ISSN 2250-3153

Study on Machining Parameters of TiB_2 Reinforced Aluminum 6063 Composites

K.Krishnamurthy*and J.Venkatesh**

[*] Department of Mechanical Engineering, Adichunchanagiri Institute of Technology, Chikmagalur-577102, INDIA
[**] Department of Automobile Engineering, PES College of Engineering, Mandya-571401, INDIA

Abstract- In this experimental study, three TiB_2/Al metal matrix composites (MMCs) with 40 µm in mean size were produced using a melt stirring squeeze casting route. Test was carried out to find the parameters influencing surface roughness (R_a) and material removal rate (MRR) on machining the TiB_2 reinforced Al-6063 composite materials. The orthogonal array, the signal-to-noise ratio, and analysis of variance were employed to study the performance characteristics in turning operations of 5 and 10 wt. % TiB_2 particles reinforced aluminum (Al-6063) metal matrix composites. Taguchi method was used to find the optimal cutting factors for surface roughness (Ra) and material removal rate (MRR). The factors considered were weight percentage of TiB_2, cutting speed, depth of cut and feed rate. The plan for the experiments and analysis was based on the Taguchi L_{27} orthogonal array with three cutting factors and two carbide tools of K_{10} and K_{20} type. The optimal parametric combination for K_{10} and K_{20} carbide insert was found to be feed, speed, depth of cut and percentage of TiB_2 reinforcement. The analysis of variance (ANOVA) results show that feed the most significant process parameter on surface roughness followed by speed/TiB_2 reinforcement for both K_{10} and K_{20} carbide insert tools. From MRR data also, it is clear that the speed and feed are the most significant parameters followed by the TiB_2 filler loading/depth of cut for the two carbide tools. The confirmatory test for the optimal condition yields low R_a value and high MRR value for the K_{20} type carbide tool.

Index Terms- TiB_2 reinforced 6063 aluminum composites, Taguchi Method, Surface Roughness, Material Removal Rate, K_{10} and K_{20} type Carbide Tool.

I. Introduction

In order to meet the demands of engineering applications, rigid ceramic fillers were added to the metal matrix such as aluminum and its alloys. Through compound effect, the strength, stiffness and wear resistance of metal matrix composites (MMCs) were greatly enhanced compared to unreinforced alloys. Besides, MMCs also have some outstanding properties like low density, high modulus, high thermal conductivity and low thermal expansion which make them find increasing applications in automobile, aerospace, electronics and medical industries [1]. There are manufacturing techniques with which it is possible to produce high quality MMC components to near-net shape. Unfortunately, for reasons as component design and dimensional tolerance requirements, the need for machining can not be completely eliminated [2]. However, MMCs are difficult to be machined to a good surface quality due to their low plasticity, non-uniformity and high abrasive nature of the ceramic reinforcement, which causes rapid tool wear rate and excessive machining induced defects [3-5].

In-situ composites are multiphase materials where the reinforcing phase is synthesized within the matrix during composite fabrication. Recently, In-situ techniques have been developed to fabricate aluminum-based metal matrix composites [6-8], which can lead to better adhesion at the interface and hence better mechanical properties. Literature review of aluminum-based composites show that this system has been widely investigated both in terms of understanding the mechanism of formation and property evaluation of composites [9-16]; the main dispersoids being SiC and Al_2O_3. Although investigations with varying volume fraction of dispersoids have been done, meaningful results have been obtained when the dispersoid percentage has been restricted to 15. As far as ceramic reinforced aluminum matrix composites are concerned, the machined surface possesses various flaws and damages. Generally, machined under conventional methods, four types of Surface/ subsurface damages may be produced when machining powder-formed MMCs: cracked SiC particles, delaminated matrix–reinforcement interface, pulled out/missing particles and work-hardened matrix [14]. Crack that initiated from either a fractured SiC particle or a delaminated matrix–reinforcement interface was also occasionally seen. And for the cast-MMCs, two additional types of subsurface defects were identified, i.e. numerous cracked SiC particles due to casting and collapsed or halved voids due to machining. Using polycrystalline diamond (PCD) tools and under high speed turning, Gallab and Sklad[3] investigated that the machined surface revealed grooves, voids around the SiC particles, pulled-out SiC particles, and fractured or crushed SiC particles. They found that the plastic deformation due to machining extended to about 60–100 µm below the machined surface.

Mechanical and physical properties are greatly influenced by the condition of the work piece surface. Hence, the effect of machining on the type of surface defects, as well as on their distribution, has a major impact on the performance of the machined component. Such machine-induced defects could be a concern when using MMCs in a critical or precise application.

Again the size of the dispersoids is dependent on/or restricted to the processing route adopted. There are different routes to synthesize Al–TiB_2 composites, but in-situ approach is gaining importance due to simplicity of its fabrication. Among the reinforcements, TiB_2 has emerged as a promising candidate for Al-based composites. This is due to the fact that TiB_2 is stiff, hard and more importantly, does not react with aluminum to form reaction product at the interface of reinforcement and matrix. TiB_2 is a refractory compound that exhibits outstanding features such as high melting point (2790°C), high hardness (86 HRA or 960 HV) and high modulus characteristics. Its resistance to plastic deformation even at high temperatures portrays it to be a good potential reinforcing candidate in an aluminum matrix.

5 and 10 wt. % TiB_2 particles reinforced aluminum (Al-6063) metal matrix composites produced by using master alloys of Al-Ti & B by stir casting process to obtain the material for the experiment [6-8,17]. Few researchers have dedicated themselves to the study of diamond turning of SiC/Al composites [18-21]. Unfortunately, most researchers limited their studies to relating the effect of the machining cutting parameters and reinforcement to the work piece surface roughness. To the best of the authors' knowledge, no research has yet comprehensively demonstrated the type of the surface/subsurface defects and the factors that affect them when ultra-precision machining SiC/Al composites. Surface roughness has become the most significant technical requirement and it is an index of product quality. In order to improve the tribological properties, fatigue strength, corrosion resistance and aesthetic appeal of the product, a reasonably good surface finish is desired. Nowadays, the manufacturing industries specially are focusing their attention on dimensional accuracy and surface finish. In order to obtain optimal cutting parameters to achieve the best possible surface finish, manufacturing industries have resorted to the use of handbook based information and operators' experience. This traditional practice leads to improper surface finish and decrease in the productivity due to sub-optimal use of machining capability. This causes high manufacturing cost and low product quality [18, 22-24]. In addition to the surface finish quality, the material removal rate (MRR) is also an important characteristic in turning operation and high MRR is always desirable [22, 24]. Several researchers carried out experiments on machining of MMCs.

