Comparing and Optimizing the Process Parameters of two types of Al-MMC's in Turning

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Abstract - *Aluminium Metal Matrix Composites (Al MMC's) are the nearby elements which can replace conventional materials which are in use. Al MMC's, now gained the space in applications such as aerospace, structural members, automotive, ship buildings etc because of their properties like high strength to weight ratio, hardness, stiffness and corrosion resistance. This paper presents an investigation on machining (Turning) of Al (6061)-SiC and Al (6063)-SiC MMC's. SiC particles are reinforced in Al matrix with 0%, 10%, and 20% by weight. Taguchi's L27 orthogonal array experimentation was used to optimize the parameters of Al-SiC MMC's. The effect of parameters such as Speed, Feed, Depth of cut and Percentage of contribution on Metal Removal Rate and Cutting Force in turning was calculated. Signal to Noise ratio and ANOVA was used for finding significant parameter. Required comparisons are done between two Al MMC's. The experiments are conducted using HSS tool under dry condition. A Taguchi analysis is carried out. The effect of parameters is studied and presented.*

Key Words: *Signal to Noise ratio, ANOVA, metal removal rate, cutting Force.*

1. INTRODUCTION

Frequent use of modern materials for the required applications in the present scenario, made clear that a quality product at the end is necessary, after performing the machining operations on the work piece. Therefore quality is an important part of production. Machining operations are performed in the process to achieve the required output, so now product's quality depends on the operations performed on the product. Turning is the operation performed for metal removal in most applications, as it can give a good surface finish. Volume of metal removed from a cylindrical work piece per unit time is called as metal removal rate and highest metal removal rate is expected from turning operation, so that it leads to reduced cost and highest production. The cutting tool feeds into the rotating work piece and cuts away material in the form of small chips to create the desire shape.

Problems associated with machining of MMC's should be minimised if these materials need to be used extensively. Here in this paper study of effects of process parameters such as speed, feed, depth of cut and percentage of composition on metal removal rate and cutting force in turning of Al MMCs is calculated. Taguchi methods are statistical methods developed by Genichi Taguchi to improve the quality of manufactured goods and more recently also applied to engineering.

Design of experiments or Taguchi's technique is used to complete the objective and generate the optimised value. Here L27 orthogonal array was used for conducting the experiments and ANOVA was employed to analyze the percentage contribution and influence of process parameters. Taguchi's technique was found using Minitab 17 software.

2. METHODOLOGY

In this paper, the machining parameters are determined by using Taguchi's design method. Orthogonal arrays of Taguchi, the signal-to-noise (S/N) ratio, the analysis of variance (ANOVA), and regression analysis are used to get the optimal levels and to analyze the effect of the machining parameters on material removal rate & cutting force.

2.1 TAGUCHI METHOD

Taguchi has developed a methodology for the application of factorial design experiments that has taken the design of experiments from the exclusive world of the statistician and brought it more fully into the world of manufacturing [1].Thus the marriage of design of experiments with optimization of control parameters to obtain best results is achieved in Taguchi method. Orthogonal arrays provide a set of well balanced experiments & desired output. [2]

Conventional procedures need more number of experiments to be performed, when more number of parameters increased, this issue is resolved by Taguhci method, it uses special design to study the parameters with small number of experiments. Saving time, cost and finding significant factors at more ease. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. There are several S/N ratios available, depending on the type of characteristic; lower the better, nominal the best or higher the better.

The S/N ratio for the higher-the-better criterion is given by Taguchi as:

$$\frac{S}{N} = -10 \log_{10}[\frac{1}{n}\Sigma\frac{1}{y^2}] \quad (1)$$

The S/N ratio for the lower-the-better criterion is given by Taguchi as:

$$\frac{S}{N} = -10 \log_{10}\left[\frac{\Sigma y^2}{n}\right] \quad (2)$$

Where 'y' is the observed data and 'n' is the number of observations.
Regardless of the category of the performance characteristics, a greater S/N value corresponds to a better performance. Therefore, the optimal level of the machining parameters is the level with the great S/N ratio value [10].

