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OPTIMIZATION OF MACHINING PARAMETERS ON SURFACE ROUGHNESS OF AL2285 - SI_3N_4 - MULLITE HYBRID MMC'S USING TAGUCHI METHOD

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Abstract - The surface roughness is one of the most important requirements in machining process, as it is considered an index of product quality. It measures the finer irregularities of the surface texture. Achieving the desired surface quality is critical for the functional behavior of a part. The better surface quality is desired for the proper functioning of the produced parts. Surface roughness measurement presents an important task in many engineering applications. In the present work, the turning parameters like cutting speed, feed rate and depth of cut are optimized for minimizing the Ra in turning of Al2285 – 4 wt.% Si_3N_4 – 6 wt.% Mullite Hybrid MMC's with HSS tool. The Taguchi and Analysis of Variance (ANOVA) conveniently used to optimize the cutting parameters with several well-designed experimental runs. Taguchi's L27 orthogonal array is used in the design of experiment. Furthermore, analysis of variance is performed to see which process parameters are statistically significant.

Keywords: Hybrid MMC's, Surface Roughness, Taguchi, ANOVA, Mullite.

1. INTRODUCTION

The turning process is the removal of metal from the outer diameter of a rotating cylindrical work piece. Turning is used to reduce the diameter of the work piece, usually to a specified dimension and to produce a smooth finish on the metal. From past so many years it has been recognized that conditions during machining such as cutting speed, feed and depth of cut should be selected to optimize the economics of machining operations. Manufacturing industries in developing countries suffer from a major drawback of not running the machine at their optimal operating conditions. Machining industries are dependent on the experience and skills of the machine tool operators for optimal selection of cutting conditions. In machining industries, the practice of using hand book based conservative cutting conditions are in progress at the process planning level. The disadvantage of this unscientific practice is the decrease in productivity due to sub optimal use of machining capability. The literature survey has revealed that several researchers attempted to calculate the optimal cutting conditions in turning operations [1]. Ch. Maheswara Rao and K. Venkatasubbaiah [2] analyzed that the effect of cutting parameters like feed speed and depth of cut in CNC turning of AA7075 to achieve low surface roughness using tungsten carbide insert. Finally, the relationship between cutting parameters and response was developed by using MINI TAB-16 software and regression analysis was done. The predicted values were compared with the experimental values and it was observed that both the values were very nearer and hence the models prepared were more accurate and adequate. The hybrid metal matrix composites were fabricated by stir casting process and conducted the machining by varying feed, speed and depth of cut. They found that the surface finish improves by 16.02%

and cutting forces reduced by 22% [3]. Anthony Xavior M et al., [4] focuses on the influence of reinforcement particle's types, shape, size and volume fractions on the machinability issues like the cutting force, tool wear, chip formation and surface roughness. Further, the role of various cutting parameters like cutting speed, feed, depth of cut and tool material, tool geometry and cutting conditions during turning of hybrid metal matrix composites are critically reviewed. Chambers [5] and Gallab [6] determined cutting forces in machining MMCs with PCD tools under varying cutting speeds [7]. Pramaniket al. [8] developed a mechanics model to predict cut-ting forces in machining of Al_2O_3/SiC reinforced metal matrix composites. They considered the cutting force generation mechanism to be based on chip formation, ploughing and particle fracture forces. They computed chip formation forces using Merchant's theory applicable to orthogonal cutting [9]. Usage of more than one reinforcement usually denoted as hybrid composites increasing significantly due to its outstanding mechanical and physical properties. Hybrid composites considered as good alternative for single reinforced particle composites [10]. Matrix and reinforcements are in particulate form are called particulate metal matrix composites (PMMC) giving superior manufacturability than the other fabrication methods [11].