Channakesava rao et al. [25] have experimented with different cutting tools and reported that, the crater wear is not substantial in K_{10} tools and is having superior wear resistance and produce continuous chips. Hoecheng et al. [26] have studied the effect of speed, feed, depth of cut, rake angle and cutting fluid on the chip form, forces, wear and surface roughness. Yuan et al. [27] have studied the effect of percentage volume reinforcement, cutting angle, feed rate and speed on the surface integrity in ultra precision diamond turning of MMCs.

The main concerns when machining MMCs is the extremely high tool wear due to the abrasive action of the ceramic fibers or particles. Therefore, materials of very high resistance to abrasive wear are often recommended. The HSS tools are inadequate, cemented carbide tools are preferred for rough machining and PCD tools for finish machining operations [28]. The cost of PCD tools increase the cost of production so it is necessary to carryout basic machinability studies, in order to find cutting conditions using carbide tools, which can result in high productivity at low cost. Most of the studies on Al/SiC-MMCs composite machining show that minimizing the surface roughness has been very difficult and is to be controlled. Taguchi emphasizes on the fact that quality provides robustness and immune to the uncontrollable factors in the manufacturing state. This approach helps to reduce the large number of experimental trials when the number of process parameters increases. [29-31]. In the present work, a procedure has been introduced to assess and optimize the chosen factors to attain minimum surface roughness and maximum material removal rate by incorporating response table, response graph and analysis of variance (ANOVA) technique.

II Experimental Details

A Materials and method of fabrication

Aluminium 6063 alloy was selected as the base line material as it possesses good formability, weldability, machinability and corrosion resistance, with medium strength compared to other grades of aluminium alloys. Its nominal chemical composition is shown in Table 1. The commercially available Al-6063 matrix alloy and master alloy are melted in an electric resistance furnace. The percentage weight of Al-Ti &B % was varied from 0-10 wt % in steps of 5 wt%. The mixture of matrix alloy and master alloy were melted in an electric resistance furnace at a temperature of 800^0C and allowed to stand for a duration of about 30 min to get melts. The melt was degassed using commercially available chlorine based tablets (Hexachloroethane) to remove the entrapped gases before stirring the melt using stirrer to get in-situ composites of TiB_2 in Al-6063 alloy. The melt is poured into the preheated metallic moulds. The different wt% composition (0, 5 and 10) of Al6063-TiB_2 composites rods are prepared of size Ø 22 mm x120 mm length.

Table 1. Chemical composition of base alloy Al-6063.

Elem ent	Mg	Si	Fe	Cu	Mn	Zn	Ti	Cr	Al
Wt.%	0.45 -0.9	0.2-0.6	0.35	0.1	0.1	0.1	0.1	0.1	Bala nce

B Microscopy, Density and Hardness Measurement

In order to know the dispersion of TiB_2 in Al-6063, the samples were analyzed by scanning electron microscope (SEM). The density of the composites was obtained by the Archimedes's principle of weighing small pieces cut from the composite disc first in air and then in water. Then, theoretical density of composite and its alloy was calculated from the chemical analysis data. The porosity of the composites was also determined. The hardness of the composites and matrix alloy were measured after polishing to a 3 mm finish. The magnification of the images was 500x. Hardness of all samples was measured by Brinell hardness tester and mean of at least five readings was taken to represent the sample.

C Cutting conditions

The experiments were carried with four factors at three levels each as shown in Table 2. The factorial design used is a standard L_{27} (3^{13}) orthogonal array. This orthogonal array is chosen due to its capability to check the interactions among factors. The turning trials were carried out on the CNC turning center (MITSUBISHI-EZ Motion NC E60) in dry machining condition shown in Figure 1. The insert used is of K_{10} type carbide tool (SANDVIK: DNMG 3005 TOOL: $K_5 - K_{20}$) and K_{20} type carbide tool (SANDVIK: DNMG 3215 TOOL: $K_{15} - K_{35}$) shown in Figure 2 (a) and 2(b) respectively. The material used is 0, 5 and 10wt % TiB_2 reinforced Al-6063 composite material cut into the of size Φ20 mm x 60 mm length as shown in Figure 3.

The surface roughness (R_a) of the machined surface was measured using HANDYSURF E-35A instrument shown in Figure 4 and the MRR is calculated using the following equation [18].

$$\text{MRR } (mm^3/min) = \frac{[\text{Intial weight of the work(gms) - Final Weight of the work(gms)}]}{\text{Density } (gms/mm^3) \text{ x Machining time(min)}}$$

Figure 1: CNC turning center. (MITSUBISHI-EZ Motion NC E60)

Figure 2: (a) SANDVIK: DNMG 3005 Tool (K_{10})

(b)SANDVIK: DNMG 3215 Tool (K_{20})

Figure 3: Composite Material 0, 5 & 10 wt%TiB_2 Reinforced with Al-6063.

Table 2: Factors (process parameters) and Levels Used in the Experiments

Process Factors	Levels		
	1	**2**	**3**
A-Cutting Speed (m/min)	37.69	75.39	113.07
B-Feed rate (mm/min)	0.05	0.10	0.15
C- Depth of Cut (mm)	0.25	0.50	0.75
D- Material (Al6063 + wt%TiB_2)	0	5	10

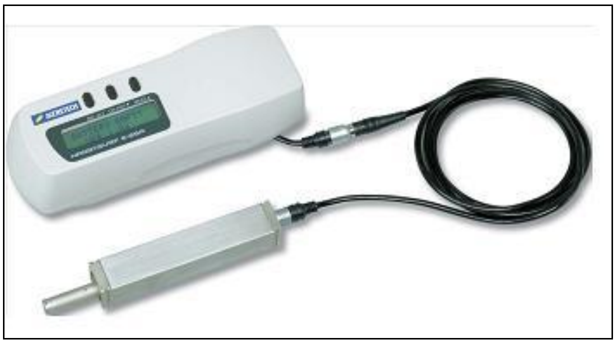


Figure 4. HANDYSURF E-35A, Surface Roughness Measuring Instrument.

