Optimization of Machining Parameters in AA7050/B_4C MMC by Taguchi Method

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Abstract: **Every manufacturing sector seeks to produce a variety of products in a short amount of time. Present work is focused at machining parameters optimization during CNC turning of boron carbide reinforced with AA7050 alloy by Taguchi method of experimental design. The Taguchi L_{16} design has been selected for the experimental method. In this investigation, the reinforced alloy is turned using a tool with PCD inserts while it is dry. To observe the impact on the surface roughness and rate of material removal, cutting parameters including cutting speed, feed, depth of cut and reinforcement of boron carbide are varied. According to Taguchi's investigation, surface roughness is more sensitive to feed whereas material removal rates are highly influenced by cutting speed.**

Keywords— Metal matrix composite, surface roughness, material removal rate, ANOVA

1. INTRODUCTION

When compared to unreinforced alloys, aluminium alloys reinforced with ceramic materials have better qualities such as specific strength, superior resistance to corrosion and wear, higher hardness, lower coefficient of thermal expansion, and higher resilience to thermal shock [1, 3-4]. Materials with superior mechanical characteristics and lightweight are in high demand in the aerospace and automotive industries. Therefore, researchers concentrated on creating and characterizing aluminium metal matrix composites (AMMCs) with reinforcement from ceramic particles. [1-2, 5-6]. The AMMCs are difficult to machine and have a rough surface, which increases tool wear rate. This is due to the strong ceramic reinforcements present in the AMMCs [7-9, 11]. Engine blocks, cylinders, and pistons are examples of automotive components that demonstrate the value of having appropriate machining process parameters. It was found that for quality parameters such as surface roughness (Ra) and material removal rate (MRR) on turning of A356/5 wt.% SiCp, feed rate is the most important factor followed by the depth of cut and cutting speed [8]. According to Pradhan and Sahoo [10] when turning SiC reinforced AMMCs with uncoated carbide inserts, feed is the most important factor affecting the surface finish, followed by cutting speed and depth of cut. Ciftci et al. [11] discovered that uncoated carbide tools produced better surface roughness values than coated carbide tools during dry machining of Al 2014/SiC MMCs. Reddy et al. [12] conducted research on the machining capabilities of composites made of aluminium and discovered the most important influencing factors when turning the composite specimens. MCDM techniques were used in their study to find the optimal combinations for machining. The current analysis focuses on the turning performance of AA7050/B_4C AMMC in terms of Ra and MRR when using polycrystalline diamond tool inserts in a dry machining environment.

2. FABRICAION AND EXPERIMENTATION

2.1 Fabrication of Metal Matrix Composites

The stir casting technique was used to create the metal matrix composites. Table 1 shows the chemical composition of AA7050, which is used as the base metal. The aluminium metal matrix composites are created using an AA7050 alloy matrix and B_4C proportions of 0, 3, 6, and 9 weight percent. In this step, the AA7050 alloy composition pieces were placed in the furnace while boron carbide (B_4C) particles were weighed and heated. The melting took place in an electrical resistance heating furnace at around 850°C. Following that, various weight ratios of preheated B_4C particles were physically poured into the furnace. To achieve uniform distribution of the reinforcement particles in the matrix alloy, the stirrer speed and time period in this analysis were set at 650 revolutions per minute and 10 minutes, respectively. The stirrer RPM was then gradually lowered after the composite combination mixture was ready. The combination was then fed through the die to create the composite specimens, which had 130 mm of length and a 20 mm thickness. Figure 1 depicts the prepared AA7050/B_4C composite specimens.

Table 1 Chemical composition of AA7050 alloy

Element	Weight (%)
Zn	6.40
Cu	2.450
Mg	2.360
Zr	0.13
Al	Remaining

Fig 1. Specimens of AA7050 reinforced with B_4C

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The cutting tool is an insert made of polycrystalline diamond. The first step in creating specimens with a uniform diameter on the lathe is rough turning on the manufactured ingots. Pilot studies were first carried out to determine the range of feeds and speeds for good surface quality and material removal rate based on the available feeds and speeds on the CNC lathe. Taguchi's L_{16} orthogonal array is chosen for the experiment design after the levels for cutting speed, feed, and depth of cut and B_4C reinforcement have been determined. Table 2 lists the factors and the levels that were chosen.

Table 2. Factors and levels selected

S.No	Factor	Unit	Levels of Factors			
			L-1	L-2	L-3	L-4
1	Cutting speed, S	m/min	150	325	450	710
2	Feed, F	mm/rev	0.05	0.10	0.15	0.20
3	Depth of cut, D	mm	0.1	0.3	0.5	0.7
4	% of B_4C Reinforcement, R	%	0	3	6	9

2.2 . Plan of Experimentation

The CNC lathe machine depicted in Fig. 2 is to be used for the turning experiments on the aluminum-based composite material AA7050/B_4C. The tests on the work piece were conducted on CNC HYTECH CLT Machine. In this study turning of aluminium metal matrix composites, experiments were carried out by taking into account the key process factors including speed, feed, depth of cut, and B_4C reinforcement at 4 levels. According to the 4 level full factorial design 16 experiments were designed and conducted.

