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Research Paper

An Investigation on Surface Roughness in Turning Hybrid MMC (Al/SiCp/B_4Cp) by Taguchi Experimental Technique and S/N-ANOVA Analysis

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In this paper an attempt has been made to discuss the application of Taguchi experimental technique and the S/N-ANOVA analysis approach for optimizing the surface roughness in machining of fabricated aluminium hybrid metal matrix composite (MMC) (Al/SiCp/B_4Cp) during continuous turning of composite rods by Poly Crystalline Diamond (PCD 1600 Grade) inserts. The volume fraction of SiCp is 10% and that of B_4Cp is 5%. Machining of Hybrid MMC's with good surface finish is very difficult and 'open' literature survey proves that PCD tools are best suited. The experiments have been conducted using Taguchi's experimental design technique. The machining parameters used are cutting speed, feed and depth of cut. The effect of machining parameters on surface roughness is evaluated and the optimum cutting condition for minimizing the surface roughness is determined using S/N ratio. Analysis of Variance technique is used to find the most influencing machining parameter for surface roughness. It is concluded as feed followed by cutting speed for the hybrid aluminium metal matrix composite (Al/SiCp/B_4Cp).

Key Words: Machining; Hybrid MMC PCD Surface Roughness; Taguchi Method; S/N Ratio; ANOVA

1. Introduction

Metal matrix composites (MMC) are materials that are fabricated by the combination of a tough metal matrix with reinforcement of hard ceramic particulate material. Generally incorporation of carbide particles enhances the properties like hardness, adhesiveness, abrasiveness, diffusion wear resistance, thermal properties, and stiffness. By choosing the particle shape, size and distribution the mechanical properties can be fine tuned to the requirement. Hybrid composites are unique materials manufactured by two or more reinforcing elements of different properties in to the base alloy to improve the thermal and mechanical properties. For the past few years the usage of Al-Carbide composites have been increased in the industries of aerospace, automobile and advanced arm systems such as satellite bearing, inertia navigation system, and laser reflector [1, 2]. Due to the addition of reinforcing materials, which are normally harder and stiffer than matrix, machining of these MMC become significantly more difficult than those of conventional materials [2]. Despite their higher specific properties the non-homogeneous and anisotropic nature combined with the abrasive reinforcements render their machining difficult. The work piece may get damaged and the cutting tools experience high wear rates, which may lead to an uneconomical machining. The machinability of a

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particular material can be evaluated by assessing any one of the following five parameters:

(i) surface finish of test specimen, (ii) tool life or tool wear, (iii) cutting force requirement, (iv) electrical power requirement, and (v) cutting temperature. Among different cutting tool materials like HSS, carbide tool, PCD tool 'open' literature survey proves that poly-crystalline diamond (PCD) tool is more suited and has significant effect on cutting performance [6].

2. Machine, Tool Used, Material and Experimental Methods

2.1 Machine

The dry turning operation is carried out using a medium duty lathe of following specification

Distance between centers	:	4.5 feet
Main spindle power	:	2 kw
Feed type	:	Cross & longitudinal
Drive system	:	Gear
Head stock	:	3 jaw chuck

2.2 Cutting Tool Inserts

After doing a quick review (Table 3) over different grades of the PCD tool, for the dry turning of hybrid MMC material, PCD 1600 is chosen.

2.3 Material

The work material used for the present investigation is aluminium alloy (Al 356) with particle reinforcements of 10% SiCp and 5% B4C. The grain size varies from 20 µm to 50 µm.This composite material is fabricated in the form of cylindrical rods of diameter 60 mm and length 330 mm. The rod is manufactured in-house by stir-casting process. The chemical composition of the base material used in this work is given in Table 4. The microstructure of the specimen is shown in Fig. 1.

2.4 Experimental Method

In this paper the experiment is designed by Taguchi method. The optimization of cutting parameters in machining of hybrid MMC is done by Signal-to-Noise ratio also called as (S/N) ratio method which is very attractive and effective method to deal with responses influenced by number of variables. In this method, main parameters are assumed to have influence on process results, which are located at different rows in a designed orthogonal array (L-27). This method is useful for studying the interactions between the parameters and it also is a powerful design of experiments tool, which provides a simple, efficient and systematic approach to determine optimal cutting parameters. Compared to the conventional approach of experimentation, this method reduces drastically the number of experiments that are required to model the response functions [17, 18]. Once the levels of each design parameter have been identified, analysis of the influence of machining parameters on surface roughness has been performed using the response table for S/N ratios, which indicates the response at each level of control factors. The optimum level of cutting parameters can be found from its corresponding S/N ratios. The analysis of variance is performed to find the significant parameters.