III Results and Discussion

A Microstructure, Density and Hardness of TiB2/Al-6063 Composites

The properties of the MMCs depend not only on the matrix, particle, and the volume fraction, but also on distribution of reinforcing particles and interface bonding between the particle and matrix. In practical way, to achieve a homogenous distribution is difficult. The photomicrographs of the aluminum composite reinforced with 5 and10 wt. % of TiB_2 are shown in Fig. 5(a) and (b) respectively. The particles, with the average particle size of 25 µm, mainly formed in the surface showed a character of homogenous distribution.

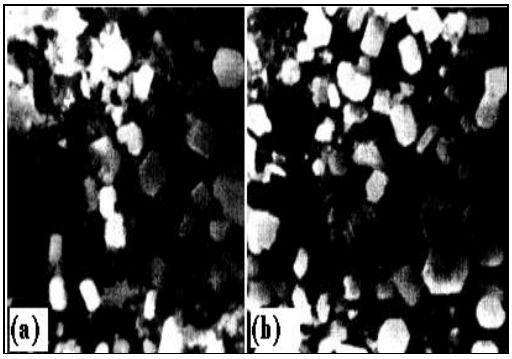


Figure 5. Photomicrographs of Al-6063 composites (a) 5 wt% TiB_2 and (b) 10 wt% TiB_2.

The variations of density and hardness of the composites are shown in Figure 6. The density and hardness of the MMCs increased more or less linearly with the weight fraction of particles in the alloy matrix due to the increasing ceramic phase of the matrix alloy. A significant increase in both density and hardness was found in 10 wt. % TiB_2 into aluminum composite. The increase in density indicates that particle breakage may not have any significant influence on the composites. It is believed to achieve an improvement of the bonding between the particle and matrix. The porosities of composites were evaluated from the difference between the expected and the observed density of each sample. The variations of porosity level in these composites are 1.3 and 1.5 % for 5 and 10 wt. % TiB_2 in aluminum composites respectively. The porosity level increased, since the contact surface area was increased.

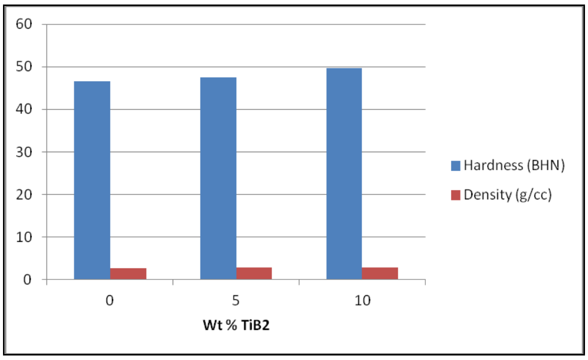


Figure 6. Density and hardness of TiB_2/Al MMCs.

B Analysis of Variance of Surface Roughness and Material Removal Rate

Assessing the factors and its effects on surface roughness (R_a) and material removal rate (MMR) of TiB_2/ Al-MMC machining process has been carried out through response table, response graph and analysis of variance (ANOVA) technique. The influence of machining parameters on R_a and MMR has been performed using response table. Response tables are used to simplify the calculations needed to analyze the experimental data. The complete response table for a three level, four factors using L_{27} orthogonal array is shown in Table 3.

C Surface Roughness

The response data recorded in Table 3, for surface roughness subjected to ANOVA for finding the significant factors at above 85% confidence levels and the result of ANOVA for these response parameters are presented in the Tables 4, 5 and 6 respectively for both type of carbide tool. For MRR subjected to ANOVA for finding the significant factors, at above 95% confidence levels and the result of ANOVA for these response parameters are presented in the Tables 7, 8and 9 respectively for both type of tool. Average S/N ration for each level of experiment and the different values of S/N ration between maximum and minimum are shown in Table 4 for surface roughness. The feed rate and cutting speed are two factors that have highest different values of 8.34 and 4.75 respectively for K_{10} type tool & the feed rate and TiB_2 reinforcement are two factors that have highest different values of 6.12 and 3.61 respectively for K_{20} type tool. Based on the Taguchi prediction that the bigger different values of S/N ratio will give more effect or more significant. Increase in the feed rate will increase the surface roughness significantly.

The results of analysis of variance for surface roughness are shown in Table 5. DF (degree of freedom), SS (sum of squares), MS (mean of squares), F (variance ratio), P (Significant factor) and percentage contribution of each level [30-34].

Table 5. Shows that the feed rate and the cutting speed have more influence on the surface roughness value. The significant factor (P) values for both are 0.000 and 0.005 respectively for K_{10} tool. In statistical analysis of Taguchi method, the smallest P value gives more significant effect on responded surface roughness parameters. The values for the feed rate and the cutting speed are significant. The contributions are 60.29% and 17.29% respectively for K_{10} type tool. The type of work material contributes about 8.18%, where as the contribution of the depth of cut and the interactions are insignificant.

Table 6. provides values for K_{20} tool, the feed rate(0.024) and TiB_2 reinforcement o (0.158) are significant followed by the speed of about 0.238. The values for the feed rate and reinforced material are significant. Their contributions are 38.52% and 13.22% respectively for K_{20} type tool. The cutting speed contributes about 9.53%, where as the contribution of interaction, speed and material is significant and contribute about 11.20%, the depth of cut and the other interactions are insignificant.