However, products made by particulate metal matrix composites required some machining operations to attain good dimensional tolerance and surface finish. Turning is the most important machining operation for cutting and finishing operations. Presence of hard abrasive reinforcement particles influences greatly in tool wear and cost associated with machining. Selection of optimum machining parameters is very important to attain high cutting performance in metal matrix composites (MMCs) [12,13]. Machinability generally expressed in factors like cutting forces, angle of friction, tool wear, formation of chip and surface finish. Good machinability consumes less power, low tool wear rate, excellent surface finish etc. Achieve a good assessment of the machinability is a difficult concern due to complexity of the reinforcement mechanisms of the hard ceramic particles [14]. In aerospace and automotive applications aluminum silicon carbide composites are showing great demand because, aluminum possess the advantage of light weight and ceramic reinforcement giving excellent hardness [15, 16]. Metal matrix composite reinforced with carbon nanotube (CNT) shows excellent strength and improved elastic modulus than the monolithic materials [17, 18]. Aluminium, magnesium and copper mostly investigated matrix materials due to its high strength to weight ratio. [19]. Aluminium and magnesium have earmarked their slot in the MMCs due to low density and machinability [20]. Elements like silicon, zinc, magnesium, and copper are gifted with adequate solubility which makes them feasible to be used as key alloying elements [21]. Those composites which have a mixture of two or more reinforcement particles are capable of enhance the mechanical properties of the composite [22]. Kannan et al. [23] presented cemented carbides and ceramic tools also used to machining metal matrix composites due its lower cost than the PCD tools.

Surface finish is an important parameter to decide the quality of the product and also very essential factor for machining process [24]. Surface roughness in machining operations mainly depends on the machining parameters like cutting speed, feed, depth of cut and approach angle [25]. Ravinder Kumar and Santram Chauhan [14] studied good surface finish at low feed rate (0.05 mm/rev) and high cutting (170 m/min). Existence of graphite particle into Al metal matrix composite enhances the surface roughness due to the lubricating effect [26]. The present investigation is to find the effect of cutting parameters on Al2285 – 4% wt.% Si_3N_4 - 6% wt.%

Mullite Hybrid MMC's surface roughness by employing Taguchi's orthogonal array design and analysis of variance.

2. TAGUCHI METHOD

Taguchi method is a powerful tool for the design of high-quality systems. It provides simple, efficient and systematic approach to optimize designs for performance, quality and cost [27, 28]. Taguchi method is efficient method for designing process that operates consistently and optimally over a variety of conditions. To determine the best design, it requires the use of a statistically designed experiment [29]. Taguchi approach to design of experiments in easy to adopt and apply for users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community [30].

3. EXPERIMENTAL DETAILS

3.1 Material selection

The work piece was Aluminum 2285 – 4wt.% Si_3N_4 – 6wt.% Mullite Hybrid MMC of 25mm diameter and 300mm length. Hybrid MMC has a wide range of applications in the field of manufacturing and aerospace applications.

Table 1: Chemical composition of Al 2285 alloy (by wt.%)

Cu	Mg	Si	Fe	Mn	Ni	Zn	Ti	Pb	Sn	Al
4.0	1.5	0.6	0.6	0.6	2.0	0.1	0.2	0.05	0.5	Rest

One of the reinforcement materials selected for the development of the hybrid composite material is Si_3N_4. The elements silicon and nitrogen combine to form silicon nitride. The second reinforcement material selected for the development of the hybrid composite material is Mullite ($3Al_2O_3 + 2SiO_2$).

3.2 Casting of hybrid metal matrix composite

Aluminum 2285 – 4wt.% Si_3N_4 – 6wt.% Mullite Hybrid MMC fabricated by liquid metallurgy method. The weighted quantity of aluminium 2285alloy was melted in electrical resistance furnace to desired superheating temperature of 710^0C in graphite crucible. After melting, the 4wt.% Si_3N_4 and 6wt.% Mullite reinforcement particulates were preheated to around 400^0C, then added into the molten metal and stirred continuously by using mechanical stirrer. The stirring speed of 350 rpm was maintained for duration of 8 min. The melt with the reinforced particulates were then poured into a prepared cylindrical metallic die. The castings were taken out from the dies and the castings were tested to know the common casting defects using ultrasonic flaw detector.

