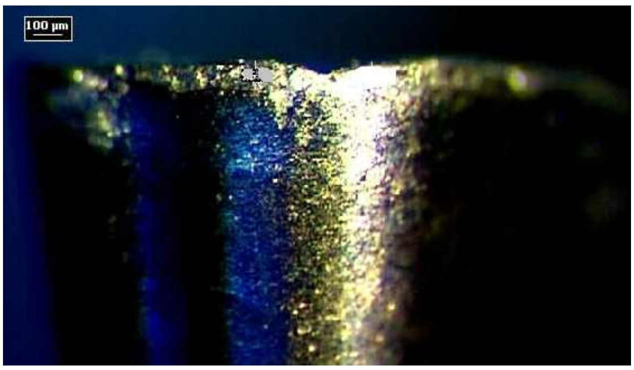

Fig. 12. Tool flank wear appearance (VB = 121 µm) at cutting speed of 250 m min^{-1}, feet rate of 0.125 mm rev^{-1} and depth of cut of 1.5 mm when length of cut reached 4050 mm

Summary

In this work, effect of parameters cutting speed, feed rate, and depth of cut on surface roughness and tool wear during turning of LM6 aluminium with 2 wt.% TiC composite using uncoated carbide tool have been investigated. Based on the experiment results, the following can be concluded.

1. The optimum surface roughness in the workpiece was found at high cutting speed of 250 m min^{-1} with various feed rate within range of 0.05 to 0.2 mm rev^{-1}, and depth of cut within range of 0.5 to 1.5 mm.
2. Turning operation at high cutting speed of 250 m min^{-1} produced faster tool wear as compared to low cutting speed of 175 m min^{-1} and 100 m min^{-1}.
3. The flank wear progression increases rapidly at high depth of cut of 1.5 mm and feed rate 0.2 mm rev^{-1}.
4. The flank wear minimum (VB = 42 μm) was found at cutting speed of 100 m min^{-1}, feet rate of 0.2 mm rev^{-1}, and depth of cut of 1.0 mm until the length of cut reached 4050 mm.
5. Based on the results of surface roughness in the workpiece and flank wear in the tool, recommended that turning operation should be carried out at cutting speed higher than 175 m min^{-1} but at feed rate of less than 0.05 mm rev^{-1} and depth of cut less than 1.0 mm

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.

References

[1] S. Sulaiman, M. Sayuti, R. Samin, Jour. of Mater. Proc. Technl. 201 (2008) 731-735.

[2] K.U. Kainer, Metal Matrix Composites: Custom-made Materials for Automotive and Aerospace Engineering, WILEY-VCH Verlag GmbH & Co. KGaA, 2006.

[3] R.K. Bhushan, S. Kumar, S. Das, Int J Adv Manuf Technol. 50 (2010) 459-469.

[4] S. Basavarajappa, Mater. and Manufac. Proc. 24 (2009) 484-487.

[5] M. Seeman, G. Ganesan, R. Karthikeyan, A. Velayudham, J. Adv Manuf. Technol. 48 (2010) 613-624.

[6] N. Muthukrishnan, J.P. Davim, J. of Mech. Eng. Resch. 3(1) (2011) 15-24.

[7] M. Yusuf, M.K. Anuar, N. Ismail, S. Sulaiman, Key Eng. Mater. 471-472 (2011) 233-238.

[8] R. Behera, S. Das, D. Chatterjee, G. Sutradhar, Jour. of Minerals & Materials Characterization & Eng. 10 (2011) 923-939.

[9] R.N. Rai, G.L. Datta, M. Chakraborty, A.B. Chattopadhyay, Mater. Scie. and Eng. A 428 (2006) 34-40.

[10] A. Manna, B. Bhattacharayya, Int J Adv Manuf Technol. 25 (2005) 850-856.

[11] Metin Kok, Proceedings of the 11th Int. Inorganic Fiber-Bonded Fiber Composite Comference, November 5-7; Madrid, Spain, 2008, pp. 272-281.

[12] M. Sayuti, S. Sulaiman, B.T.H.T. Baharudin, M.K.A. Ariffin, S. Suraya, G. Esmaeilian, Key Eng. Mater. 471-472 (2011) 721-726.

[13] R.H. Myers and D.C. Montgomery, Response Surface Methodology, 2nd edition, John Wiley & Sons, 2002.

[14] M. Yusuf, M.K.A. Ariffin, N. Ismail, S. Sulaiman, Appld. Mech. and Mater. 117-119 (2012) 1561-1565.

[15] G. Boothroyd, W.A. Knight, Fundamentals of Machining and Machine Tools, third Ed, CRC Press, Taylor & Francis Group, 2006.

[16] ISO 3685, Tool-life testing with single-point turning tools, International Standard 1993.

[17] G.A. Ibrahim, C.H. Che Haron, J.A. Ghani, Int. J. of Mech.and Mater. Eng. 4 (2009) 35-41.

[18] A.S. David, S.A. John, Metal Cutting Theory and Practice, Taylor & Francis Group, 2006.