2.2 ANALYSIS OF VARIANCE (ANOVA)

ANOVA is a statistical process in which the existence of differences among several population means determined. While the aim of ANOVA is the detect differences among several populations means, the technique requires the analysis of different forms of variance associated with the random samples under study-hence the name analysis of variance. The relative influence of the parameters is measured by total sum of square value (SST) and is given by:

$$SS_T = \Sigma_{i=1}^{n}[n_i\_n_m]^2 \quad (3)$$

Where n is the number of experiments in the orthogonal array, n_i is the mean S/N ratio for the i_{th} experiment and n_m is the total mean S/N ratio of all experiments.

2.3 REGRESSION ANALYSIS

A statistical tool that allows you to examine how multiple independent variables are related to a dependent variable. Once you have identified how these multiple variables relate to your dependent variable, you can take information about all of the independent variables and use it to make much more powerful and accurate predictions about why things are the way they are. It is also used to understand which among the independent variables are related to the dependent variable and to explore the forms of these relationships. The general form of a multiple regression model is as follows:
Independent variable = b0 + b1 (Independent variable 1) + b2 (Independent variable 2) + … +ε. (4)
Where b1, b2 … are estimates of the independent variables 1, 2 … and ε is the error.

3. EXPERIMENTAL WORK

Samples of 30mm dia and 30cm length of Al (6061)-SiC and Al (6063)-SiC composites with 0%, 10% and 20% weight of SiC are fabricated by stir casting method [12]. Experiments are conducted on lathe based on Taguchi's design of experiments. Speed, feed and depth of cut values are controllable and are maintained nominal, thus preventing harm to the machine. Machining criteria also depends on the work piece density, with increasing the percentage of reinforcement in composites the density too varies. Therefore to study the effect of percentage of reinforcement on machining criteria, SiC is varied from 0%-20% by weight in Al-SiC composites. The factors to be studied and their levels are given in Table 1. Tool used for machining is High speed steel. The observations (MMR and Cutting force) are made by changing speed, feed, depth of cut and percentage of reinforcement. Figure 1 & 2 shows the prepared work pieces of Al (6061)-SiC and Al (6063)-SiC respectively. Table 2 & Table 3 lists Taguchi's L27 orthogonal array, the measured values of responses and the S/N ratios of both Al MMC's.

Metal Removal Rate, MMR = π*D_{avg}*d*f*N (5)
Where D_{avg} = (D_i +D_f) /2
D_i=Intial dia of rod
D_f=Final dia of rod
d= depth of cut
f= feed
N= spindle speed
Cutting force, CF= (Torque)/D_{avg} (6)
Where Torque = (Power consumed)/ω
ω = 2Πn

Table 1. Factors and their levels

Symbol	Factors	Level 1	Level 2	Level 3
A	Speed (rpm)	315	500	775
B	Feed (mm/rev)	0.71	1.42	2.85
C	Depth of cut (mm)	0.4	0.8	1.2
D	% of reinforcement	0	10	20

Table 2. L27 orthogonal array for Al 6061-SiC

S. no	Factors				Responses		S/N ratio	
	A	B	C	D	MMR mm³/min	CF N	MMR	CF
1	1	1	1	1	8660	0.0370	78.962	28.622
2	1	1	2	2	16420	0.040	83.311	27.931
3	1	1	3	3	18219	0.0579	86.021	24.733
4	1	2	1	1	16870	0.037	84.393	28.470
5	1	2	2	2	31040	0.041	88.742	27.592
6	1	2	3	3	32390	0.066	91.452	23.571
7	1	3	1	1	32955	0.041	89.799	27.564
8	1	3	2	2	58687	0.042	94.148	27.384
9	1	3	3	3	56881	0.079	96.858	22.007

