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Experimental Study on Parameter Optimization of CNC End Milling for Composite Material LM6 Al/SiC_p

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***Abstract*— In this research work an attempt is made to access the effect of certain control parameters on both surface roughness and material removal rate in cnc end milling on the machinability of LM6/ SiCp metal matrix composites under wet cutting condition. Weight percentage of SiC_P in the metal matrix, cutting speed, depth of cut, feed & different diameter of end mill cutter are selected as the influencing parameters. To evaluate the output quality characteristics an experiment is performed on the five factors with three levels and Taguchi's Design of Experiment (DoE) with L_{27} orthogonal array. Analysis of Variance (ANOVA) is used to calculate percentage contribution of individual parameter to explain their influences on output performance characteristics.**

It was observed that most significant parameter is feed in surface roughness and depth of cut is in material removal rate, but it was also observed that higher weight percentage give a higher surface roughness & less material removal rate and one common input parameter end mill cutting tool's diameter play significant role in both surface roughness & maximum material removal rate. This experiment result will provide essential guidelines to the manufacturers.

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***Keywords*— Metal matrix composites, Taguchi, ANOVA, Surface roughness, Material removal rate**

I. INTRODUCTION

Composite materials are named as the 'materials of the future' in 1970 when they have been introduced in engineering applications [1]. Metal matrix composites (MMC) have become a large leading material in composite materials. The most common MMC material is an aluminum matrix reinforced with SiC particles [2]. Reinforced aluminium MMCs have received considerable attention due to their excellent engineering properties. These materials are known as the difficult-to-machine materials, because of the hardness and abrasive nature of reinforcement element like silicon carbide (SiC) particles [3]. Aluminium-based SiC particle reinforced MMC materials have become useful engineering materials due to their properties such as low weight, heat-resistant, wear-resistant and low cost [4]. Al/SiC particulate composites are increasingly being used for varieties of engineering applications from automotive to aircraft components. The common applications are bearings, automobile pistons, cylinder liners, piston rings, connecting rods, sliding electrical contacts, turbo charger impellers, space structures, etc [5].

There are numerous methods of manufacture of MMCs. Of these, the stir casting method is most popular due to its unique advantages. In this method the reinforcing particles are introduced into the melt and are stirred thoroughly to ensure their homogeneous mixing with the matrix alloy. The properties of the particle reinforced metal matrix composites produced this way are influenced to a large extent by the type, size and weight fraction of the reinforcing particles and their distribution in the cast matrix [6]. A problem with MMCs is that they are hard to machine due to the reason of high hardness of the reinforcement materials which in mostly cases are significantly harder than the commonly used high speed steel cutting tools. MMCs reinforced with SiCp particles are extremely difficult to machine (turning, milling, drilling, threading) due to their extreme abrasive. As the presence of hard reinforcement particles makes them extremely difficult to machine as they lead to rapid tool wear [7].

Machinability studies of metal matrix composites has been receiving growing attention from investigators because these studies have mainly focused on optimizing certain influencing parameters so that an output quality characteristic can be controlled. Mostly studies are on Al/SiC-MMC composite machining shows that minimizing the surface roughness because that is very difficult to be controlled.

In the present research work an experiment study is made on parameter optimization of end milling for MMCs composite material LM6 Al/SiC_p under wet cutting condition by using some statistical technique for design of experiments(DoE). Weight percentage of SiC, cutting speed, feed, depth of cut and diameter of end mill cutting tool were chosen as the influencing control parameters and a taguchi's orthogonal array L_{27} design of experiments was carried out to collect the experimental data and to analyze the effect of these parameters on surface roughness and material removal rate.

II EXPERIMENTAL PROCEDURE

Fabrication of MMCs

The Metal matrix composites (MMCs) used in present study was carried out with LM6 Aluminum alloy reinforced with silicon carbide particles of mesh size 200 with 5%, 10%, and 15% weight manufactured through stir casting machine is used for experimentation. The composition of LM6 is tabulated in Table1.

