Optimization of Machinability Properties on Aluminium Metal Matrix Composite Prepared By In-Situ Ceramic Mixture Using Coconut Shell Ash - Taguchi Approach

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Abstract- **This paper presents an experimental investigation on the surface roughness of pure commercial Al and Al-15 wt% coconut shell ash (CSA) composites produced by stir casting method. The effect of reinforcements and machining parameters such as cutting speed, feed rate, and depth of cut on surface roughness, which greatly influence the performance of the machined product, were analyzed during turning operation. The optimum machining parameters were found in minimizing the surface roughness of the materials by using the Taguchi [L_9] and ANOVA approach. Results show that the presence of the CSA particles reduces the surface roughness of composites compared with pure Al. Confirmation tests were performed to validate the regression models.**

Keywords: Al MMCs, Surface roughness, Taguchi [L_9], CSAp, ANOVA.

I. INTRODUCTION

Aluminium metal matrix composites (Al-MMCs) have emerged as a potentially desirable material because of their excellent engineering properties, particularly in aerospace, automotive, and electronic industries [1-4]. The surface quality of machined components play a vital role because of the increasing demand for functional attributes such as fitness, fatigue, creep strength, heat transfer, corrosion, and wear behavior [5]. Machining parameters with respect to tool and work piece have to be optimized to attain the minimum cutting forces, increased tooling life, and improved surface texture of machined components. The selection of optimal machining parameters significantly affect the economics of machining operations [6].Manna and Bhattacharayya [7] reported that high cutting speed with low feed rate and low depth of cut enhances the quality of surface roughness during the turning of Al reinforced with 10% SiCp composites. Seeman et al. [8] studied tool wear and surface roughness evaluation through the response surface methodology in machining Al reinforced with a 20% SiCp composite. The surface roughness is low at high speeds, low feed rates, and low depths of cut ranges. Hoecheng et al. [9] investigated the influence of speed, feed, depth of cut, tool rake angle, and cutting fluid on the surface roughness of Al alloy-graphite (Gr) composites. Yuan and Dong [10] analyzed the effect of reinforcement, cutting angle, feed rate, and speed on the surface finish in the ultra-precision diamond turning of Al-SiC composites. Paulo Davim [11] employed the Taguchi method for optimizing the cutting conditions to obtain a good surface finish. Results show that the cutting velocity and feed have considerable influence on roughness, followed by depth of cut.Rabindra Behera et al [12]carried out machining tests on Al-Si MMCs with different cutting speeds (30, 68 and 103 m/min) and depth of cut (0.5, 1 and 1.5 mm) at constant feed of 0.05 mm/rev, and found that there is a decrease in cutting force components Ft , Ff and Fr with increase in cutting speed of the composite reinforced with 7.5 wt%,10 wt%,12.5wt% of SiCp under same cutting conditions .It also reveals that there is linear increase in weight percentage of SiCp in composite. However, few of the existing researchers have applied a Taguchi approach to cross examine the impact of individual factors and factor interactions although the Taguchi method is relatively simple and can be used for optimizing different production stages with few experimental runs [13].

In present study, the surface roughness in turning of the Al/CSAp MMCs with the aid of a Taguchi design of experiment, using ceramic cutting tools under various cutting conditions. In addition, an analysis of variance is employed to find out effective cutting parameters on surface finish. The setup for work piece (Al and Al-CSAp) and cutting tool (carbide) contact interface shown fig 1.

Figure 1: The work piece and tool setup

II. MATERIALS AND METHODS

A. Materials:

Aluminum (Al 99.0) is used as a matrix material. The coconut shell ash particles of size 60 µm are used as the reinforcement materials. The composites are fabricated with 5–15 wt% of the coconut shell ash particle in steps of the 5 wt% .The composites are fabricated by stir casting method as it ensures uniform distribution of the reinforcements. The Al alloy, which is in the form of ingot, has been cut into small pieces to accommodate into the graphite Crucible. Aluminum alloy is at first melted in an electric furnace. Coconut shell ash, preheated to a temperature of about 920 ^{0}C, are added to the molten metal at 720 ^{0}C and stirred continuously. The stirring is done at 600 rpm for 9 min. Then Magnesium is added in small amounts during stirring to increase the wetting. Finally, the melt with reinforcement is poured into permanent metallic mould. The Stir casting setup is given in Fig. 2.

Figure 2: Bottom pouring Melting Furnace (Stir casting Method)

B. Measurement of Surface Roughness

The surface roughness of the Al/CSAp-MMCs was measured by the help of a stylus instrument. The equipment used for measuring the surface roughness was a portable surface roughness tester SURTRONIC 25. The direction of the roughness measurement is perpendicular to the cutting velocity vector. A total of five measurements of surface roughness were taken at random on each machined surface and the average value is used in the analysis.