10	2	1	1	2	11068	0.034	82.472	29.272
11	2	1	2	3	23921	0.029	87.472	30.690
12	2	1	3	1	36952	0.0297	90.039	30.532
13	2	2	1	2	21422	0.0326	87.903	29.732
14	2	2	2	3	44986	0.0328	92.903	29.675
15	2	2	3	1	67478	0.0320	95.47	29.877
16	2	3	1	2	41561	0.0334	93.309	29.508
17	2	3	2	3	84555	0.0366	98.308	28.713
18	2	3	3	1	122534	0.0357	100.87	28.940
19	3	1	1	3	20476	0.0219	85.487	33.185
20	3	1	2	1	28777	0.0256	90.344	31.814
21	3	1	3	2	44825	0.0311	92.404	30.124
22	3	2	1	3	39844	0.0196	90.918	34.122
23	3	2	2	1	53126	0.0241	95.775	32.336
24	3	2	3	2	79689	0.0359	97.835	28.892
25	3	3	1	3	77748	0.0175	96.324	35.092
26	3	3	2	1	97740	0.0291	101.18	30.704
27	3	3	3	2	139946	0.0449	103.24	26.942

Table 3. L27 orthogonal array for Al 6063-SiC

S. no	Factors				Responses		S/N ratio	
	A	B	C	D	MMR mm^3/min	CF N	MMR	CF
1	1	1	1	1	8885	0.03324	79.203	29.671
2	1	1	2	2	16420	0.03874	83.309	27.342
3	1	1	3	3	18219	0.05611	85.991	26.122
4	1	2	1	1	17319	0.03607	84.64	28.814
5	1	2	2	2	31040	0.04208	88.746	26.486
6	1	2	3	3	32390	0.06207	91.428	25.265
7	1	3	1	1	33858	0.03771	90.053	28.217
8	1	3	2	2	58687	0.04195	94.159	25.888
9	1	3	3	3	56881	0.06974	96.841	24.668
10	2	1	1	2	11068	0.03079	82.442	31.687
11	2	1	2	3	23921	0.02944	87.484	30.597
12	2	1	3	1	38024	0.02957	90.31	29.194
13	2	2	1	2	21422	0.03287	87.88	30.831
14	2	2	2	3	44986	0.03232	92.921	29.740
15	2	2	3	1	69621	0.03279	95.747	28.337
16	2	3	1	2	41561	0.03511	93.293	30.233
17	2	3	2	3	84555	0.03451	98.335	29.143
18	2	3	3	1	126833	0.03721	101.16	27.739
19	3	1	1	3	20476	0.01692	85.485	34.322
20	3	1	2	1	29883	0.02547	90.671	33.049
21	3	1	3	2	44825	0.02813	92.417	30.590
22	3	2	1	3	39844	0.01767	90.922	33.465
23	3	2	2	1	55339	0.02873	96.108	32.192
24	3	2	3	2	79689	0.03421	97.854	29.733
25	3	3	1	3	77748	0.02052	96.336	32.868
26	3	3	2	1	102183	0.03034	101.52	31.594
27	3	3	3	2	139970	0.03421	103.26	29.136

Figure 1. Al 6061-SiC

Figure 2. Al 6063-SiC

4. ANALYSIS OF EXPERIMENTAL RESULTS

After conducting 27 experiments each on Al 6061-SiC and Al 6063-SiC composites, performance evaluation and the effects of process parameters on metal removal rate and cutting force is studied.

4.1 ANALYSIS OF SIGNAL TO NOISE RATIO

Metal removal rate and cutting force values are obtained by equation (5) & (6) respectively and there signal to noise ratio values are calculated by equation (1) & (2) respectively.

4.1.1 Metal removal rate

The metal removal rate response table for each level of machining parameters (speed, feed, D.O.C & % of SiC) is obtained and results are presented in Table 4 for Al 6061-SiC and in Table 6 for Al 6063-SiC. Optimal levels at which optimal values can be obtained are darkened in the tables. Chart 2 and 4 shows the effect of process parameters on metal removal rates.