TABLE 1: CHEMICAL COMPOSITION (LM6)

Elements	Al	Si	Cu	Mn	Mg	Fe	Zn	Cr
%age	87.33	10.41	0.14	0.35	0.28	0.98	0.38	0.02
Elements	Ni	Ti	Ca	Pb	V	P	As	
%age	0.01	0.02	0.01	0.01	0.01	0.001	0.008	

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To prepare the specimens the LM6 aluminum alloy was melted in an electric resistance furnace having a clay graphite crucible. The melt was mechanically stirred after addition of silicon carbide particles of mess 200 micron. The processing of the composite was carried out at a temperature of 640^{o}C with a stirring speed of 400 rpm in order to disperse the particles in the melt. The melt was poured into sand mold. The dimension of the work piece was rectangle block (100mm × 100mm × 10mm).

III PLAN OF EXPERIMENTATION

The experiments of end milling process on Aluminium based composite material LM6 Al/SiC are to be performed on Jyoti VMC 430 vertical machine centre shown in figure 1. It is installed in AVTS Hi-Tech Training Centre, Tarsali, Vadodara.

Figure-1: Jyoti VMC 430

The machining length was approximately 100mm. After performing the machining process, the surface roughness was measured using a HOMMEL surface roughness tester at MS university, vadodara shown in figure-2.

Figure-2: HOMMEL surface roughness tester

It was done at seven different locations along machining length and the mean value of these seven reading was used for the purpose analysis.

In this work the end mill cutting tools are made up of solid carbide tool of different diameters are 6mm, 8 mm & 10 mm shown in figure 3.

Figure 3: Solid carbide end mill with different diameters

IV TAGUCHI'S TECHNIQUE

In the globalized market, manufacturing companies have to counter the challenges in producing high quality products while simultaneously improving the processes with a significant slash in time and cost. One of the most efficient tools to counter the challenge is Taguchi method [8]. Taguchi Method was proposed by *Dr. Genichi Taguchi* in the year 1950. Taguchi defines the quality of a product, in terms of the loss to society caused by a product during its life cycle [9]. Taguchi's technique shown in figure-4 is a powerful tool in quality optimization. Taguchi's technique makes use of a special design of orthogonal array (OA) to examine the quality characteristics through a minimal number of experiments. Taguchi proposed the experimental design, which involves orthogonal arrays to organize the parameters affecting the process and the levels that should be varied [10].

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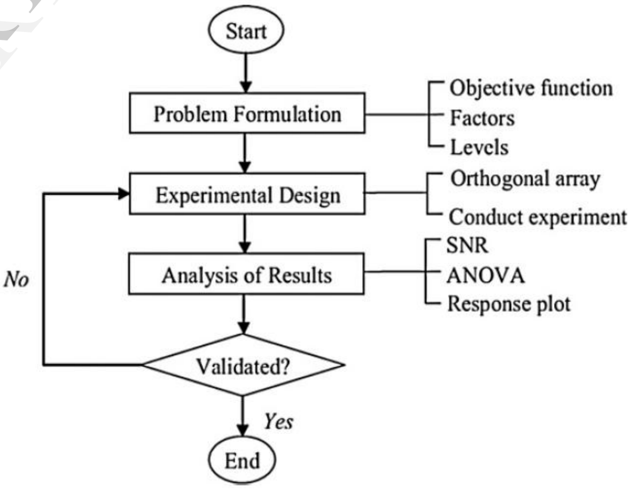

Figure-4: Taguchi method flowchart [11]

The orthogonal array design reduces number of experimental runs in order to obtain the best optimal solution. The numbers of influencing parameters running on experimental are based on Orthogonal Array (OA), which is analyzing data, identifying the optimal condition and conducting the confirmation runs [12].

The experimental results based on the orthogonal array are then transformed into S/N ratios to evaluate the performance characteristics. The S/N ratio transforms several repetitions into one value which reflects the amount of variation present and the mean response. There are several S/N ratios available depending on the type of characteristic: continuous or discrete [13]. Two of the applications in which the concept of S/N ratio is useful are the improvement of quality through variability reduction and the improvement of measurement [14].

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The S/N ratio characteristics can be divided into three categories when the characteristic is continuous:

Smaller-is-the-better (Minimize):

$$S/N = -10log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \qquad (1)$$

Larger-is-the-better (Maximize):

$$S/N = -10log\left(\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i^2}\right) \qquad (2)$$

Nominal-is-the-best:

$$S/N = 10log\left(\frac{1}{n}\sum_{i=1}^{n} \frac{\bar{y}}{s_y^2}\right) \qquad (3)$$

Where n is number of replications of each experiment, y_i represents the experimentally observed value of ith experiment, $\bar{y}$ is the average of observed and s_y^2 is the variance of y.