C. Taguchi Method

Taguchi is a technique which is used to predict optimal performance level based on optimal control factor level combination and conduct a confirmation experiment to verify the results product designed with this performance will deliver more consistent performance. Taguchi experimental verification is done based on orthogonal array technique is a systematic software technique is used when no of inputs of the system is relatively small and two large to allow exhaustive testing of every possible input to the system. **Table 1** shows the levels of parameters considered for the optimization of design. Using Taguchi design L9 orthogonal array is generated for the mixed levels. In addition, it is expected that the optimal process parameter values obtained from the

Parameter design is insensitive to the variation of environmental conditions and other noise factors. Therefore, the parameter design is the key step in the Taguchi method in achieving high quality without increasing the costs [14-15].

The value of the loss function is further transformed into a signal-to-noise (*S/N*) ratio. Usually, there are three categories of the performance characteristic in the analysis of the *S/N* ratio, the lower-the-better, the higher- the- better, and the nominal-the-better. The *S/N* ratio for each level of process parameters is computed based on the *S/N* analysis [16-18].

Table 1: Process Parameters and Their Levels

Parameters	Unit	Levels (- 1)	Levels (0)	Levels (+1)
Cutting Speed (v)	m/min	60	120	180
Feed (f)	mm/rev	0. 5	1 0.	1.5
Depth of cut (d)	mm	0.2	0.3	0.4

Regardless of the category of the performance characteristic; the larger *S/N* ratio corresponds to the better performance characteristic. Therefore, the optimal level of the Process parameters is the level with the highest *S/N* ratio. Furthermore, a statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. With *S/N* and ANOVA analyses, the optimal combination of the process parameters can be predicted [19-21].Finally; a confirmation experiment is conducted to verify the optimal process parameters obtained from the parameter design.

III. RESULTS AND DISCUSSIONS

A. S/N ratio results

The S/N ratio is obtained through the Taguchi technique. The S/N ratio for each parameter was determined by averaging

Table 2: Experimental results and corresponding S/N ratios

SPEED	FEED	DEPTH OF CUT	R_a Al	R_a Al-CSAP	S/N Al	S/N Al-CSAp
60	0.5	0.2	2.12	1.19	-6.527	-1.511
60	1	0.3	2.57	1.66	-8.199	-4.402
60	1.5	0.4	3.2	2.25	-10.1	-7.044
120	0.5	0.3	1.93	1.06	-5.711	-0.506
120	1	0.4	2.34	1.39	-7.384	-2.86
120	1.5	0.2	2.42	1.62	-7.676	-4.19
180	0.5	0.4	1.92	0.935	-5.666	0.5838
180	1	0.2	1.87	0.99	-5.437	0.0873
180	1.5	0.3	2.39	1.36	-7.568	-2.671

the S/N ratios at the corresponding level. The influence of parameters such as cutting speed, feed rate, and depth of cut on the surface roughness (R_a) for Al and Al-CSAp was analyzed table 2. Given that the process parameters with the highest S/N ratio will yield the optimum quality with minimum variance, we can determine from the response tables that the feed rate is a dominant parameter on the surface roughness of tested specimens, followed by cutting speed and depth of cut.

The ranking of the parameters is presented in S/N response in Tables 3&4.

TABLE 3: Response Table for Signal to Noise Ratios for Al			
Smaller is better			
Level	**SPEED**	**FEED**	**DEPTH OF CUT**
1	-8.276	-5.968	-6.547
2	-6.924	-7.007	-7.159
3	-6.224	-8.449	-7.718
Delta	2.053	2.481	1.171
Rank	2	1	3

Given that the process parameters with the highest S/N ratio will yield the optimum quality with minimum variance, we can determine from the response tables that the feed rate is a dominant parameter on the surface roughness of tested specimens, followed by cutting speed and depth of cut.

Table 4:Response Table for Signal to Noise Ratios (Al-CSAp)			
LEVEL	SPEED	FEED	DEPTH OF CUT
1	1.7	1.062	1.267
2	1.357	1.347	1.36
3	1.095	1.743	1.525
DELTA	0.605	0.682	0.258
RANK	2	1	3

The average S/N ratios were plotted for each parameter against each of its levels (Figs. 3&4). The optimum parameters are cutting speed (180 m/min), feed rate (0.5 mm/rev), and depth of cut (0.2 mm) irrespective of the machined surface of the tested materials.

