Optimization of Machining Parameters in Fly ash/Sic Reinforced Al 7075 MMC by Taguchi Method

V. Venkata Reddy, M. Gopi Krishna, K. Srinivasulu Reddy

***Abstract:** Present work is aimed at machining parameters optimization during turning of fly ash and silicon carbide reinforced Al 7075 alloy by Taguchi method of experimental design. Taguchi L16 design is selected for the design of experiments. In this study, machining is done by turning the reinforced alloy with uncoated tungsten carbide inserts tool in dry condition. Cutting parameters feed, cutting speed, and depth of cut are varied to observe the effect on responses surface roughness and material removal rate. As per Taguchi's analysis, 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.*

I. INTRODUCTION

Aluminium alloys reinforced with ceramic materials are the new breed of engineering materials with improved properties like specific strength, superior resistance to corrosion and wear, higher hardness, lower coefficient of thermal expansion, higher resistance to thermal shock when compared to the unreinforced alloys [1, 3-4]. Aerospace and automotive industries demand for materials with lightweight and improved mechanical properties. Hence researchers focused on fabrication and characterization of Aluminium metal matrix composites (AMMCs) with ceramic particulates reinforcement [1-2, 5-6]. Presence of hard ceramic reinforcements in the AMMCs, which makes them difficult to machine and make the surface rough leading to higher tool wear rate [7-9, 11]. Automobile parts like engine blocks, cylinders, and pistons justify the importance of optimal machining process parameters. It was reported that feed rate is the most influencing parameter followed by the depth of cut and cutting speed for quality characteristics like surface roughness (Ra) and material removal rate (MRR) on turning of A356/5 wt.% SiCp, [8]. Pradhan and Sahoo [10] reported that the most significant parameter for the surface finish is feed, followed by cutting speed and depth of cut, during turning of SiC reinforced AMMCs with uncoated carbide inserts. Ciftci et al. [11] observed uncoated carbide tools produced better surface roughness values when compared to the coated carbide tools, during turning of Al 2014/SiC MMCs in dry machining condition. The present investigation is focused on turning performance of Al 7075/Fly ash/SiC AMMC in terms of Ra and MRR under dry machining condition with uncoated carbide tipped tool inserts.

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II. EXPERIMENTATION

Fabrication of Composites

AMMCs having 10 % by weight SiC and Fly ash particles of size 53µm were fabricated by stir casting route are taken as reference for machining as at this percentage, better mechanical properties were observed by Venkata Reddy et al. [2]. Al 7075 is taken as base metal, and its chemical composition is depicted in Table 1.The composites were prepared by stir casting route. Melting of Al 7075 ingots was performed in an electric furnace with graphite crucible. At 770°C, the molten metal pool is stirred in the middle of the crucible using a mechanical stirrer at 500 rpm. SiC and fly ash particulates are preheated and dropped uniformly into the melt. To avoid the agglomeration, smooth, and continuous flow of the particles is ensured during stirring. As the casting is exposed to the atmosphere during the stirring, Argon inert gas shielding is maintained throughout for 2 to 3 minutes to avoid oxidation. Then, molten metal is poured into cast iron moulds which is preheated to 200 ^{0}C. The fabricated ingots were kept in a muffle furnace at 110 ^{0}C for 24 hours to remove any residual stresses induced in the castings and to reduce the chemical inhomogeneities. Uncoated tungsten carbide inserts are used as the cutting tool. Rough turning on fabricated ingots is first performed on the lathe machine to make specimens of uniform diameter as shown in figure 1. Initially, based on the available feeds, and speeds on the Lathe, pilot experiments were conducted to find the range of feeds and speeds for good surface finish and material removal rate. After identifying the levels for cutting speed, feed and depth of cut, Taguchi's L16 orthogonal array is selected for the design of experiments. Factors and their levels selected are given in Table 2.

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Table 1. Elemental analysis of Al 7075 alloy by weight percentage.

Zn	Cu	Mg	Si	Cr	Mn	Fe	Pb	Sn	Ti	Al
5.6	1.3	2.4	0.4	0.18	0.3	0.5	0.03	0.012	0.2	89

Table 2. Factors and levels selected.

S.No	Factor	Unit	Levels of Factors			
			L-1	L-2	L-3	L-4
1	Cutting speed, v	m/min	20	50	75	115
2	Feed, f	mm/rev	0.05	0.10	0.16	0.20
3	Depth of cut, d	mm	0.2	0.4	0.6	0.8

Figure 1. Specimens of Al 7075 reinforced with fly ash and SiC.