In this present work Taguchi's Design of Experiments is used to design the orthogonal array L_{27} for 5 control parameters varied through 3 levels. The control parameters and their levels chosen are shown in Table 2.

TABLE 2: CONTROL PARAMETER & THEIR LEVELS

Control Parameter	**Symbol**	**Levels**		
		1	**2**	**3**
SiC (%)	A	5	10	15
Cutting Speed (rpm)	B	2500	3500	4500
Feed (mm/m.)	C	50	75	100
Depth of Cut (mm)	D	0.5	1	1.5
Cutter Dia (mm)	E	6	7	8

The various combinations of weight percentage of SiC, Cutting Speed, Feed, Depth of cut and diameter of cutting tool, based on orthogonal array L_{27} are presented in Table 3.

TABLE-3: COMBINATION OF CONTROL PARAMETER WITH ORTHOGONAL ARRAY L_{27}

Trial No.	**SiC% (A)**	**SPEED (B)**	**FEED (C)**	**DEPTH OF CUT(D)**	**Cutter Dia. (E)**
1	5	2500	50	0.5	6
2	5	2500	50	0.5	8
3	5	2500	50	0.5	10
4	5	3500	75	1	6
5	5	3500	75	1	8
6	5	3500	75	1	10
7	5	4500	100	1.5	6
8	5	4500	100	1.5	8
9	5	4500	100	1.5	10
10	10	2500	75	1.5	6
11	10	2500	75	1.5	8
12	10	2500	75	1.5	10
13	10	3500	100	0.5	6
14	10	3500	100	0.5	8
15	10	3500	100	0.5	10
16	10	4500	50	1	6
17	10	4500	50	1	8
18	10	4500	50	1	10
19	15	2500	100	1	6
20	15	2500	100	1	8
21	15	2500	100	1	10
22	15	3500	50	1.5	6
23	15	3500	50	1.5	8
24	15	3500	50	1.5	10
25	15	4500	75	0.5	6
26	15	4500	75	0.5	8
27	15	4500	75	0.5	10

ANALYSIS OF SURFACE ROUGHNESS:

Metal matrix composite LM6 Al/SiC workpieces subjected to straight grooving operation is shown in Figure 5.

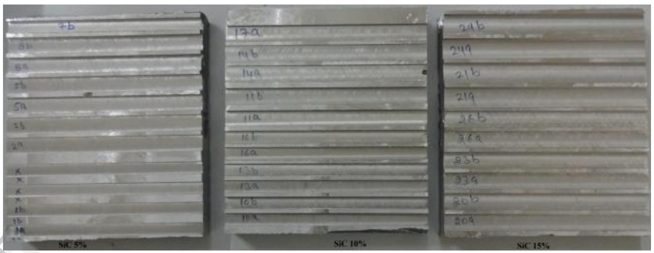

Figure 5: CNC End milled LM6 Al/SiC workpieces at different SiC%

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Each experiment has been repeated twice at same trial i.e sample size is two per trial and the average values of R_a has been recorded. The surface roughness (R_a) of the machined surface on the composite materials LM6 Al/SiC workpieces has to be minimize for a given set of input parameters. The surface roughness obtained is used to calculate the signal-to-noise (S/N) ratio to obtain the best setting of the parameters arrangement. Hence, the Smaller-is-the-better condition is chosen as given in Equation-1. Table 4 shows the S/N ratio for surface roughness values measured on the workpiece surface.

