Analysis of Surface Roughness and Burr Height in Drilling of Aluminium Matrix Composites using Taguchi Technique

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Abstract: *The present research involves the opportunity of utilising the signal to noise (S/N) ratio analysis to set machining factors in the drilling of aluminium alloy LM6-Fly ash composites (AMCs). The purpose of this research is to understand, during drilling of AMCs, the consequences of variables, feed rate, spindle speed, drill material and amount of reinforcing material on surface roughness and burr height. AMCs are formed with LM6 (Al alloy) as continuous component via the stir casting process and fly ash as reinforced content. The Taguchi design strategy is a widely accepted method which is used to produce quality products that require minimum commitment. Likewise, the L_{27} orthogonal array is used for conducting experiments. The response table, response graphs and analysis of variance (ANOVA) illustrate the prospective atmosphere and the impacts of input process variables. Taguchi technique considerably enhances the drilling operation.*

Key Words: *Taguchi Technique, ANOVA, Drilling, Composites, Burr Height, Surface Roughness*

1. INTRODUCTION

Composite materials are composed of more than one material which differ in their characteristics, and they are insoluble in each other. The basic component of a composite material is the phase of the matrix which offers weight transfer and good structural stability, but the role of second phase material is to improve the properties of the composite [1].

Owing to the outstanding combinations of characteristics, metal matrix composites combined with ceramic based discontinuous components are really attractive materials for functional applications [2].

Metal matrix composites combine the characteristics of metal alloys with ceramic components resulting in a superior characteristic profile [3]. The AMCs constitute a class of metal matrix composites with characteristics like low density, highly stiff and strong, excellent resistance to wear, regulated thermal expansion coefficient, better fatigue strength and they are stable at extreme temperature [4].

Because of this enhanced properties, they are used in the construction of a broad variety of technical application [5]. The total weight, fuel consumption and emissions in automobiles and aircraft can be minimized by the use of aluminium matrix composites [6].

Metal matrix Composites (MMCs) are hard to process because of their tough properties. An appropriate method of upheaval for their efficient machining needs to be created [7]. AMCs play a major role in the technological world of everyday living. Due to their design characteristics, MMCs are of significant concern [8].

They are made through the method of stir casting, where ceramic particles are mixed along with a molten metal. This cycle is conducted by stirring and strengthening of the melt. Due to their low density, fly ash becomes a major concern among scientists [9, 10].

Drilling is conducted at the end of manufacturing. Therefore, the operation failures are taken with carefulness [11, 12]. The force of the thrust should be kept in check when drilling. Drilling joins the frameworks, and such drilling is required for many useful applications [13].

There is a noteworthy difference to that of MMC among the drilling of traditional metal alloy and its composite material [14]. Design of Experiment (DoE) is a remarkable strategy to demonstrate and evaluate the effect of different control variables.

DoE is developed in accordance with Taguchi technique to optimize operations and determine the finest set of factor. Taguchi technique was designed in such a way as to be able to describe the experiment plan [15, 16].

Experiments are performed to calculate the constraints which affect the response. The S/N ratios are being used as measures of the impact of process parameters on the responses [17].

Analysis of variance is a statistical method used to quantify variables or their interactions in response. Analysis of variance measures the comparative contribution of each controlling parameter to the total assessed response and depicts it in percentage [18].

Machining of composites is difficult due to hard abrasive particles, which cause higher surface roughness and higher tool costs.

This research work contributes to find novel composites and optimum drilling process parameters.

2. EXPERIMENTAL DETAILS

Materials Used

Aluminium alloy (LM6) is used as the matrix material and fly ash as second phase material. The materials chosen in this research are focused solely on property, expense, and usage. Due to the presence of high silicon content, aluminium alloy is difficult to process. Aluminium alloy composite (LM6) serves as the strongest safety in regular as well as marine environments.

This can be made relatively very thin and more complex than any other kind of casting. The constituents of the LM6 are shown in Table 1.