Figure 1: The electrical resistance furnace with stirring of Aluminum 2285 – 4wt.% Si_3N_4 – 6wt.% Mullite Hybrid MMC molten metal

Figure 2: Al2285 – 4wt.% Si_3N_4 – 6wt.% Mullite Hybrid MMC

3.3 Cutting Tool

HSS tool has been used as a cutting tool for the experimentation which contains the chemical composition of 18% Tungsten, 4% chromium, 1% vanadium, 0.7% carbon and addition of 5% to 8% cobalt for higher strength and wear resistance. Back rake angle is 12^0, side rake angle is 12^0, end relief angle is 10^0, end cutting angle is 30^0 and side cutting edge angle is 15^0 and nose radius of 0.8mm

4. EXPERIMENTAL PROCEDURES

The turning tests on the work piece were conducted on lathe having maximum speed of 2000 rpm. Prior to the actual machining, the rust layers were removed by 0.2mm depth of cut in order to minimize any effect of homogeneity on the final results.

Table 2: Parameters with levels

Parameters	Symbols	Units	Level 1	Level 2	Level 3
Speed	S	rpm	540	630	840
Feed	F	mm/rev	1.1	1.2	1.3
DOC	D	mm	0.2	0.4	0.6

Figure 3: Machining of Al2285 – 4 wt.% Si_3N_4 - 6% wt.% Mullite Hybrid MMC specimen

Figure 4: Surface roughness measuring instrument

5. RESULTS AND DISCUSSIONS

A series of experiments were conducted on Al2285 – 4 wt.% Si_3N_4 - 6% wt.% Mullite Hybrid MMC with a HSS tool. S/N ratios for surface roughness values were calculated using smaller-the-better characteristic proposed by Taguchi and given in the table 3.

Table 3: Experimental results of surface roughness

L_{27}	Speed (rpm)	Feed (mm/rev)	Doc (mm)	Ra	S-N ratio
1	540	1.1	0.2	3.22	-
2	540	1.2	0.4	3.65	-
3	540	1.3	0.6	3.98	-
4	540	1.1	0.4	3.32	10.4228
5	540	1.2	0.6	3.65	-
6	540	1.3	0.2	3.74	-
7	540	1.1	0.6	3.38	-
8	540	1.2	0.2	3.4	-
9	540	1.3	0.4	3.85	-
10	630	1.1	0.4	3.12	-9.8831

11	630	1.2	0.6	3.62	-
12	630	1.3	0.2	3.98	-
13	630	1.1	0.6	3.42	-
14	630	1.2	0.2	3.56	-
15	630	1.3	0.4	3.88	-
16	630	1.1	0.2	3.2	-
17	630	1.2	0.4	3.58	-
18	630	1.3	0.6	4.2	-
19	840	1.1	0.6	3.2	-
20	840	1.2	0.2	3.25	-
21	840	1.3	0.4	3.62	-
22	840	1.1	0.2	2.98	-9.4843
23	840	1.2	0.4	3.45	-
24	840	1.3	0.6	3.75	-
25	840	1.1	0.4	2.98	-9.4843
26	840	1.2	0.6	3.56	-
27	840	1.3	0.2	3.65	-

5.1 Main effect plot analysis:

The data were further analyzed to study the effect of cutting parameters on surface roughness. From the S/N ratios given in the table 4 and 5 effective plots were drawn using MINITAB-17 as shown in the figure 5 and 6 respectively. The plots show the variation of response with the change in cutting parameters. In plots 5 and 6 the x- axis indicates the process parameters at three levels and y – axis the response value. The main effect plots are used to determine the optimal design conditions to obtain the low surface roughness value.