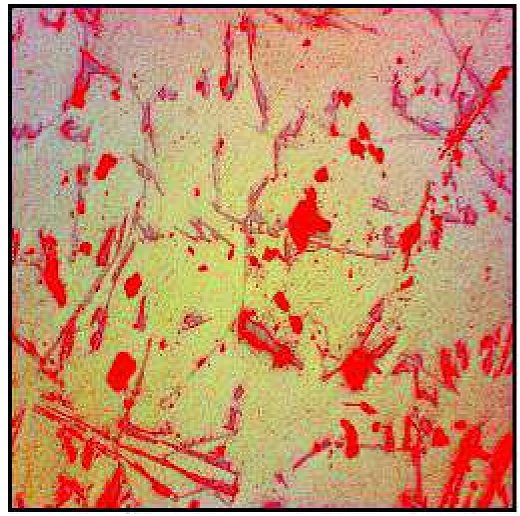

Fig. 1: Microstructure of Al-Metal Matrix Composite with10% SiC and 5% B4C particles

3. Experimental Details

Using Taguchi's orthogonal array the experiments are planned in the design of experiments (DoE), which helps in reducing the number of experiments. The

Table 1: Specification of the tool holder and PCD insert

Characteristic	Specification
Substrate	Tungsten Carbide
Insert PCD	1600 grade
Nose radius	0.8 mm
Shank size	25 mm x 25 mm
Tool holder specification	PCLNR 25 25 M 12
Product name	Diapax

experiments were conducted according to orthogonal array L27. In the present investigation the three cutting parameters are selected as cutting speed (v), feed (f) and depth of cut (d). Since the considered factors are multi-level variables and their outcome effects are not linearly related, it has been decided to use three level tests (Table 5) for each factor. Taguchi's orthogonal array [18] of L27 is most suitable for this experiment as shown in Table 2 and the S/N ratio results and analysis as shown in Tables 6, 7 and 8.

Table 2: Taguchi's experimental design (L27) and results

S.No.	Cutting speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	Surface Roughness (Ra) Microns				Values of S/N ratios
				Trial 1	Trial 2	Trial 3	Average	
1	1	1	1	1.93	1.76	1.84	1.84	–5.318
2	1	1	2	1.72	1.98	1.89	1.86	–5.420
3	1	1	3	2.02	1.83	1.88	1.91	–5.628
4	1	2	1	2.28	2.73	2.78	2.60	–8.321
5	1	2	2	2.67	2.96	2.55	2.73	–8.729
6	1	2	3	2.77	2.82	2.87	2.82	–9.006
7	1	3	1	3.53	3.22	3.46	3.40	–10.645
8	1	3	2	3.74	3.54	3.38	3.55	–11.020
9	1	3	3	3.76	4.03	3.99	3.93	–11.817
10	2	1	1	1.86	2.06	1.99	1.97	–5.897
11	2	1	2	2.11	1.86	2.26	2.08	–6.375
12	2	1	3	1.95	2.05	2.29	2.10	–6.451
13	2	2	1	2.69	2.91	2.79	2.80	–8.937
14	2	2	2	2.77	3.18	3.25	3.07	–9.754
15	2	2	3	3.25	3.46	3.67	3.46	–10.792
16	2	3	1	4.17	4.32	4.43	4.31	–12.685
17	2	3	2	4.48	4.19	4.75	4.47	–13.024
18	2	3	3	4.55	4.90	4.19	4.55	–13.172
19	3	1	1	2.14	2.61	2.24	2.33	–7.380
20	3	1	2	2.15	2.69	2.79	2.54	–8.161
21	3	1	3	2.31	3.08	2.38	2.59	–8.344
22	3	2	1	3.36	3.58	3.53	3.49	–10.859
23	3	2	2	3.45	3.78	3.88	3.70	–11.382
24	3	2	3	3.95	3.93	3.36	3.75	–11.496
25	3	3	1	4.48	4.80	5.02	4.89	–13.782
26	3	3	2	5.12	4.86	5.02	5.10	–13.982
27	3	3	3	5.16	5.22	5.06	5.15	–14.231