Surface Roughness

Average surface roughness (Ra) of 16 specimens was measured with Surface Roughness measuring instrument Mitutoyo's Surftest SJ-210. Athematic average of the roughness profile of the surface Ra of all eighteen specimens is presented in Table 3. Surface roughness is measured at three different locations, and the average value is taken. Based on Taguchi's smaller the better quality characteristic, Signal to Noise ratio (S/N) values are calculated using the formula -10 $\log_{10}[Ra^2]$ and shown in Table 3. Taguchi analysis results are shown in table 4 and found that feed is highly responsible for surface roughness with rank 1 and cutting speed and depth of cut are responsible with ranks 2 and 3, respectively. Main effects plots for S/N ratios are shown in figure 2. From figure 2, it is clear that a better signal to noise ratio is obtained at cutting speed of 115 m/min, feed at 0.05 mm/rev and depth of cut at 0.2 mm. This setting of the experiment is not present in the L16 orthogonal array, and hence new experiment is conducted at these settings and found that Ra is 1.42 µm whereas Taguchi predicted value is 1.11 µm as shown in table 5. The experimental value is within the 95% confidence interval of Taguchi's predicted value, and hence, values are verified.

Analysis of Variance (ANOVA) in Ra

ANOVA is conducted to find various sources of variation and their contribution in the measurement of surface roughness and tabulated in table 6. R-square and adjusted R-square values of the ANOVA model are shown in Table 7. Regression equation obtained to measure the surface roughness (Ra) is given as equation 1.

Table 3. Surface roughness and S/N values.

Exp. No.	v	f	d	Ra(µm)	S/N
1	20	0.05	0.2	1.52	-3.637
2	20	0.1	0.4	1.78	-5.008
3	20	0.16	0.6	2.48	-7.889
4	20	0.2	0.8	2.8	-8.943
5	50	0.05	0.4	1.72	-4.710
6	50	0.1	0.2	1.5	-3.521
7	50	0.16	0.8	2.28	-7.158
8	50	0.2	0.6	2.32	-7.309
9	75	0.05	0.6	1.36	-2.670
10	75	0.1	0.8	1.48	-3.405
11	75	0.16	0.2	2.14	-6.608
12	75	0.2	0.4	2.24	-7.005
13	115	0.05	0.8	1.31	-2.345
14	115	0.1	0.6	1.39	-2.860
15	115	0.16	0.4	1.71	-4.659
16	115	0.2	0.2	2	-6.021

Table 4. Taguchi analysis of S/N ratios of Ra.

Level	v	f	d
1	-6.369	-3.341	-4.947
2	-5.675	-3.699	-5.346
3	-4.922	-6.579	-5.182
4	-3.972	-7.320	-5.463
Delta	2.398	3.979	0.516
Rank	2	1	3

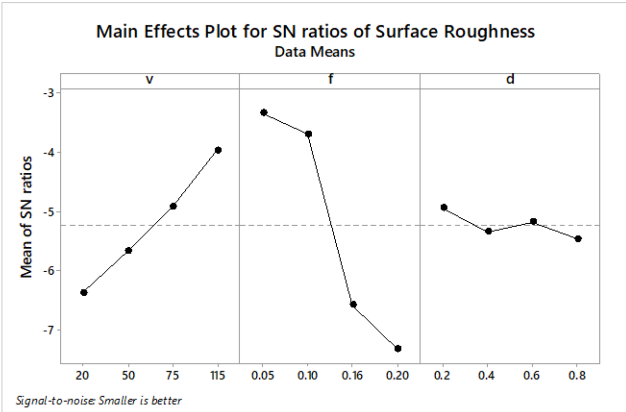

Figure 2. Main effects graph of surface roughness.

Table 5. Taguchi predicted and actual Ra values.

v	f	d	S/N Ratio	Predicted Ra(µm)	Actual Ra(µm)
115	0.05	0.2	-1.79	1.11625	1.42

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Table 6. ANOVA table for Ra.

Source of variation	DOF	Seq SS	Adj MS	F-Value	P-Value	Contribution
v	1	0.63167	0.005077	0.17	0.698	20.34%
f	1	2.09834	0.008170	0.27	0.624	67.57%
d	1	0.06216	0.010458	0.34	0.580	2.00%
v*v	1	0.00206	0.002432	0.08	0.788	0.07%
f*f	1	0.04838	0.041243	1.35	0.290	1.56%
d*d	1	0.00006	0.000041	0.00	0.972	0.00%
v*f	1	0.02715	0.041960	1.37	0.286	0.87%
v*d	1	0.05073	0.050393	1.65	0.247	1.63%
f*d	1	0.00111	0.001110	0.04	0.855	0.04%
Error	6	0.18369	0.030615			5.92%
Total	15	3.10534				100.00%

Table 7. Model Summary - ANOVA of Ra.