Table 4: Response Table for Signal to Noise Ratios

Level	S	F	D
1	-11.05	-10.10	-10.70
2	-11.13	-10.94	-10.84
3	-10.56	-11.70	-11.19
Delta	0.58	1.60	0.49
Rank	2	1	3

Table 5: Response Table for Means

Level	S	F	D
1	3.577	3.202	3.442
2	3.618	3.524	3.494
3	3.382	3.850	3.640
Delta	0.236	0.648	0.198
Rank	2	1	3

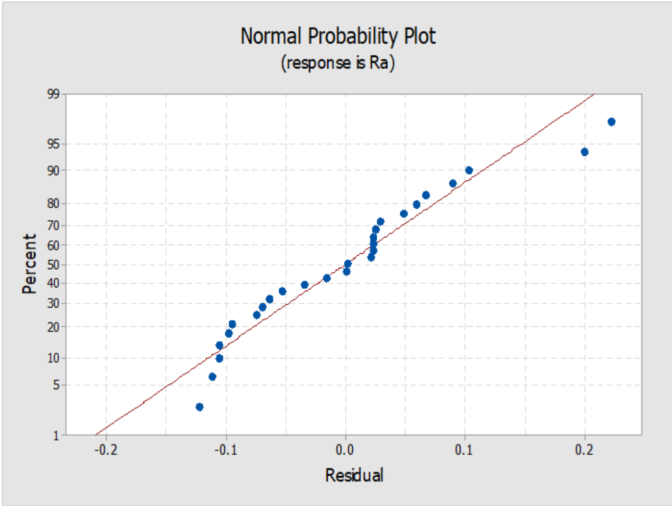

Figure 5: Normal probability plot for R_a

Figure 6: Main effects plot for means of R_a

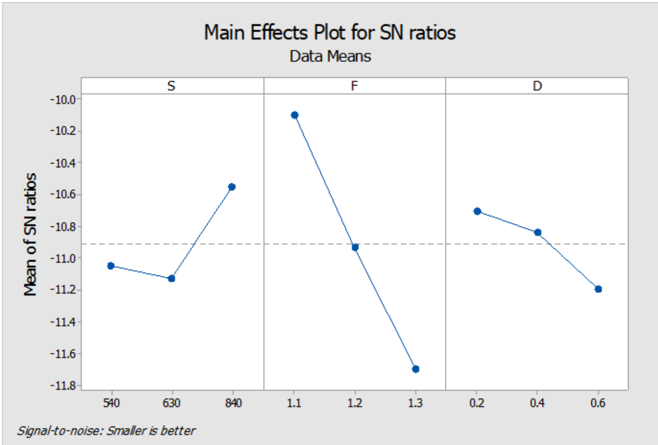

Figure 7: Main effects plot for S/N Ratios of R_a

5.2 Analysis of variance:

The experimental results of surface roughness values were analyzed with analysis of variance

(ANOVA), used to identify the factors significance on the response. The result of ANOVA of surface roughness was given in table 6. This analysis was carried out for a significance level of $\alpha = 0.5$ i.e., for a confidence level of 95%. The source with a P value less than 0.05 are considered to have a statistically significant contribution to the performance measures. From, the results, it is observed that the feed is the most significant parameter followed by cutting speed and depth of cut has less significance in controlling the surface roughness values.

Table 6: Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Seq MS	F-Value	P-Value
S	2	0.2286	9.14%	0.2286	0.2286	25.17	0.000
F	2	1.8883	75.47%	1.8883	1.8882	207.8	0.000
D	2	0.1760	7.04%	0.1760	0.1760	19.38	0.000
Error	20	0.2089	8.35%	0.2089	0.0090		
Total	26	2.5019	100%				

Table 7: Coefficients

Term	Co-ef	SE Co-ef	T-Value	P-Value
Constant	-0.068	0.291	-0.24	0.816
S	-0.000732	0.000146	-5.02	0.000
F	3.239	0.225	14.42	0.000
D	0.494	0.112	4.40	0.000

Table 8: Model Summary

S (Error)	R-sq	R-sq(adj)
0.0953136	91.65%	90.56%

5.3 Regression Equation

The relationship between cutting parameters (speed, feed and DOC) and the response (Surface roughness) was modeled by linear regression using the MINITAB-17 software.

$$Ra = -0.068 - 0.000732\, S + 3.239\, F + 0.494\, D$$

5.4 Comparison of Experimental and regression values of surface roughness

The experimental and the regression values of surface roughness were compared and the comparison graph was plotted by taking experiment number on X-axis and surface roughness value on y- axis and shown in figure 7. It is observed that both experimental and regression values were more accurate and can be used for the prediction of surface roughness values. %Errors between experimental and regression values of surface roughness were calculated.