Table 3: Characteristics of PCD inserts

Characteristics	Grade 1300	Grade 1500	Grade 1600
Volumetric % of diamond	92	94	90
Transverse rupture strength (GPa)	1.4	0.85	1.7
Elastic modulus (GPa)	950	1100	850
Average particle size (ìm)	5	25	4
Compressive strength (GPa)	7.5	7.5	7.5
Knoop hardness (kg/mm^2)	4000	4000	4000

Table 4: Chemical composition of the aluminum alloy (Al 356) matrix

Element	% weight	Element	% weight
Si	7.98	Ti	0.01
Cu	0.88	Ni	0.01
Mg	0.64	Zn	0.10
Mn	0.01	Pb	0.046
Fe	0.11	Sn	0.036
Cr	0.034	V	0.005
Zr	0.001	Al	***

*** The remaining % is aluminum

Table 5: Machining parameters and their levels

Control parameters	Unit	Symbol	Levels		
			1	2	3
Cutting speed	m/min	v	90	140	220
Feed rate	mm/rev	f	0.1	0.2	0.32
Depth of cut	mm	d	0.5	0.75	1.0

4. Results and Discussion

Study of the surface roughness characteristics of Aluminium metal matrix composites require more analysis due to the presence of abrasive phase in the reinforcing SiC and B4C particles. The presence of these ceramic particles in the metal matrix increases hardness and strength. When it is machined, discontinuous chips are produced, resulting in different machining characteristics.

4.1 Effect of Control Parameters on Surface Roughness

In Taguchi method, the term 'signal' represents the desirable value and 'noise' represents the undesirable value. The objective of using S/N ratio is a measure of performance to develop products and processes insensitive to noise factors [18]. The S/N ratio is calculated using the formula, $S/N = -10 \log_{10} \{1/3 \times (R_1^2 + R_2^2 + R_3^2)\}$ where 3 indicates the number of trials and R_1, R_2, R_3 are the observed values on those trials.

The S/N ratio indicates the degree of the predictable performance of a product or process in the presence of noise factors. Process parameter settings with the highest S/N ratio always yield the optimum quality with minimum variance. The S/N ratio for each parameter level is calculated by averaging the S/N ratios obtained when the parameter is maintained at that level. Table 6 shows the S/N ratios obtained**.** And also the response characteristics are found out using average surface roughness values at all the three levels as shown in Table 7. As shown in Table 6 & 7 and Figs. 2, 3 the feed is a dominant parameter on the surface roughness followed by cutting speed. The depth of cut had a lower effect on the surface roughness. Lower surface roughness is always preferred. The quality characteristic

Table 6: Response table for S-N ratios

Levels	Cutting speed	Feed rate	Depth of cut
1	–8.434	–6.553	–9.314
2	–9.676	–9.920	–9.761
3	–11.067	–12.707	–10.104
Δ	2.633	6.154	0.79
Rank	II	I	III
Optimal parameters	90 m/min	0.1mm/rev	0.5 mm

Table 7: Response table for means of surface roughness

Levels	Cutting speed	Feed rate	Depth of cut
1	2.738	2.136	3.069
2	3.199	3.156	3.223
3	3.715	4.360	3.360
Δ	0.977	2.224	0.291
Rank	II	I	III
Optimal parameters	90 m/min	0.1mm/rev	0.5 mm