S	R-sq	R-sq(adj)
0.174973	94.08%	85.21%

The regression equation for surface roughness Ra is obtained as

Ra = 1.129 + 0.00407 v + 3.02 f + 0.86 d + 0.000012 v*v + 21.6 f*f + 0.04 d*d - 0.0439 v*f - 0.01225 v*d - 1.09 f*d (1)

Material Removal Rate

Material Removal rate (MRR) is calculated by multiplying the three machining parameters cutting speed, feed, and depth of cut. Larger-the-better quality characteristic is selected, and the signal-to-noise ratio is calculated using the formula -10 $\log_{10}[1/(MRR)^2]$ and presented in Table 8. From the response Table 9 and main effects plot figure 3, it is clear that cutting speed (v) is critical for high MRR. As per Taguchi's predictions, high MRR of 0.26825 g/sec can be obtained at cutting speed 115 m/min, feed 0.2mm/rev and DOC 0.8 mm. This setting of te experiment is not conducted in Taguchi's L16 orthogonal array, and hence another experiment is conducted at this setting and calculated the material removal rate as 0.275 g/sec which is within the 95% confidence interval and hence values are verified as shown in Table 10.

Table 8. Material Removal Rate and S/N values.

Exp. No.	v	f	d	MRR(g/sec)	S/N ratio
1	20	0.05	0.2	0.020	-33.97
2	20	0.1	0.4	0.038	-28.40
3	20	0.16	0.6	0.066	-23.60
4	20	0.2	0.8	0.170	-15.39
5	50	0.05	0.4	0.042	-27.53
6	50	0.1	0.2	0.038	-28.40
7	50	0.16	0.8	0.220	-13.15
8	50	0.2	0.6	0.174	-15.18
9	75	0.05	0.6	0.070	-23.09
10	75	0.1	0.8	0.210	-13.55
11	75	0.16	0.2	0.112	-19.01
12	75	0.2	0.4	0.162	-15.80
13	115	0.05	0.8	0.140	-17.07
14	115	0.1	0.6	0.220	-13.15
15	115	0.16	0.4	0.250	-12.04
16	115	0.2	0.2	0.122	-18.27

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

Level	v	f	d
1	0.0735	0.0680	0.0780
2	0.1185	0.1265	0.1230
3	0.1385	0.1620	0.1325
4	0.1830	0.1547	0.1850
Delta	0.1095	0.0940	0.1070
Rank	1	3	2

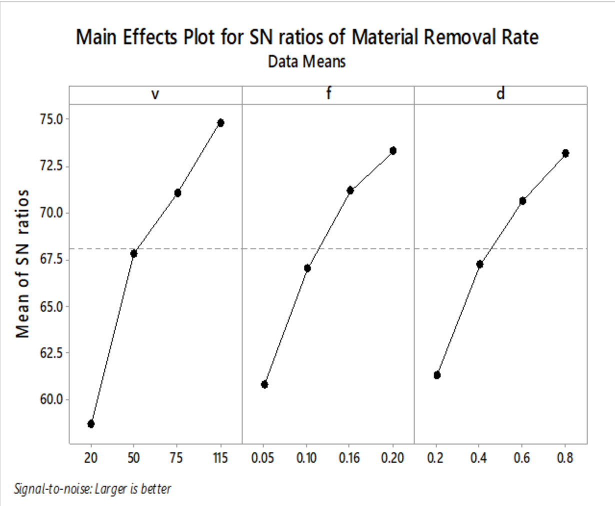

Figure 3. Main effects graph of material removal rate

Table 10. Taguchi predicted and actual values of MRR.

v	f	d	S/N Ratio	Predicted MRR g/sec	Actual MRR g/sec
115	0.2	0.8	-6.38	0.26825	0.275

Analysis of Variance in Material Removal Rate

If ANOVA is performed to find various sources of variation and their contribution in the measurement of material removal rate and tabulated in Table 11. R-square and adjusted R-square values of the ANOVA model are shown in Table 12. Regression equation obtained to measure the material removal rate (MRR) is given as equation 2.

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Table 11. ANOVA of MRR.