The most significant factor, which affects the surface roughness measured in turning the 5 and 10wt % TiB_2 reinforced with Al-6063 composite material, is the feed rate for both type of tool and therefore the surface roughness can be controlled with a suitable feed rate value. Previous researchers suggest the similar results. They claimed that the surface roughness strongly depends on the feed rate followed by the cutting speed or the reinforced material.[32-34].

Table 3. Factor Settings, Surface Roughness Data and MRR Data.

Exp No	Cutting Speed (m/min)	Feed (mm/min)	Depth of cut (mm)	wt% TiB_2	For K_{10} Tool		For K_{20} Tool	
					Material Removal Rate (mm^3/min)	Surface Roughness (R_a) µm	Material Removal Rate (mm^3/min)	Surface Roughness (R_a) µm
1	37.69	0.05	0.25	0	0.136	0.40	0.152	0.40
2	37.69	0.05	0.50	5	0.380	0.67	0.276	0.73
3	37.69	0.05	0.75	10	0.236	0.83	0.099	1.90
4	37.69	0.10	0.25	5	0.360	1.03	0.282	1.47
5	37.69	0.10	0.50	10	0.321	1.37	0.719	1.73
6	37.69	0.10	0.75	0	0.470	0.67	0.590	0.57
7	37.69	0.15	0.25	10	0.395	1.70	0.325	1.70
8	37.69	0.15	0.50	0	0.683	1.97	0.724	1.87
9	37.69	0.15	0.75	5	0.909	2.13	1.066	1.95
10	75.39	0.05	0.25	5	0.302	1.87	0.339	0.60
11	75.39	0.05	0.50	10	0.180	0.90	0.553	0.90
12	75.39	0.05	0.75	0	0.599	1.10	0.793	1.00
13	75.39	0.10	0.25	10	0.488	1.23	0.367	1.10
14	75.39	0.10	0.50	0	2.269	1.20	1.653	0.87
15	75.39	0.10	0.75	5	1.522	1.13	1.616	1.20
16	75.39	0.15	0.25	0	2.559	2.33	0.925	1.73
17	75.39	0.15	0.50	5	2.016	3.10	2.678	2.32
18	75.39	0.15	0.75	10	1.209	1.97	1.396	1.57
19	113.07	0.05	0.25	10	0.312	0.53	0.504	0.63
20	113.07	0.05	0.5	0	0.585	0.47	0.717	0.60
21	113.07	0.05	0.75	5	0.791	0.63	0.727	0.87
22	113.07	0.10	0.25	0	1.856	0.57	1.037	0.67
23	113.07	0.10	0.50	5	2.316	1.23	2.397	1.67
24	113.07	0.10	0.75	10	1.775	0.80	1.925	0.83
25	113.07	0.15	0.25	5	2.005	2.07	1.525	1.50
26	113.07	0.15	0.50	10	2.150	1.43	2.865	1.37
27	113.07	0.15	0.75	0	3.022	1.22	3.032	0.70

Surface roughness plays an important role in many areas and is a factor of great importance in the evaluation of machining accuracy. Although many factors affect the surface condition of a machined part, machining parameters such as cutting speed, feed rate and depth of cut have a significant influence on the surface roughness for a given machine tool and work piece set-up.

The studies on machining characteristics of TiB_2/6063Al MMCs acquire more importance due to the presence of abrasive phase in metal matrix. The presence of TiB_2 in metal matrix is reported to increase the hardness, tensile strength and heat resistance. The rate of change in these properties is dependent on the weight fraction of TiB_2 added to the matrix alloy. The cutting speed plays an important role in deciding the surface roughness. At high cutting speeds, the surface roughness decreases. At low speeds, the built-up edge (BUE) is formed and also the chip fracture readily producing the rough surface [35]. As the speed increases, the BUE vanishes, chip fracture decreases, and hence the roughness decreases.

The increase in depth of cut results in high normal pressure and seizure on the rake face and promotes the BUE formation. Hence, the surface roughness increases along with increase in depth of cut. The increase in feed rate, increases the surface roughness linearly upto 0.15 mm/rev. At feed rates between 0.15 and 0.05 mm/rev, the BUE forms readily and is accomplished by feed marks resulting in increased roughness.

The results shown prove that the surface roughness of TiB_2/Al-6063 composite is highly influenced by the feed rate, cutting speed and % weight fraction of TiB_2 particles in the work piece. The depth of cut also plays a significant role on composite machining process in deciding the surface roughness.

Table 4. Average for S/N Ratio and Main Effect of Surface Roughness.

Process parameters	Designation	For K_{10} Tool					For K_{20} Tool				
		Levels			Max-Min	Rank	Levels			Max-Min	Rank
		1	2	3			1	2	3		
Cutting Speed (m/min)	A	-0.39	-3.65	- 1.10	4.75	2	-1.55	-1.32	0.79	2.34	3
Feed rate (mm/min)	B	2.64	0.11	-5.69	8.34	1	2.24	-0.42	-3.89	6.12	1
Depth of cut (mm)	C	-0.82	-1.55	-0.55	0.99	4	0.31	-1.71	-0.67	2.03	4
Wt% TiB2 material	D	0.61	-2.64	-0.90	3.25	3	1.65	-1.96	-1.76	3.61	2

Table 5. ANOVA Analysis of S/N Ratio for Surface Finish of K_{10} Tool

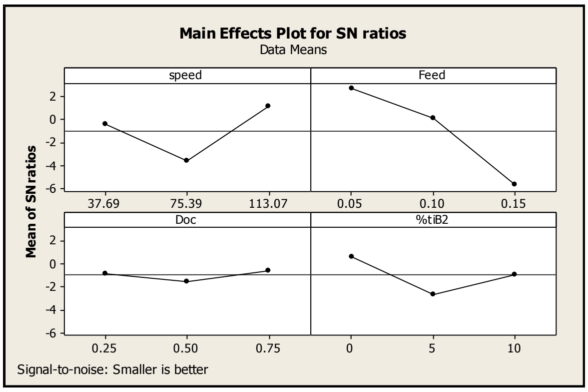
Process parameters	Designation	DF	SS	MS	F	P	SS (%)
Cutting Speed (m/min)	A	2	2.01	1.01	14.00	0.005	17.29
Feed rate (mm/min)	B	2	7.02	3.51	48.80	0.000	60.29
Depth of cut (mm)	C	2	0.20	0.10	1.39	0.319	01.70
%TiB2 material	D	2	0.95	0.48	6.63	0.030	08.18
Speed*Feed	A*B	4	0.35	0.09	1.21	0.396	02.99
Speed * DOC	A*C	4	0.27	0.07	0.94	0.500	02.32
Speed * %TiB2	A*D	4	0.40	0.10	1.40	0.338	03.46
Error		6	0.43	0.07			03.77
Total		26	11.64				100.00