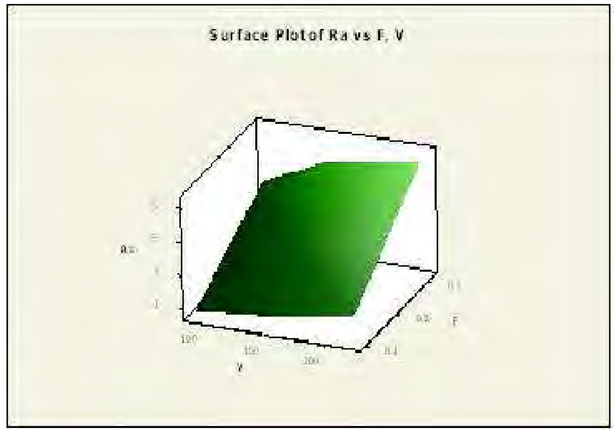

Fig. 2: Surface plot of Surface roughness *vs* feed and cutting speed

considered in the investigation is lower-the-better characteristics. The surface roughness observed at lower cutting speed is more than the surface roughness observed at higher cutting speed. In the present investigation, when the cutting speed is set at 90 m/min, the surface roughness is minimized. From the experimental results, it is observed that at low depth of cut the surface roughness is minimal. Contrary to the cutting speed and depth of cut, the maximum S/N ratios, which were the values of minimum surface roughness, were obtained at the lowest level for feed. This is the fact that, the increase in feed increases the heat generation and tool wear, which results in higher surface roughness. The increase in feed also increases the chatter, and it produces incomplete machining of work piece, which leads to higher surface roughness. The results proved that the roughness of the machined surface is highly influenced by the feed. Based on the above discussions and also evident from Figs. 2, 3, and the

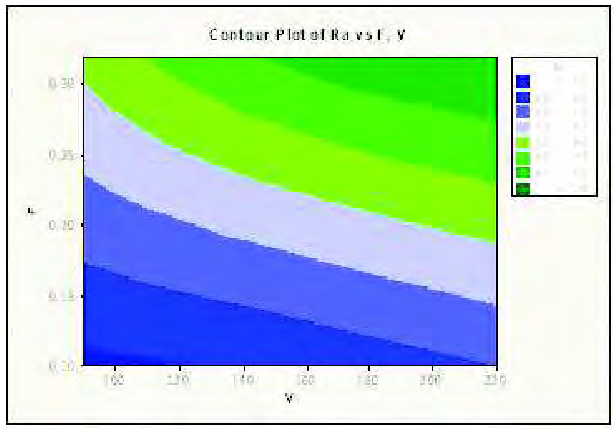

Fig. 3: Contour Plot of Surface roughness *vs* feed and cutting speed

Tables 6, 7 the optimum conditions for the surface roughness could be established.

It is emphasized that these conditions only

Table 8: Analysis of variance for Ra

Source	Degree of freedom	Seq SS	Mean square	F	P	Percentage contribution
Cutting speed (v)	2	4.4064	2.2032	61.51	0.00	15.694
Feed rate (f)	2	22.5675	11.2837	315.05	0.00	80.397
Depth of cut (d)	2	0.3861	0.1930	5.39	0.013	1.375
Error	20	0.7163	0.0358			2.551
Total	26	28.0762				

provide best surface roughness among the cutting conditions selected. Table 8 shows the results of analysis of variance (ANOVA) for the surface roughness. The percentage of error is 2.551%, which is lesser than 15% (allowable value) and hence acceptable. The ANOVA table validates that all the cutting parameters are significant at 95% confidence level. The optimal cutting parameters and the percentage contribution may be established as follows

Cutting speed (v): 90 m/min	& Percentage contribution: 15.694%
Feed rate (f) : 0.1 mm/rev.	& Percentage contribution: 80.379%
Depth of cut (d): 0.5 mm	& Percentage contribution: 1.375%

5. Conclusions

The surface roughness in the turning process has been investigated for machining of aluminium (Al 356) MMC with reinforcements of ceramic particles with 10% by weight of SiC and 5% by weight of B4C under different cutting conditions with a PCD tool of 1600 grade using Taguchi's orthogonal array. Based on the experimental and analytical results, the following conclusions are drawn

a) With the help of Taguchi method the effect of machining parameters on the surface roughness has been evaluated and optimal machining conditions would be arrived at to minimize the surface roughness.

b) It is found that the feed rate is the dominant parameter for surface roughness followed by the cutting speed. Compared to other parameters the depth of cut shows minimal effect on surface roughness.

c) The results of the analysis of variance revealed that minimal surface roughness could be arrived at significantly for hybrid composite turning operations through the specified machining conditions: v = 90 m/min, f = 0.1 mm/rev and d = 0.5 mm.

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