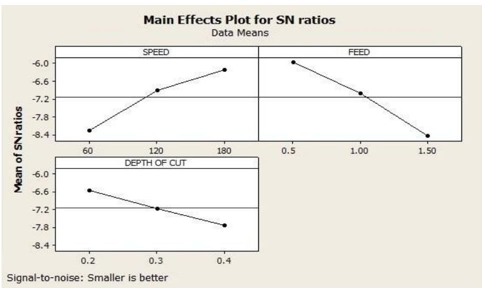

Figure 3 Means of SN ratio for Al

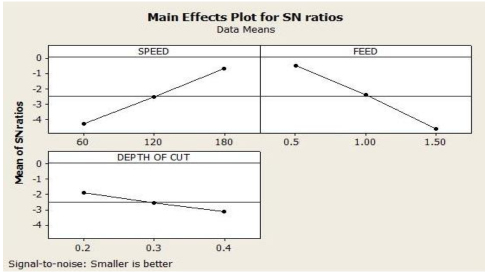

Figure 4 Means of SN ratio for Al-CSAp

B. Analysis of variance

Analysis of variance is a method of portioning variability into identifiable sources of variation and the associated degree of freedom in an experiment. The frequency test (*F*-test) is utilized in statistics to analyze the significant effects of the parameters, which form the quality characteristics. Table 5&6 shows the result of ANOVA analysis of S/N ratio of Al and Al- CSAp for surface roughness. This analysis was carried out for a level of significance of 5%, i.e., for 95% a level of confidence. The last column of the table shows the "percent contribution" (*P*) of each factor as the total variation, indicating its influence on the result.

TABLE 5: Analysis of variance for SN Ratios for Al						
Source	DF	Seq SS	Adj SS	Adj MS	F	P
SPEED	2	6.5317	6.53174	3.26587	420.06	0.002
FEED	2	9.3155	9.31552	4.65776	599.09	0.002
DEPTH of cut	2	2.0589	2.05889	1.02945	132.41	0.007
Residual error	2	0.0155	0.01555	0.00777		
Total	8	17.9217				
S = 0.08817		**R^2 = 99.9%**		**R^2_{adj} = 99.7%**		

Table 6: Analysis of variance for SN ratios Al-CSAp						
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Speed	2	20.0108	20.0108	10.0054	127.76	0.008
Feed	2	25.977	25.977	12.9885	165.86	0.006
Depth of cut	2	2.2922	2.2922	1.1461	14.63	0.064
Residual error	2	0.1566	0.1566	0.0783		
Total	8	48.4366				
S = 0.2798		**R^2 = 99.7%**		**R^2_{adj} = 98.7%**		

C. Multiple linear regression models:

Multiple linear regression equations were developed to establish the correlation among the parameters on the response. The value of regression coefficient R^2 (0.999) is in good agreement with the adjusted R^2 (0.997) for the surface roughness of the pure Al. R^2 (0.997) is in good agreement with the adjusted R^2 (0.987) for the surface roughness of the Al-CSAp composite. Considering that both values are reasonably close to unity, the models provide a good explanation for the relationship between the independent parameters and responses.

The regression equation developed for the surface roughness of the pure Al is as follows:

SRN Al = 1.97 - 0.00475 Speed + 0.445 Feed + 1.75 Depth of cut – (1)

The regression equation developed for the surface roughness of the Al- CSAp composite is as follows:

SRN Al-CSAp = 1.22 - 0.00504 Speed + 0.448 Feed + 1.29 Depth of cut – (2)

We can observe from Equations. (1) & (2) that the feed rate % (B) plays a major role on surface roughness, followed by cutting speed (A) and depth of cut (C). The coefficient associated with cutting speed (A) is negative, thus indicating that the surface roughness of the machined surfaces decreases with increasing cutting speed. Conversely, the surface roughness increases with increasing feed rate and depth of cut because the coefficients associated with these factors are positive. Feed rate has a larger effect on surface roughness compared with the depth of cut according to its coefficient value in the machining of tested materials.

D. Confirmation test

The confirmation test is the final step in the design of the experiment process. Confirmation tests were conducted to validate the statistical analysis by selecting experimental conditions that are different from those employed in the analysis. The parameters used in the confirmation test are presented in table 7.

Table 7: Parameters used in the confirmation test.

TEST	SPEED	FEED	DEPTH OF CUT
1	60	1.5	0.4
2	180	0.5	0.2

Experimental results were compared with the computed values developed from the regression models. Table 8 shows that the experimental values and calculated values from the regression equation are nearly the same with the least error (±5%). The resulting equations are capable of predicting the surface roughness to an acceptable level of accuracy.

IV. CONCLUSIONS

Table 8: Results of confirmation test.

	Test 1			Test 2		
	Model eq.	Exper.	% Error	Model eq.	Experi	% Error
Al	3.052	2.745	2.153	1.487	1.275	-4.953
Al-CSA	2.105	2.089	1.11	1.84	1. 925	-4.619

The investigation results show that

- The feed rate has the highest influence on surface roughness in the machining of an Al- CSAp composite followed by cutting speed and depth of cut.
- Cutting conditions, such as cutting speed (60 m/min), feed rate (1.5 mm/rev), and depth of cut (0.4 mm), can be used to achieve the minimum surface roughness in machining Al, Al-CSAp composites.
- The confirmation tests show that the error associated with the surface roughness of the tested materials varies by approximately (±5%). The closeness of the prediction results based on the regression models and experimental values show that the Taguchi experimental technique can be used successfully for both optimization and prediction.

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