Table 9: Comparison of experimental and predicted values of surface roughness

No. of Experiments	Ra (EXP)	Ra (REG)	% Error
1	3.22	3.2	0.7
2	3.65	3.62	0.8
3	3.98	4.04	-1.6
4	3.32	3.3	0.7
5	3.65	3.72	-1.9
6	3.74	3.85	-2.8
7	3.38	3.4	-0.5
8	3.4	3.52	-3.6
9	3.85	3.95	-2.5
10	3.12	3.23	-3.6
11	3.62	3.65	-0.9
12	3.98	3.78	5
13	3.42	3.33	2.6
14	3.56	3.46	2.9
15	3.88	3.88	0
16	3.2	3.13	2.1
17	3.58	3.56	0.7
18	4.2	3.98	5.3
19	3.2	3.18	0.7
20	3.25	3.3	-1.6
21	3.62	3.73	-2.9
22	2.98	2.98	0
23	3.45	3.4	1.4
24	3.75	3.82	-2
25	2.98	3.08	-3.3
26	3.56	3.5	1.7
27	3.65	3.63	0.6

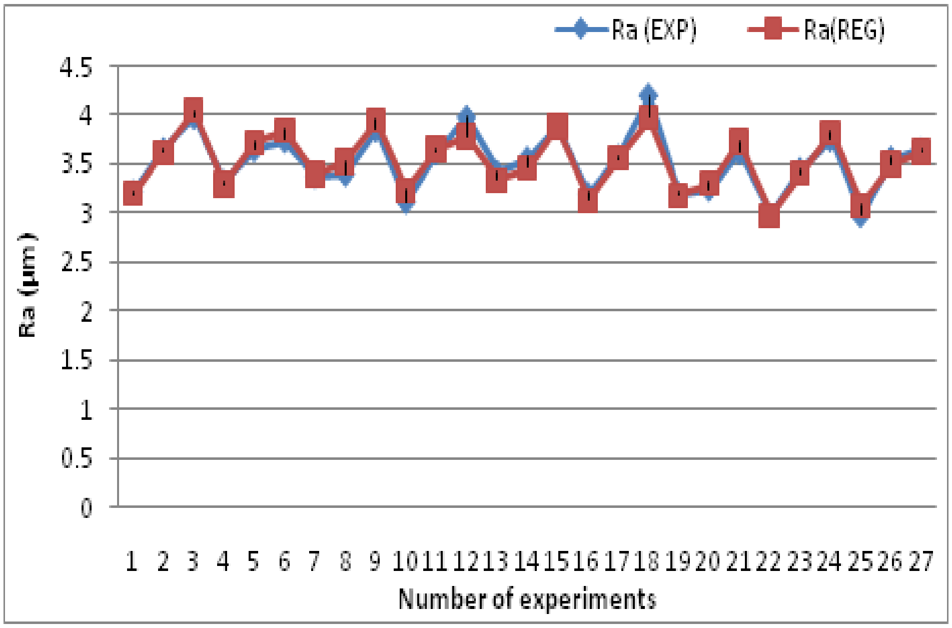

Figure 8: Comparison of experimental and regression values of R_a

6 CONCLUSIONS

The conclusions are pinched on the basis of experimental results of S/N ratio and analysis of variance for machining of Al2285 – 4 wt.% Si_3N_4 - 6% wt.% Mullite Hybrid MMC. All the three parameters are most significant parameters for surface roughness for mild steel material. For better surface finish the parametric combinations is speed 840rpm, Feed 1.1(mm/rev) DOC 0.2 (mm) for machining of material. The number of experiments conducted to arrive at the optimum cutting parameters, Taguchi's method is an efficient methodology to find the optimum cutting parameter. Verification experiments carried out show that the empirical models developed can be used for turning of Al2285 – 4 wt.% Si_3N_4 - 6% wt.% Mullite Hybrid MMC within the 5.3% error.

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