Table 1. Elemental Composition of Aluminium Alloy (LM6)

Constituent	Si	Cu	Fe	Mg	Mn	Ti	Ni	Zn	Al
Weight%	11.48	0.013	0.52	0.02	0.01	0.02	0.01	0.01	Remainder

For this work, 12-micron size fly ash particulates are used as the reinforcement. The advantage of using fly ash is to improve resistance to wear, strength, damping properties, and to reduce the weight of the composite.

Fly ash particulates are used as discontinuous dispersions because they are known as cheap and light material available in large quantities.

The concentration of fly ash via chemical analysis is defined in Table 2. Figure 1 shows the surface structure of fly ash.

Table 2. Elemental Composition of Fly Ash

Constituent	Al	Si	O_2	Fe	Ti	K	Ca	LOI
Weight%	16.73	26.43	38.88	3.82	1.42	0.99	0.05	Remainder

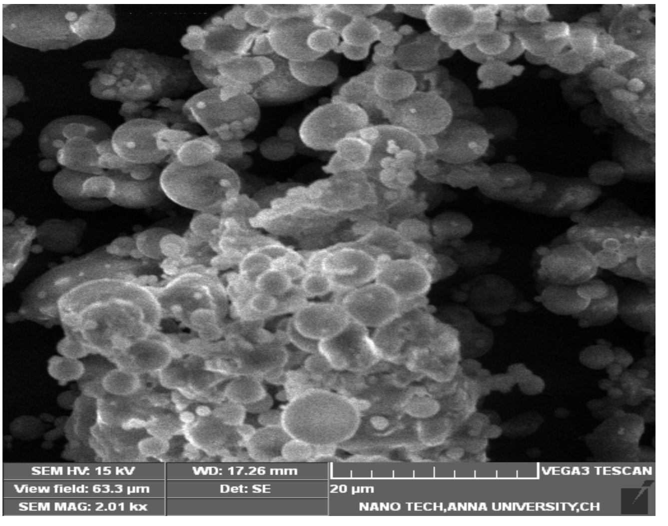

Fig. 1 Morphology of fly ash particles

Preparation of LM6/Fly Ash Composites

Ingots of the LM6 (Al alloy) are taken in a graphite crucible and heated in a furnace. The heat energy supplied is progressively increased to 850ºC; at 800ºC, the melt had been degassed with degasser. The molten aluminium was agitated to form a vortex, as well as the preheated fly ash particles (250ºC) were added. To improve the wettability of molten aluminium particles, 1% magnesium is added to the molten metal. The slurry mixture was agitated for 10 minutes at 600rpm. The amount of reinforcement incorporated is three, six, and nine percentages by weight. The agitated molten aluminium – fly ash slurry is transferred into preheated mould (650°C) and afterwards cooled to ambient temperature. Figure 2 displays the stir casting equipment.

Fig. 2 Stir Casting Setup

Drilling of Aluminium Matrix Composites (AMCs)

Drilling of aluminium metal matrix composites is an efficient machining strategy. The experiments were conducted using the Vertical Machining Centre (Figure 3) with prefixed cutting parameters.

The data processing device is used in the capturing and storage of experimentation data. The Kistler dynamometer is used to measure the thrust force.

Fig. 3 Vertical Machining Centre

Drill Materials

Three different cutting tool materials are used, which are HSS, Carbide and TiN coated carbide.

The drill diameter is 6 mm, point angle is 118° and helix angle is 30° for all the three drills. Figure 4 shows the photograph of drills.

Fig. 4 Photograph of Drills

Surface Roughness Measurement

This measurement is very essential for several basic problems like friction, surface deformation, heat transfer and electrical current, stiffness of joints and spatial precision. Figure 5 demonstrates the surface roughness tester used for this case (Marsurf PS1) to evaluate the surface roughness.

Fig. 5 Surface Roughness Tester

Burr height Measurement – Vision Measuring System

Burr is formed at the hole's outlet by the plastic deformation of the material. These burrs cause many problems with quality of product and performance because they can connect with component assembly and can create jamming effect.