Fig 2. CNC HYTECH CLT 100

2.3 Surface Roughness

In this work, stylus type surface roughness instrument was used for the surface roughness measurement and it is shown in figure 3. Stylus type surface roughness measurement is used because of its easy availability and easy to operate. The average surface roughness (Ra) of 16 specimens was measured using the surface roughness measuring instrument Talysurf.

Fig 3. Stylus Type Surface Roughness Testing instrument

The Ra value which is measured from the stylus type surface roughness instrument for the given input parameters is shown in the table 3. Surface roughness is measured three times and the average value is taken. Table 4 shows a Taguchi analysis of S/N ratios of Ra results, which revealed that feed is highly responsible for surface roughness rank 1, while cutting speed, depth of cut, and B_4C reinforcement percentage are responsible for ranks 2, 3, and 4 respectively.

Table 3. Surface roughness values

Exp No.	S	F	D	R%	Ra
1	150	0.05	0.1	0	0.526
2	150	0.10	0.3	3	0.732
3	150	0.15	0.5	6	0.798
4	150	0.20	0.7	9	0.973
5	325	0.05	0.3	6	0.528
6	325	0.10	0.1	9	0.509
7	325	0.15	0.7	0	0.816
8	325	0.20	0.5	3	0.804
9	450	0.05	0.5	9	0.601
10	450	0.10	0.7	6	0.593
11	450	0.15	0.1	3	0.621
12	450	0.20	0.3	0	0.658
13	710	0.05	0.7	3	0.395
14	710	0.10	0.5	0	0.449
15	710	0.15	0.3	9	0.551
16	710	0.20	0.1	6	0.653

Table 4 Response table for S/N ratios of Ra

Level	S	F	D	R
1	2.622	5.905	4.821	4.484
2	3.769	5.017	4.267	4.203
3	4.184	3.260	3.808	3.937
4	5.975	2.367	3.653	3.926
Delta	3.354	3.537	1.169	0.559
Rank	2	1	3	4

The main effects plots used to identify the optimal parameters and most significant factors in the machining process by a graphical representation of the influencing factors. Figure 4 displays main effects plots for data means, and the surface roughness main effects plot demonstrates that

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the feed rate has the greatest impact on surface roughness followed by cutting speed, depth of cut and percentage of reinforcement of composites. At higher cutting speed and lower feed rate better surface roughness was achieved.

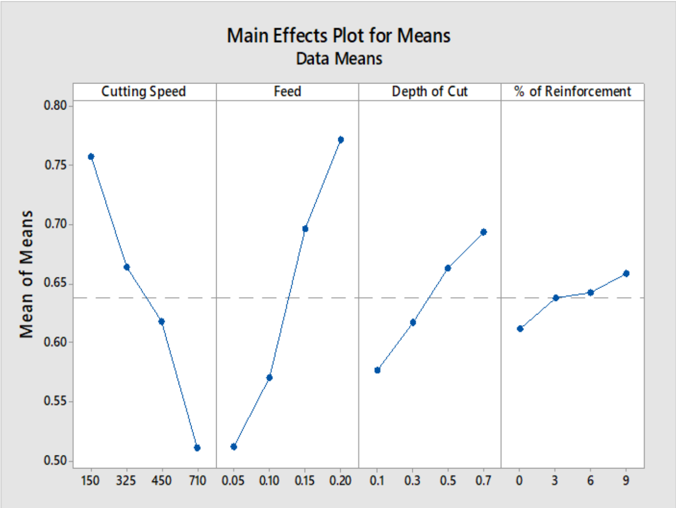

Fig 4. Main effects graph of surface roughness

2.4 *Analysis of Variance (ANOVA) in Ra*

ANOVA is used to identify different sources of variance and their impact on the assessment of surface roughness, and the results are presented in Table 6. Table 7 displays the R-square and adjusted R-square values for the ANOVA model. The regression equation obtained to measure surface roughness (Ra) is given as equation 1. The regression equation for surface roughness Ra is as follows:

$$Ra = 0.4874 - 0.000432\,S + 1.808\,F + 0.1984\,D + 0.00479\,R \quad \text{---------} \quad (1)$$

Ra MMC	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Regression	4	0.32315	0.08079	28.96	<0	
Cutting Speed	1	0.124	0.124	44.46	0	35.05
Feed	1	0.16353	0.16353	58.63	0	46.22
Depth of Cut	1	0.03148	0.03148	11.29	0.006	8.9
% of Reinforcement	1	0.00413	0.00413	1.48	0.249	1.17
Error	11	0.03068	0.00279			8.67
Total	15	0.35383				100

Table 6. ANOVA table for Ra

Table 7. Model Summary - ANOVA of Ra

S	R-sq	R-sq(adj)
0.0528141	91.33%	88.18%

2.5 *Material Removal Rate*

The larger-the-better quality characteristic is chosen and the signal-to-noise ratio is determined and presented in Table 8 using the formula $-10\,\log_{10}[1/(MRR)^2]$. From the response Table 9 and main effects plot figure 5, it is clear that cutting speed is critical for high MRR.