TABLE 4 : S/N RATIO FOR SURFACE ROUGHNESS

Trial No.	**Surface Roughness (µm)**		**S/N Ratio**
	First Sample (Ra1)	**Second Sample (Ra2)**	
1	1.390	1.506	-3.221
2	1.603	1.549	-3.951
3	1.536	1.611	-3.940
4	1.313	1.290	-2.289
5	1.907	2.084	-6.011
6	1.967	1.656	-5.192
7	1.521	1.369	-3.209
8	2.029	2.129	-6.358
9	1.686	1.446	-3.920
10	2.321	2.437	-7.531
11	1.781	2.359	-6.403
12	1.371	1.371	-2.743
13	2.593	2.644	-8.362
14	2.134	2.266	-6.852

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15	1.521	1.511	-3.616
16	1.253	1.154	-1.617
17	1.253	1.429	-2.565
18	1.476	1.437	-3.267
19	2.911	2.853	-9.195
20	2.749	2.770	-8.816
21	1.474	1.357	-3.027
22	1.906	1.427	-4.524
23	2.144	1.824	-5.980
24	1.686	1.686	-4.536
25	1.980	1.683	-5.284
26	2.200	2.066	-6.584
27	1.593	1.433	-3.608

The best levels of various parameters are identified by calculating S/N ratio, corresponding to every level of parameters of surface roughness, which are consolidated in Table 5.

TABLE 5: RESPONSE TABLE FOR SURFACE ROUGHNESS

Level/Parameter	SiC%	Speed	Feed	Depth of cut	Cutter Dia.
1	-4.232	-5.425	-3.733	-5.047	-5.026
2	-4.773	-5.262	-5.072	-4.664	-5.947
3	-5.728	-4.046	-5.928	-5.023	-3.761
Max - Min	1.496	1.38	2.195	0.382	2.186
Rank	3	4	1	5	2

From the response table of surface roughness, the optimal parameter levels are identified as, SiC of 5%, speed of 4500 RPM, feed of 50 mm/min, depth of cut of 1 mm and cutter diameter of 10mm. Hence, the optimum condition is represented as $A_1B_3C_1D_2E_3$. Along with optimal condition it is also observed that higher weight percentage of SiC give a higher surface roughness but cutter diameter play significant role to obtain good surface quality.
From the response table of surface roughness, the main effects plot is drawn, as shown in figure 6.

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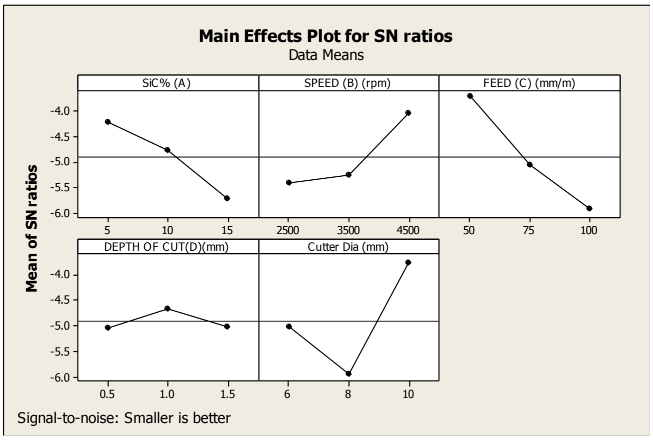

Figure 6: Main effects plot for surface roughness

ANOVA for Surface Roughness:
Analysis of variance (ANOVA) for Surface Roughness (R_a) is carried out using MINITAB software for experimental data obtained during CNC End Milling of three workpiece of composite material LM6 Al/SiC with varying weight percentage of SiC . To make the analysis simple and avoid longer procedure of carrying out general linear model of ANOVA and associated errors in calculation, Multi Factor ANOVA technique is used for determining the most contributing parameter on surface roughness with level of significance for individual parameters effect as well as interaction effect of combination of input parameters. It was seen that diameter of cutting tool is play a significant role in order to obtain good surface quality, due to that reason here taken interaction with other control parameters. Analysis of variance is performed and the outcomes are tabulated in Table 6 for surface roughness (R_a).

From the ANOVA table it is evident that the Feed Rate is the most significant control parameter contributing by 19.61 %, followed by cutter diameter by 19.3%. The contribution of depth of cut towards surface roughness is negligible.