R-Sq = 96.29%

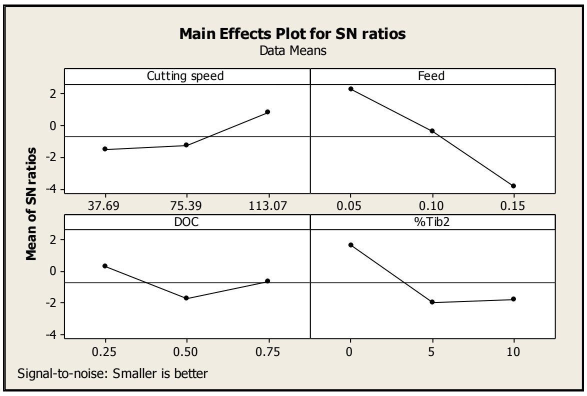
Table 6. ANOVA Analysis of S/N Ratio for Surface Finish of K_{20} Tool

Process Parameters	Designation	DF	SS	MS	F	P	SS (%)
Cutting Speed (m/min)	A	2	0.71	0.36	1.84	0.238	09.53
Feed rate (mm/min)	B	2	2.87	1.43	7.43	0.024	38.52
Depth of cut (mm)	C	2	0.29	0.15	0.76	0.509	03.89
wt%TiB2 material	D	2	0.98	0.49	2.55	0.158	13.22
Speed*Feed	A*B	4	0.41	0.10	0.53	0.722	05.50
Speed * DOC	A*C	4	0.19	0.05	0.25	0.900	02.68
Speed * %TiB2	A*D	4	0.84	0.21	1.08	0.443	11.20
Error		6	1.16	0.19			15.55
Total		26	7.45				100.0

R-Sq=84.45%



(a) K_{10} tool



(b) K_{20} tool

Figure 7(a) and (b) Main Effect Plots for S/N Ratio of process parameters on Surface Roughness.

Figure 7(a) shows that the S/N ratio of surface finish for K_{10} tool, the B1 (low level of feed) is at the maximum value with 2.64 of S/N ratio, decrease dramatically to B2 (0.11) and then to B3 (-5.69). S/N ratio for B2 and B3 decreased, due to increase in the feed rate. The parameter A1 (low level speed) is at the minimum value at -0.39 and it increased to a value of 1.10 as the speed increases. The material composition is at the maximum value of 0.61 and decreased to -2.64 as the inclusion of TiB_2 reinforcement increases [36].

The signal to noise ratio are shown in Figure 7(b) for the process factors on surface roughness for K_{20} tool. The value B1 (low level of feed) is at the maximum value with 2.24, decrease dramatically to B2 (-0.42) and then to B3 (-3.89). S/N ratio for B2 and B3 decreased, due to increase in the feed rate. The parameter D1 (low level of material reinforcement) is at the maximum value at 1.65 and it decreased to a value of -1.76 as the feed increases. The cutting speed is at the minimum value of -1.55 and increased to 0.79[37]

From the above S/N ratio results for feed variation values, the K_{20} tool provides low values compared to K_{10} tool. From the analysis, the optimal machining parameters for the TiB_2/Al MMCs machining process are achieved for the maximum surface finish. The optimal conditions arrived are:(i) Cutting speed (113.07 m/min),(ii) % weight fraction of TiB_2 (0),(iii) Depth of cut (0.25 mm) and (iv) Feed rate (0.05 mm/rev) shown in Table 7.

D Material Removal Rate

In machining operation, maximizing the material removal rate (MRR) is an important criterion. Experimental results of the MMR for turning 5 and 10 wt% TiB_2 reinforced with Al6063 composites with various cutting parameters are shown in Table 7, which also gives the S/N ratio for the material removal rate. The feed rate and the cutting speed are the most significant factor that influences the MRR with the value of 12.31 and 10.99 respectively for k_{10} tool and for K_{20} tool the speed and feed are significant with 11.39 and 10.78 respectively.

Table 8. Shows the feed rate and the cutting speed values for K_{10} tool are significant with the factor (P) value for both are 0.000 in percentage. The contribution of the feed rate and the cutting speed are 37.62 and 34.00 respectively. The type of work material contribute about 7.54% and the interaction parameter between the cutting speed and feed rate (A * B) is significant with a factor of 0.016, and its contribution is 10.15%. The other interactions are insignificant [36]

Table 9. Shows the cutting speed and the feed rate values are significant with the factor (P) value for both are 0.001 and 0.002 respectively. The contribution of the cutting speed and the feed rate are 32.28 and 31.86. The depth of cut contributed about 16.64% and the interaction parameter between the cutting speed and feed rate (A * B) is significant with a factor of 0.158, and its contribution is 6.75%. The other interactions are insignificant [37].

Table 7. Average for S/N Ratio and Main Effect of MRR.