Table 8. Material Removal Rate values

Exp. No.	S	F	D	% R	MRR (g/sec)
1	150	0.05	0.1	0	0.0296
2	150	0.10	0.3	3	0.2361
3	150	0.15	0.5	6	0.5300
4	150	0.20	0.7	9	0.6208
5	325	0.05	0.3	6	0.2250
6	325	0.10	0.1	9	0.3214
7	325	0.15	0.7	0	0.5235
8	325	0.20	0.5	3	0.5725
9	450	0.05	0.5	9	0.5980
10	450	0.10	0.7	6	0.6640
11	450	0.15	0.1	3	0.4471
12	450	0.20	0.3	0	0.5158
13	710	0.05	0.7	3	0.7539
14	710	0.10	0.5	0	0.6057
15	710	0.15	0.3	9	0.7566
16	710	0.20	0.1	6	0.7571

Table 9. Response table for S/N Ratios of MRR

Level	S	F	D	R
1	-13.192	-12.613	-12.461	-11.575
2	-8.320	-7.577	-8.417	-6.707
3	-5.191	-5.138	-4.795	-6.111
4	-2.912	-4.288	-3.943	-5.222
Delta	10.280	8.324	8.517	6.353
Rank	1	3	2	4

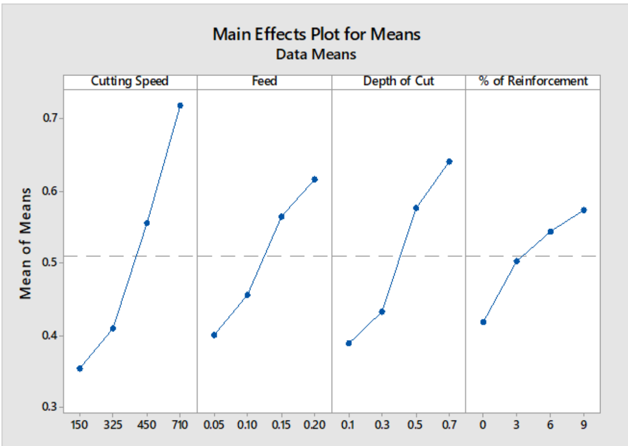

Fig 5. Main effects graph of material removal rate

2.6 *Analysis of Variance in Material Removal Rate*

The results of an ANOVA were presented in Table 11 to show the different sources of variation and how they affected the measurement of material removal rate. Table 12 displays the R-square and adjusted R-square values for the ANOVA model. The regression equation obtained to measure the material removal rate (MRR) is given as equation 2.

Table 11. ANOVA of MRR

MRR MMC	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Regression	4	0.63495	0.15874	57.48	0	
Cutting Speed	1	0.30866	0.30867	111.76	0	46.39
Feed	1	0.11318	0.11318	40.98	0	17.01
Depth of Cut	1	0.16143	0.16143	58.45	0	24.26
% of Reinforcement	1	0.05167	0.05167	18.71	0.001	7.77
Error	11	0.03038	0.00276			4.57
Total	15	0.66533				100

Table 12. Model Summary – ANOVA of MRR

S	R-sq	R-sq(adj)
0.0525532	95.43%	93.77%

The regression equation for material removal rate MRR is obtained as MRR = -0.2125 + 0.000681 S + 1.505 F + 0.4492 D + 0.01694 R --------- (2)

3. Conclusion

From the tests carried out using the Taguchi design and analysis of variance the following conclusions can be made.

1. Taguchi method predicted that the surface roughness is more influenced by the feed rate and it is the major factor.
2. The percentage contribution of feed, cutting speed, depth of cut and % of reinforcement on surface roughness was 46.22%, 35.05%, 8.9% and 1.17% respectively.
3. Taguchi method predicted that the material removal rate is more influenced by the cutting speed and it is the major factor which contributes the improvement.
4. The percentage contribution of cutting speed, depth of cut, feed and % of reinforcement on material removal rate was 46.39%, 24.26%, 17.01% and 4.57% respectively.
5. ANOVA is performed to find the significance and % contribution of input parameters on the output parameters and found that feed is the highly influencing factor for Ra and speed is the highly influencing factor for MRR.
6. Regression analysis is done to find out the relationship between the factors and output responses.

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