Table 4. Response Table for SN Ratios for Al 6061-SiC

Level	Speed	Feed	D.O.C	% of reinforcement
1	88.19	86.28	87.73	**91.87**
2	92.08	91.71	92.46	91.49
3	**94.83**	**97.12**	**94.91**	91.75
Delta	6.65	10.84	7.18	0.39
Rank	3	1	2	4

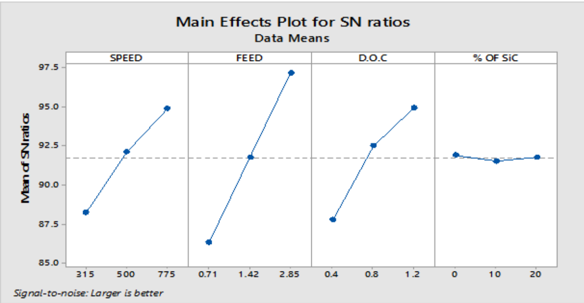

Chart-1: Main effects plot for SN ratios for Al 6061-SiC

Table 5. Response table for means for Al 6061-SiC

Level	Speed	Feed	D.O.C	% of reinforcement
1	30236	23257	30067	51677
2	50497	42983	48806	49406
3	64686	79179	66546	44336
Delta	34450	55921	36479	7341
Rank	3	1	2	4

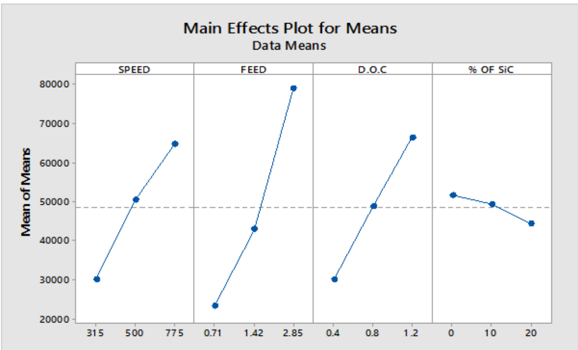

Chart-2: Main effects plot for means for Al 6061-SiC

Table 6. Response Table for SN Ratios for Al 6063-SiC

Level	Speed	Feed	D.O.C	% of reinforcement
1	88.26	86.37	87.81	**92.16**
2	92.17	91.81	92.58	91.49
3	**94.95**	**97.22**	**95**	91.75
Delta	6.69	10.85	7.20	0.67
Rank	3	1	2	4

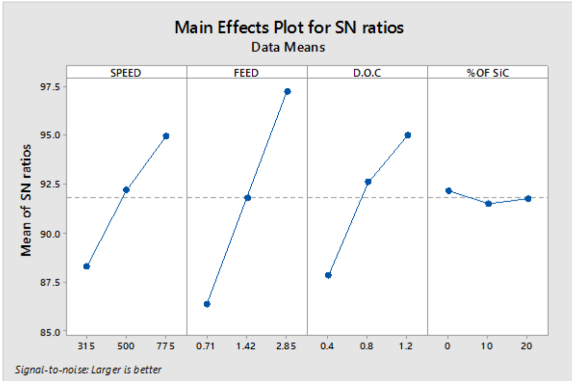

Chart-3: Main effects plot for SN ratios for Al 6063-SiC

Table 7. Response table for means for Al 6063-SiC

Level	Speed	Feed	D.O.C	% of reinforcement
1	30236	23257	30067	51677
2	50497	42983	48806	49406
3	64686	79179	66546	44336
Delta	34450	55921	36479	7341
Rank	3	1	2	4