TABLE 6: ANOVA FOR SURFACE ROUGHNESS

Factor	DOF	SS	MSV= SS/DF	F	P	% Contri bution
SiC%	2	10.3269	5.1635	10.41	0.026	9.19
SPEED	2	10.2313	5.1157	10.32	0.026	9.11
FEED	2	22.0264	11.0132	22.21	0.007	**19.61**
DEPTH OF CUT	2	0.826	0.413	0.83	0.498	0.73
Cutter Dia	2	21.6727	10.8363	21.85	0.007	**19.3**
SiC%*Cutter Dia	4	18.5261	4.6315	21.85	0.026	16.5
SPEED* Cutter Dia	4	10.9619	2.7405	9.34	0.063	9.76
FEED* Cutter Dia	4	15.7183	3.9296	5.53	0.035	15
Error	4	1.9838	0.4959	7.92		1.76
Total	26	112.2734				

S = 0.704230 **R-Sq = 98.23%** R-Sq(adj) = 88.52%

Figure 7 shows the percentile contribution of various input control parameters over surface roughness values.

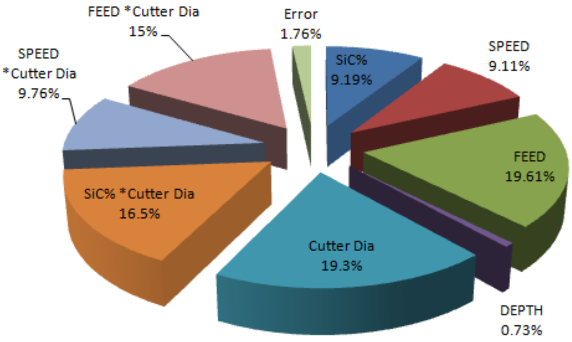

Figure 7: Percentile contribution of parameters for surface roughness

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ANALYSIS OF MATERIAL REMOVAL RATE

Material Removal Rate (MRR) can be calculated by two methods namely weight wise and volume wise. Weight wise method is more accurate in comparison of volume wise. But in this research work volume wise method is chosen due to numerous cut on the workpiece.

$$\text{MRR in mm}^3\text{/min} = \frac{(L \times D \times W)}{t}$$

Where L is the machining length, D is the depth of cut and W is the width of cut, and these dimension are measured with digital vernier caliper. In the above MRR relationship t is the machining time in minute.

For a given set of input control parameters, the amount of material removed has to be maximum. Hence, the Larger-is-the-better condition is chosen for this purpose as given in Equation. 2. Table 7 shows the S/N ratio of Material Removal Rate.

TABLE 7: S/N RATIO FOR MATERIAL REMOVAL RATE)

Trial No.	**Material Removal Rate(mm^3/min)** **First Sample (MRR$_1$)**	 **Second Sample (MRR$_2$)**	**S/N Ratio**
1	10371.735	9607.298	79.972
2	14229.633	14165.389	83.044
3	27218.789	27324.645	88.714
4	38724.204	43798.750	92.262
5	42776.607	43729.953	92.719
6	73578.148	80363.273	97.701
7	52309.072	46356.166	93.815
8	75851.223	75186.655	97.561
9	126094.086	131617.625	102.196
10	55851.279	51174.053	94.544
11	58308.467	59650.467	95.412
12	82174.231	86040.704	98.490
13	28880.679	31907.941	89.624
14	32027.021	24823.016	88.864
15	43917.247	43828.198	92.844
16	26113.607	25665.806	88.262
17	24653.086	17956.633	86.246
18	37549.494	36160.624	91.325
19	40820.963	35031.730	91.503
20	55921.722	65017.574	95.557
21	73298.629	76678.535	97.493
22	26384.463	27786.987	88.646
23	41277.708	36951.244	91.807
24	56423.543	59487.633	95.253
25	14266.027	14466.014	83.146
26	39417.904	45396.117	92.484
27	40625.256	36197.344	91.646

The best levels of various parameters are identified by calculating the average values of S/N ratio, corresponding to each level of parameters and are consolidated in Table 8.

TABLE 8: RESPONSE TABLE FOR MATERIAL REMOVAL RATE (Larger is better)

Level/Parameter	**SiC%**	**Speed**	**Feed**	**Depth of cut**	**Cutter Dia.**
1	**92**	91.64	88.14	87.82	89.09
2	91.73	**92.19**	93.16	92.56	91.52
3	91.95	91.85	**94.38**	**95.3**	**95.07**
Max - Min	0.26	0.55	6.24	7.49	5.99
Rank	5	4	2	1	3

From the response table of MRR, the optimal parameter levels are identified as, SiC% of 5 %, speed of 3500 RPM, feed of 100 mm/min, Depth of cut of 1.5 mm and cutter diameter of 10 mm. Hence, the optimum condition is represented as $A_1B_2C_3D_3E_3$ From the response table of MRR, the main effects plot is drawn, as shown in figure 8.