Process parameters	Design ation	For K_{10} Tool					For K_{20} Tool				
		Levels			Max-Min	Rank	Levels			Max-Min	Rank
		1	2	3			1	2	3		
Cutting	A	-8.42	-1.03	2.57	10.99	2	-8.66	-0.66	2.71	11.39	1
Feed rate	B	-9.42	-0.34	2.88	12.31	1	-8.42	-0.56	2.36	10.78	2
Depth of cut	C	-4.60	-1.55	-0.72	3.87	4	-6.43	0.53	-0.72	06.96	3
Wt% TiB2	D	-0.67	-0.82	-5.38	4.71	3	1.67	-1.09	-3.87	02.78	4

Table 8. ANOVA Analysis of S/N Ratio for MRR of K_{10} Tool

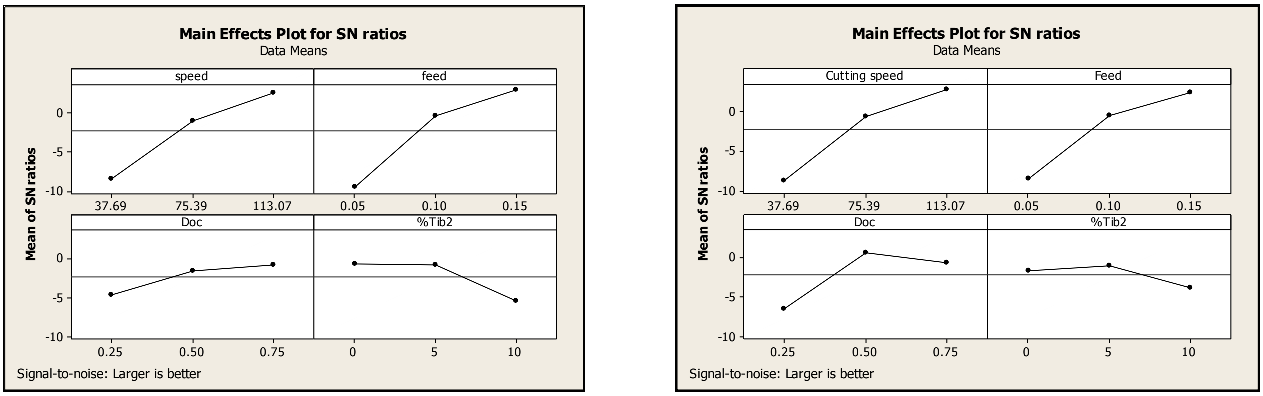
Process parameters	Desig nation	DF	SS	MS	F	P	SS (%)
Cutting Speed (m/min)	A	2	6.87	3.43	40.13	0.000	34.00
Feed rate (mm/min)	B	2	7.59	3.79	44.39	0.000	37.62
Depth of cut (mm)	C	2	0.40	0.20	2.34	0.177	01.98
%TiB_2 material	D	2	1.52	0.76	8.90	0.016	07.54
Speed*Feed	A*B	4	2.05	0.51	5.98	0.027	10.15
Speed * DOC	A*C	4	0.31	0.08	0.91	0.513	01.55
Speed * %TiB_2	A*D	4	0.93	0.23	2.72	0.132	04.62
Error		6	0.51	0.09			02.54
Total		26	20.19				100.00

R-Sq = 97.46%

Table 9. ANOVA Analysis of S/N Ratio for MRR of K_{20} Tool

Process parameters	Designation	DF	SS	MS	F	P	SS (%)
Cutting Speed (m/min)	A	2	6.17	3.09	23.37	0.001	32.28
Feed rate (mm/min)	B	2	6.09	3.05	23.08	0.002	31.85
Depth of cut (mm)	C	2	3.19	1.59	12.07	0.008	16.64
Wt %TiB_2 material	D	2	0.26	0.13	0.99	0.426	01.35
Speed * Feed	A*B	4	1.29	0.32	2.44	0.158	06.75
Speed * DOC	A*C	4	0.57	0.14	1.08	0.444	02.98
Speed * %TiB_2	A*D	4	0.75	0.19	1.43	0.332	03.92
Error		6	0.79	0.13			04.13
Total		26	19.12				100.00

R-Sq=95.86%



(a) K_{10} tool **(b) K_{20} tool**

Figure 8(a) and (b) Main Effect Plots for S/N ratio of process parameters on MRR.

Figure 8 (a) shows that the S/N ratio of material removal rate for K_{10} tool, the A1 (low cutting speed) is the minimum value with -8.42 of S/N ratio, and increase dramatically to B2 (-1.03) and then to B3 (2.57). The main effect plot for the feed and depth of cut have same trend lines but the TiB_2 reinforced Al6063 composite work material shows inverse trend as wt% of TiB_2 increases the MRR decreases [36].

Figure 8(b) shows that the signal to noise ratio of material removal rate for K_{20} tool. The A1 (low cutting speed) is at minimum value with -8.66 of S/N ratio, and it increases dramatically to A2 (-0.66) and then to A3 (2.71). The main effect plot for the feed, and depth of cut have same trend lines but the TiB_2 reinforced Al6063 composite work material shows inverse trend as wt% of TiB_2 increases the MRR decreases[37].

From the above S/N ratio results for MRR, the cutting speed variation values, the K_{20} tool provides high values compared to K_{10} tool. From the analysis, the optimum parameters for the TiB_2/Al-6063 MMCs machining process are achieved for maximizing MRR. The optimal conditions arrived are:(i) Cutting speed (113.07 m/min),(ii) % weight fraction of TiB_2 (0),(iii) Depth of cut (0.75 mm) and (iv) Feed rate (0.15 mm/rev) shown in Table 7.

Table 7. Factors with optimum levels for Surface Roughness and MRR for both K_{10} and K_{20} type tools.

Process parameters	Optimum Level for Surface Roughness	Optimum values for Surface Roughness	Optimum Level for MRR	Optimum values for MRR
Cutting Speed (m/min)	A3	113.07	A3	113.07
Feed rate (mm/min)	B1	0.05	B3	0.15
Depth of cut (mm)	C1	0.25	C3	0.75
wt%TiB_2 + Al-6063 material	D1	0%	D1	0%

Table 8. Conformation Tests with optimum levels for Surface Roughness and MRR using K_{10} and K_{20} type tools.