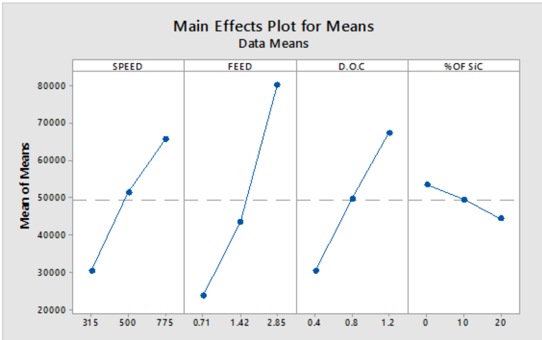

Chart-4: Main effects plot for means for Al 6063-SiC

4.1.2 CUTTING FORCE

The cutting force response table for each level of machining parameters (speed, feed, D.O.C & % of SiC) is obtained and results are presented in Table 8 for Al 6061-SiC and in Table 10 for Al 6063-SiC. Optimal levels at which optimal values can be obtained are darkened in the tables. Chart 6 and 8 shows the effect of process parameters on cutting force in Al MMC's. Previous researchers stated that the factors affecting the cutting force are the feed rate and spindle speed [9].

Table 8. Response Table for SN Ratios for Al 6061-SiC

Level	Speed	Feed	D.O.C	% of reinforcement
1	26.43	**29.66**	**30.62**	**29.87**
2	29.66	29.36	29.65	28.60
3	**31.47**	28.54	27.29	29.09
Delta	5.04	1.12	3.33	1.28
Rank	1	4	2	3

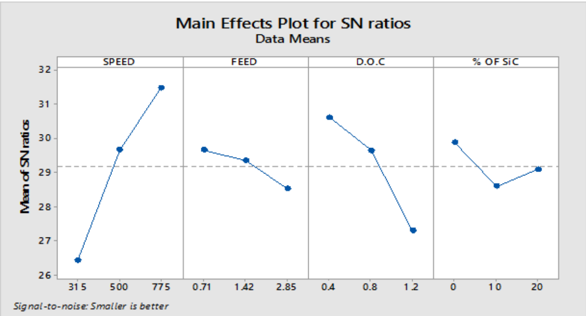

Chart-5: Main effects plot for SN ratios for Al 6061-SiC

Table 9. Response table for means for Al 6061-SiC

Level	Speed	Feed	D.O.C	% of reinforcement
1	0.04943	0.03414	0.03070	0.03257
2	0.03297	0.03589	0.03359	0.03746
3	0.02780	0.04017	0.04592	0.04017
Delta	0.02162	0.00603	0.01522	0.00760
Rank	1	4	2	3

Chart-6: Main effects plot for means for Al 6061-SiC

Table 10. Response Table for SN Ratios for Al 6063-SiC

Level	Speed	Feed	D.O.C	% of reinforcement
1	26.94	**30.29**	**31.12**	**29.87**
2	29.72	29.43	29.56	29.10
3	**31.88**	28.83	27.87	29.58
Delta	4.94	1.45	3.26	0.76
Rank	1	3	2	4

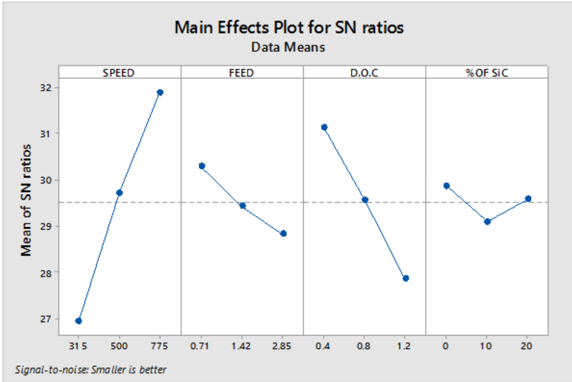

Chart-7: Main effects plot for SN ratios for Al 6063-SiC

Table 11. Response table for means for Al 6063-SiC

Level	Speed	Feed	D.O.C	% of reinforcement
1	0.04642	0.03205	0.02899	0.03235
2	0.03274	0.03543	0.03374	0.03535
3	0.02625	0.03793	0.04268	0.03771
Delta	0.02017	0.00588	0.01368	0.00535
Rank	1	3	2	4