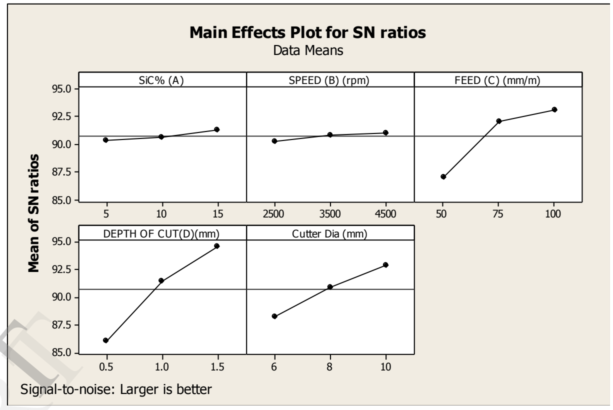

Figure 8: Main effects plot for Material Removal Rate

ANOVA forMaterial Removal Rate

Analysis of variance is performed and the outcomes are tabulated in Table 9 for material removal rate.

Table 9: ANOVA for Material Removal Rate(mm^3/min.)

Factor	**DOF**	**SS**	**MSV= SS/DF**	**F**	**P**	**% Contri bution**
SiC%	2	0.353	0.177	0.09	0.911	0.05
SPEED	2	1.405	0.702	0.38	0.707	0.20
FEED	2	196.903	98.451	52.97	0.001	**29.20**
DEPTH OF CUT	2	258.324	129.162	69.49	0.001	**38.31**
Cutter Dia	2	163.206	81.603	43.9	0.002	**24.20**
SiC%*C utter Dia	4	35.795	8.949	4.81	0.079	5.30
SPEED* Cutter Dia	4	5.817	1.454	0.78	0.591	0.86
FEED* Cutter Dia	4	5.061	1.265	0.68	0.641	0.75
Error	4	7.435	1.859			1.10
Total	26	674.299				

S = 1.36332 **R-Sq = 98.90%** R-Sq(adj) = 92.83%

Figure 9 shows the percentile contribution of various input control parameters over material removal rate values.

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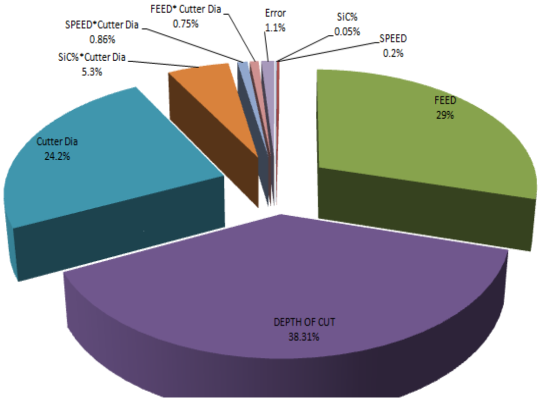

Figure 9: Percentile contribution of parameters for MRR

VI CONFIRMATORY TEST

The validity of optimum milling parameter levels hasbeen checked through confirmation experiments. The confirmation test values of both surface roughness and material removal rate are justified results of taguchi technique.

VII CONCLUSION

The research in the present study analyzes the influence of certain control parameters on both surface roughness and material removal rate and subsequently Taguchi's technique optimizes the control parameter levels within the range examined based on lower Ra and higher MRR. The outcomes from the experimental investigation and analysis for straight grooving operation.

1. For surface roughness, the optimal level of input parameters are SiC of 5%, speed of 4500 RPM, feed of 50 mm/min depth of cut of 1 mm and cutter diameter of 10 mm.
2. The best input control parameters are SiC% of 5 %, speed of 3500 RPM, feed of 100 mm/min, Depth of cut of 1.5 mm and cutter diameter of 10 mm.
3. The study also concluded that the effect of different percentage weight SiC on both surface roughness and material removal rate is negligible based on 95 % confidence level.
4. The study also observed that end mill tool cutter diameter play significant role in the both surface roughness and material removal rate.

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