Exp No	Cutting Speed (m/min)	Feed (mm/min)	Depth of cut (mm)	wt% TiB_2	For K_{10} Tool		For K_{20} Tool	
					Material Removal Rate ($mm^{3)}$/min)	Surface Roughness (R_a) µm	Material Removal Rate ($mm^{3)}$/min)	Surface Roughness (R_a) µm
1	113.07	0.05	0.25	0	--	0.376	--	0.353
2	113.07	0.15	0.75	0	3.028	--	3.037	--

E Conformation Test of Optimum Levels for Surface Roughness (R_a) and MRR

Table 8.Lists the results of the conformation test with optimal levels using two types of carbide Tools. For the surface roughness test optimum level are A3 (113.07 m/min), B1 (0.05 mm/min), C1 (0.25 mm) and D1 (Al-6063 matrix alloy) are adopted and the result show that the R_a values are 0.376 and 0.353 microns respectively for K_{10} and K_{20} carbide tool. For MRR the optimum level A3 (113.07 m/min), B3 (0.15 mm/min), C3 (0.75 mm) and D1 (Al-6063 matrix alloy) are adopted and the result show that the MRR values are 3.028 and 3.037 mm^3/min respectively for K_{10} and K_{20} carbide tool.

From the above result it shows that the K_{20} type carbide tool gives better machining conditions than the K_{10} type carbide tool. The low surface roughness value for the material Al-6063 matrix alloy (R_a) of about 0.353 microns and maximum MRR value of 3.037 mm^3/min.

IV Conclusions

1. Using Taguchi's experimental design, the parameters, which are having influence on surface Roughness and material removal rate on the machining of TiB_2/Al-6063 composites have been assessed.

2. Micro-structural examination showed that the TiB_2 distributions are more or less homogeneous and lower interface porosity could be observed.

3. Hardness of the aluminum alloy improved significantly by adding up of TiB_2 particles into it, while density of the composite also increased almost linearly with the weight fraction of particles..

4. The significant factors in turning 5 and 10 wt. % TiB_2/Al-6063 MMCs on surface roughness are feed rate and the cutting speed, with contributions 60.2% and 17.29 % respectively for K_{10} tool and for K_{20} tool the feed rate and the type of work material, with contribution about 38.52% and 13.22% respectively.

5. For material removal rate the feed rate and cutting speed are most significant factors, with contribution of 37.62% and 34.00 % respectively and the TiB_2 loading is contributed about 10.15% for K_{10} tool and for K_{20} tool the cutting speed and the feed rate are most significant factors, with contribution of 32.28% and 31.85% respectively. The depth of cut is contributed about 16.64%.

6. The optimal conditions of machining parameters for low surface finish for TiB2/Al-6063 composites are; speed of 113.07m/min; feed 0.05 mm/min, depth of cut of 0.25mm.

7. The optimal conditions of machining parameters for higher MRR for TiB2/Al-6063 composites are; speed of 113.07m/min; feed 0.15 mm/min, depth of cut of 0.75mm.

8. The optimal conditions for surface roughness and the MRR for TiB2/Al-6063 composites are shown in Table 7 and are same for two types of carbide tool.

9. The conformation test results with optimal machining conditions for surface roughness and the MRR are shown in Table 8 for both tools

10. The K_{20} type carbide tool gives better cutting conditions than the K_{10} type carbide tool with low surface roughness value of (R_a) 0.353 microns and maximum MRR value of 3.037 mm^3/min.

REFERENCES

1] Karthikeyan, R. (2000), Analysis and optimization of machining characteristics of Al/SiC particulate composites, Ph.D. Thesis, Chidambaram: Annamalai University.

[2] Abdullah Abu, (1998), Formation of built-up edge (BUE) during machining of particulate metal matrix composite (MMC), Proc Adv Mater Process Technol, 374–384.

[3] El-Gallab, M. and Sklad, M. (1998), Machining of Al/SiC particulate metal-matrix composites Part II: work piece surface integrity, J. Mater.Process. Technol., 83:277–285.

[4] Li, Xiaoping and Seah, W.K.H. (2001), Tool wear acceleration in relation to work piece reinforcement percentage in cutting of metal matrix composites, Wear, 247:161–171.

[5] Miracle, D.B. (2005), Metal matrix composites–from science to technological significance, Composites Sci. Technol. 65:2526–2540.

[6] Tee, K.L., Lu, L., and Lai, M.O. (1999), In situ processing of Al–TiB2 composite by the stir-casting Technique, Journal of Materials Processing Technology, 89–90: 513–519.

[7] Lu,L. Lai, M.O. Su, Y. Teo, H.L. and Feng, C.F. (2001), In situ TiB2 reinforced Al alloy composites, Scripta materilia,45:1017-1023.

[8] Mandal, A. Maiti, V. Chakraborty, M. and Murty, B.S. (2004), Effect of TiB2 particles on aging response of Al–4Cu alloy, Materials Science and Engineering A, 386:296–300.

[9] Lin, J.T. Bhattacharyya, D. and Lane,C.(1995), Machinability of a silicon carbide reinforced aluminium metal matrix composite, Wear ,181:883 –888.

[10] Yang. B.H. and Wang, C.C. (1993), Machinability of SiCp reinforced Al alloy composite materials, Light Met ,43(4):187 –192.

[11] Quigley, Q. Monaghan, J. and O'Reilly, P. (1994), Factors affecting the machinability of an AlySiC metal matrix composites, J Mater Process Technol. 43:21 –36.

[12] Saga, T. and Ikeda, S. (1991), Machinability of Al_2O_3.SiC short fiber reinforced Al alloy composites, JJpn Int Light Met, 41(4):264 –269.

[13] Durante,S. Ruttelli, G. and Rabezzana, F.(1997), Al-based MMC machining with diamond coated cutting tools, Surf Coat Technology, 94–95:623 –640.

[14] Sahin, Y. Kok, M. and Celik, H.(2002), Surface roughness and tool wear of Al_2O_3-reinforced metal matrix composites, J .Mater Process Technol,6060:1 –12.

[15]Chambers, A.R. (1996), The machinability of light alloy MMC's, Comp A, 27A:143–147.

[16] Hung, N.P. Boey, F.Y.C. Khor, K.A. Oh, C.A. and Lee, H.F. (1995), Machinability of cast and powder-formed aluminum alloys reinforced with SiC particles, J. Mater. Process Technol. 48:291–297.