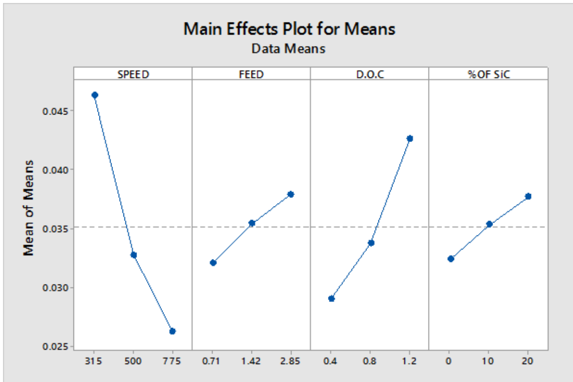

Chart-8: Main effects plot for means for Al 6063-SiC

4.2 ANALYSIS OF VARIANCE (ANOVA)

4.2.1 METAL REMOVAL RATE

Table 12 and 13 shows the ANOVA results for MMR values. During machining of composites, each factor has its own significance on the MMR. Darkened values in tables show their respective effects in percentage wise. Results shows feed is parameter which effects in both composites.

Table 12. ANOVA for MMR for Al 6061-SiC

Source	DF	SS	MS	F-value	Pr (%)
Speed	2	5395912165	2697956082	14.42	**18.29**
Feed	2	14479305580	7239652790	38.70	**49.10**
D.O.C	2	5989751197	2994875598	16.01	**20.31**
% of SiC	2	254288630	127144315	0.68	**0.86**
Error	18	3367574028	187087446		
Total	26	29486831599			

Table 13. ANOVA for MMR for Al 6063-SiC

Source	DF	SS	MS	F-value	Pr (%)
Speed	2	5623232649	2811616324	14.70	**18.39**
Feed	2	14900703415	7450351708	38.95	**48.75**
D.O.C	2	6211121075	3105560538	16.24	**20.32**
% of SiC	2	383322285	191661142	1.00	**1.25**
Error	18	3443067870	191281548		
Total	26	30561447294			

4.2.2 CUTTING FORCE

Table 14 and 15 shows the ANOVA results for CF values. During machining of composites, each factor has its own significance on the CF. Darkened values in tables show their respective effects in percentage wise. Results shows speed is the effective parameter which effects in both composites.

Table 14. ANOVA for CF for Al 6061-SiC

Source	DF	SS	MS	F-value	Pr (%)
Speed	2	0.002296	0.001148	25.15	**48.51**
Feed	2	0.000173	0.000087	1.90	**3.65**
D.O.C	2	0.001176	0.000588	12.88	**24.84**
% of SiC	2	0.000267	0.000133	2.92	**5.64**
Error	18	0.000821	0.000046		
Total	26	0.004733			

Table 15. ANOVA for CF for Al 6063-SiC

Source	DF	SS	MS	F-value	Pr (%)
Speed	2	0.001908	0.000954	29.45	**52.33**
Feed	2	0.000157	0.000078	2.42	**4.30**
D.O.C	2	0.000869	0.000434	13.41	**23.83**
% of SiC	2	0.000130	0.000065	2.00	**3.56**
Error	18	0.000583	0.000032		
Total	26	0.003646			

4.3 REGRESSION ANALYSIS

A correlation between machining process parameters and machining criteria for machining of Al MMC's are obtained by multiple linear regressions. MINITAB software package is used to develop these relations or models.

4.3.1 REGRESSION ANALYSIS FOR MMR

Equation below is for Al 6061-SiC

MMR = -66259 + 73.1 (SPEED) + 26013 (FEED) + 45599 (D.O.C) - 367 (% OF SiC) (7)

Equation below is for Al 6063-SiC

MMR = -66717 + 74.5 (SPEED) + 26389 (FEED) + 46423 (D.O.C) - 461 (%OF SiC) (8)

4.3.2 REGRESSION ANALYSIS FOR CF

Equation below is for Al 6061-SiC

CF= 0.03676-0.00045 (SPEED) +0.00284 (FEED) +0.01902 (D.O.C) +0.000380 (% OF SiC) (9)