Source of variation	DOF	Seq SS	Adj MS	F-Value	P-Value	Contribution
v	1	0.02449	0.000052	0.13	0.732	28.33%
f	1	0.01981	0.000002	0.01	0.941	22.07%
d	1	0.02387	0.001223	3.03	0.132	27.61%
v*v	1	0.00011	0.000524	1.30	0.298	0.13%
f*f	1	0.00329	0.002964	7.35	0.035	3.80%
d*d	1	0.00006	0.000008	0.02	0.895	0.01%
v*f	1	0.002878	0.002402	5.96	0.050	3.33%
v*d	1	0.001571	0.001419	3.52	0.110	1.82%
f*d	1	0.008741	0.008741	21.69	0.003	10.11%
Error	6	0.002418	0.000403			2.80%
Total	15	0.086474				100.00%

Table 12. Model summary – ANOVA of MRR.

S	R-sq	R-sq(adj)
0.0200747	97.20%	93.01%

The regression equation for material removal rate MRR is obtained as

$$MRR = 0.0309 + 0.00041\ v + 0.052\ f - 0.295\ d - 0.00006\ v*v - 5.78\ f*f + 0.017\ d*d + 0.01051\ v*f + 0.00205\ v*d + 3.071\ f*d \quad (2)$$

III. CONCLUSION

Following conclusions can be drawn from the experiments conducted as per Taguchi design and analysis of variance.

1. Taguchi method predicted the least surface roughness value of 1.11 μm, at cutting speed 115, feed 0.05 and depth of cut 0.2
2. Taguchi method predicted highest material removal rate value of 0.26825 g/sec at cutting speed 115, feed 0.2 and depth of cut 0.8.
3. ANOVA is performed to find the significance and % contribution of input parameters on the output parameters.
4. Regression analysis is done to find out the relationship between the factors and output responses.
5. Experimental results at the settings predicted by Taguchi method reveal that surface roughness of 1.42 μm, and material removal rate of 0.275 g/sec, which are matching with Taguchi predicted values with 95% confidence interval. Hence Taguchi method is very efficient in the optimization of machining problems.

REFERENCES

1. Das, Diptikanta, et al. "Turning performance of Al 7075/SiCp MMC and multi-response optimization using WPCA and Taguchi approach." Materials Today: Proceedings 5.2 (2018): 6030-6037.
2. Venkata Reddy et al. "Studies on microstructure and mechanical behavior of A7075 -Flyash/SiC hybrid metal matrix composite" IOP Conf. Series: Materials Science and Engineering, 310 (2018) 012047.
3. Koli, Dinesh Kumar, Geeta Agnihotri, and Rajesh Purohit. "Advanced aluminium matrix composites: The critical need of automotive and aerospace engineering fields." Materials Today: Proceedings 2.4-5 (2015): 3032-3041.
4. Sarada, B. N., PL Srinivasa Murthy, and G. Ugrasen. "Hardness and wear characteristics of hybrid aluminium metal matrix composites produced by stir casting technique." Materials Today: Proceedings 2.4-5 (2015): 2878-2885.
5. Mishra, P., et al. "Multi-response optimization of process parameters using Taguchi method and grey relational analysis during turning AA 7075/SiC composite in dry and spray cooling environments." International Journal of Industrial Engineering Computations 6.4 (2015): 445-456.
6. M.Chandrasekaran, and Santosh Tamang. "Desirability analysis and genetic algorithm approaches to optimize single and multi-response characteristics in machining Al-SiC MMC." 5th international & 26th all India manufacturing technology, Design and Research conference (2014) 653.1-653.6.
7. Das, D., et al. "Fabrication process optimization for improved mechanical properties of Al 7075/SiCp metal matrix composites." Management Science Letters 6.4 (2016): 297-308.
8. Gururaja, Suhasini, Mamidala Ramulu, and William Pedersen. "Machining of MMCs: a review." Machining Science and Technology 17.1 (2013): 41-73.
9. Andrewes, Caroline JE, Hsi-Yung Feng, and W. M. Lau. "Machining of an aluminum/SiC composite using diamond inserts." Journal of materials processing technology 102.1-3 (2000): 25-29.
10. Sahoo, Ashok Kumar, and Swastik Pradhan. "Modeling and optimization of Al/SiCp MMC machining using Taguchi approach." Measurement 46.9 (2013): 3064-3072.
11. Ciftci, Ibrahim, Mehmet Turker, and Ulvi Seker. "Evaluation of tool wear when machining SiCp-reinforced Al-2014 alloy matrix composites." Materials & design 25.3 (2004): 251-255.