[17] Ramesh, C.S. Abrar Ahamed, Channabasappa, B.H. and Keshavamurthy, R. (2010), Development of Al-6063-TiB2 in situ composites, Materials and Design, 31: 2230-2236.

[18] Davea, H. K. Patel, L. S. and Raval, H. K.(2012), Effect of machining conditions on MRR and surface roughness during CNC Turning of different Materials Using TiN Coated Cutting Tools – A Taguchi approach, International Journal of Industrial Engineering ,Computations 3:925-930.

[19] Rongdi, Han. and Dazhen Wand, (2003), Micro-analysis on surface of the aluminum composite in ultra-precision machining, China Mech. Engg, 14 (9):747–749, in Chinese.

[20] Cheung, C.F. Chan, K.C. To, S. and Lee, W.B. (2002), Effect of reinforcement in ultra-precision machining of Al6061/SiC metal matrix composites, Scripta Materialia, 47:77–82.

[21] Cheung, C.F. Chan, K.C. and Lee, W.B. (2003), Surface characterization in ultra-precision machining of Al/SiC metal matrix composites using data dependent systems analysis, J. Mater. Process Technol., 140:141–146.

[22] Kamal Hassana, Anish Kumar, and Garg, M.P. (2012), Experimental investigation of Material removal rate in CNC turning using Taguchi method, International Journal of Engineering Research and Applications (IJERA), 2(2):1581-1590.

[23] Hardeep Singh, Rajesh Khanna2, and Garg, M.P. (2011), Effect of Cutting Parameters on MRR and Surface Roughness in Turning EN-8, Current Trends in Engineering Research, 1(1):100-104.

[24] Kaladhar, M. Subbaiah, Rao,V.S. Ch, S. and Rao, K.N.(2010),Optimization of process Parameters in turning of AISI 202 Austenitic Stainless Steel, ARPN Journal of Engineering and Applied Sciences, 5(9):79-87.

[25] Chennakesava rao, B. Reddy, P.N. Komariah, N. and Malla Reddy, D. (2000), Machinability of vaccum hot pressed metal matrix composites, In Proceedings of the seventeenth AIMTDR conference. India: R.E.C.Warangal, 53–56.

[26]Hoecheng ,H. Yen,S.B. Ishihara, T. and Yen, B.K.(1997), Fundamental turning characteristics of tribology favored graphite/aluminium alloy composites, Comp. A, 28A:813–818.

[27] Yuan, Z.J. and Dong Geng, S. (1993), Ultra precision machining of SiCw/Al composites, Ann CIRP, 42 (1):107–109.

[28] Tomac, N. Tonnessen. T. and Rasch, F.O. (1992), Machinability of particulate aluminium matrix composites, Ann CIRP, 41(1):55–58.

[29] Madhav .S. Phadke,(1989), Quality Engineering Using Robust Design, Prentice Hall, New Jersey.

[30] Ross, P.J. (1996), Taguchi techniques for quality engineering: loss function, orthogonal Experiments, parameter and tolerance design, 2^{nd} ed., McGraw-Hill, NY.

[31] Anjaiah Devineni and Avinash .M. Chincholkar, (2009), "AWSJ cutting of ceramics – An experimental study of the effect of process parameters on the surface roughness using DOE," 9th Pacific Rim International Conference on Water Jetting Technology.

[32] Ghani,J.A. Choudhury and Hassan, H.H. (2004), "Application of Taguchi method on the Optimization of end milling parameters," J. mater process Technol, 145:84-92.

.

[33] Palanikumar, K.and Karthikeyan, R. (2007), Assessment of factors influencing roughness on the machining of Al/SiC particulate composites", Materials & Design ,28:1584-1591

.

[34] Syed Altaf Hussain, Pandurangadu,V.and Palanikumar, K.(2010)," Surface roughness analysis in machining of GFRP composites by carbide tool (K_{20})", European journal of scientific research, 41 (1):84-98.

[35] Juneja, B.L. and Nitin Seth, (2003), Fundamental of metal cutting and machine tools, New Age International Publishers, Delhi, India

[36] Krishnamurthy, K. Venkatesh, J.and Suresha, B.(2013), Study on Material Removal Rate and Surface Roughness in Machining of TiB_2 Reinforced Aluminum 6063 Composites: A Taguchi's Approach, International Journal of Advanced Materials Science, 4(1): 43-59.

[37] Krishnamurthy, K. and Venkatesh, J. (2013), Assessment of Surface Roughness and Material Removal Rate on Machining of TiB_2 Reinforced Aluminum 6063 Composites: A Taguchi's Approach, International Journal of scientific Research publications,3(1): 1-6

AUTHORS

First Author – K.Krishnamurthy: He earned his Undergraduate degree in Mechanical Engineering in the 1990 from University of Mysore, Karnataka, post graduate degree in Advanced Manufacturing Engineering from KREC (NITK) Surathkal, University of Mangalore in 1995. Presently working as Associate Professor in the department of Mechanical Engineering, Adichunchanagiri Institute of

Technology, Chikmagalur, Karnataka, India. He has published 7 papers in National/ International conferences/journals. He is a life Member of Indian Society for Technical Education. E-mail: kkm.aitmech@gamil.com , kkm_aitmech@yahoo.co.in

Second Author – Dr. J. Venkatesh: He earned his Undergraduate degrees in Science and Automobile Engineering form University of Mysore in the year 1980 & 1984 respectively, post graduate degree from MIT, Madras-44, (Anna University) in 1989 and Doctoral degree in Mechanical Engineering (Composite materials) from University of Mysore in 1998. Presently working as Professor and Head, Department of Automobile Engineering, PES College of Engineering, Mandya, Karnataka, India. He is a life Member of Indian Society for Technical Education and FIE. He has published 22 papers in National/International conferences/journals. E-mail: jvenkateshpesce@gmail.com

Correspondence Author – K.Krishnamurthy,
E-mail:kkm.aitmech@gamil.com kkm_aitmech@yahoo.co.in
Contact Number: +919480736527.