Equation below is for Al 6063-SiC

CF=0.03687- 0.000042 (SPEED) + 0.00260 (FEED) + 0.01710 (D.O.C) + 0.000268 (%OF SiC) (10)

Table 16. Optimum sequence for MMR in Al 6061-SiC

Speed	Feed	D.O.C	% of SiC	MMR
775	2.85	1.2	10	139946

Table 17. Optimum sequence for MMR in Al 6063-SiC

Speed	Feed	D.O.C	% of SiC	MMR
775	2.85	1.2	10	139970

Table 18. Optimum sequence for CF in Al 6061-SiC

Speed	Feed	D.O.C	% of SiC	CF
775	2.85	0.4	20	0.0175

Table 19. Optimum sequence for CF in Al 6063-SiC

Speed	Feed	D.O.C	% of SiC	CF
775	0.71	0.4	20	0.01692

5. COMPARING AL 6061 SIC AND AL 6063

Table 20. Compositions of elements in Al 6061 & Al 6063

Composite	**6061**	**6063**
Fe	0.70	0.35
Mn	0.15	0.10
Zn	0.25	0.10
Ti	0.15	0.10
Si	0.70	0.50
Cu	0.40	0.10
Mg	0.80	0.50
Cr	0.15	0.15
Al	remainder	remainder

- Elements present in Al 6061-SiC and Al 6063-SiC is as described above.
- Comparison between Al MMC's is done according to the results obtained in analysis of experiments in this study.
- In analysis of SN ratios for MMR, Tables 4 & 6 shows the ranks allotted to the parameters according to their significant effect. A much alike similarity is observed in between them.
- Chart 2 & 4 shows the behavior of MMR with respect to process parameters selected and it confirms that major similarity occurs between them.
- In analysis of SN ratio for CF, Tables 8 & 10 shows the ranks of parameters. It shows some what difference in the ranks comparing between them, but speed remaining the major factor to affect the CF.
- Chart 6 & 8 shows the behavior of CF with respect to process parameters, a slight difference occurs between them.
- In analysis of variance for MMR, from Tables 12 & 13 same parameters from both MMC's have same impact with some negotiable difference. Here feed is the major parameter which has most impact on MMR.
- In analysis of variance for CF, from Tables 14 & 15 same parameter from each side shows same impact, with some negotiable difference. Here speed is the major parameter which has most impact on CF.

6. SCOPE OF FUTURE WORK

- Same analysis can be done for other materials like steel, brass, copper etc.
- We can use other process parameters for MMR and CF.
- Study can be performed on milling, drilling, grinding and other metal removal processes.
- Cutting fluids and other lubricants are not used in this process, so these can be employed for improvements.

7. CONCLUSION

This study shows the usage of parameter design in optimization of metal removal rate and cutting force of Al MMC's in Turning and its application led to opt optimal values. To obtain accurate study, L27 orthogonal array is used in Taguchi method and ANOVA. ANOVA is used to know the accurate contribution of each factor and their percentage in operation. Study shows Taguchi method and ANOVA has same result in Al MMC's machining with minor difference. Spindle speed is the parameter with 48.51% and 52.31% in Al 6061-SiC and Al 6063-SiC respectively which affects the CF and stood first in rank in Taguchi method. Feed is the parameter with 49.10% and 48.75% in Al 6061-SiC and Al 6063-SiC respectively which affects the MMR and stood first in rank in Taguchi method. Optimal sequence in selected design for MMR and CF is found. Experiments shows that comparison of both Al MMC's based on MMR and CF has mere difference and it proved that they can be used at common machining parameters. Taguchi can be used for analyzing similar problems as of this study. Parameter design obtained is simple and it proved that it is an efficient methodology for optimizing process parameters.

NOMENCLATURE

s= Spindle speed, rpm
f= Feed, mm
d= Depth of cut, mm
D_{avg}= Average diameter, mm
D_i= Initial diameter, mm
D_f= Final diameter, mm
MMR= Metal removal rate, mm/min
CF= Cutting force, N
S/N or SN ratio= Signal to Noise ratio

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