Lot of articles have therefore concentrated their research on exit burr. The height and thickness of the burr can be described by its magnitude. Figure 6 displays the VMS used for burr height measurement.

Fig. 6 Vision Measuring System (VMS)

Design of Experiments

The experiments were developed using an orthogonal array (OA) of L_{27} to compare the result of percentage of reinforcement, drill material, spindle speed, and feed rate. Table 3 indicates the variables of the system, and the levels.

Table 3. Process Parameters and their Levels

Level	Feed (mm/min)	Speed (rpm)	Drill Material	Reinforcement %
1	50	1000	HSS	3
2	100	2000	Carbide	6
3	150	3000	TiN Coated Carbide	9

3. RESULTS AND DISCUSSIONS

The chosen OA is L_{27}, with twenty-seven rows corresponding to the number of experiments on three levels of thirteen columns. Factors and interactions have been given for the columns. First column is assigned for feed rate, 2nd column is allocated to spindle speed, 5th column is designated to drill material, 8th column to percentage of second phase material and the interactions to the remaining columns. The experimental findings are illustrated in Table 4.

Table 4. Experimental Results

Expt. No.	Feed rate (mm/ min)	Spindle Speed (rpm)	Drill Material	Reinforce-ment (%)	Surface Roughness R_a (μm)	S/N ratio of R_a	Burr Height (mm)	S/N ratio of Burr Height
1	50	1000	HSS	3	2.433	-7.722	0.238	12.481
2	50	1000	Carbide	6	3.444	-10.741	0.109	19.251
3	50	1000	TiNcoated	9	3.084	-9.783	0.032	29.897
4	50	2000	HSS	6	4.495	-13.055	0.034	29.286
5	50	2000	Carbide	9	3.716	-11.401	0.024	32.396
6	50	2000	TiNcoated	3	3.119	-9.880	0.256	11.847
7	50	3000	HSS	9	4.351	-12.772	0.088	21.078
8	50	3000	Carbide	3	2.827	-9.028	0.111	19.120
9	50	3000	TiNcoated	6	4.988	-13.959	0.125	18.062
10	100	1000	HSS	3	3.627	-11.192	0.238	12.468
11	100	1000	Carbide	6	3.511	-10.908	0.144	16.853
12	100	1000	TiNcoated	9	4.038	-12.124	0.017	35.391
13	100	2000	HSS	6	3.000	-9.542	0.040	28.031
14	100	2000	Carbide	9	3.087	-9.790	0.020	34.125
15	100	2000	TiNcoated	3	4.116	-12.290	0.217	13.271
16	100	3000	HSS	9	3.762	-11.509	0.238	12.468
17	100	3000	Carbide	3	2.496	-7.946	0.127	17.924
18	100	3000	TiNcoated	6	3.053	-9.695	0.156	16.156
19	150	1000	HSS	3	2.831	-9.040	0.220	13.152
20	150	1000	Carbide	6	2.569	-8.194	0.094	20.507
21	150	1000	TiNcoated	9	3.000	-9.542	0.036	28.955
22	150	2000	HSS	6	2.712	-8.665	0.024	32.276
23	150	2000	Carbide	9	3.000	-9.542	0.018	35.057
24	150	2000	TiNcoated	3	2.871	-9.160	0.163	15.739
25	150	3000	HSS	9	1.860	-5.390	0.154	16.250
26	150	3000	Carbide	3	2.462	-7.825	0.172	15.273
27	150	3000	TiNcoated	6	3.570	-11.053	0.217	13.257

As lower surface roughness and lower burr height values are considered desirable for good product quality, “smaller the better” has been selected for S/ N ratio estimation.

The optimal level parameters for machining for the responses is observed at a level in which each variable has the largest S/ N ratio [19].

From Table 5 it is evident that, at the third level of feed (A_3), third level of spindle speed (B_3), second level of drill material (C_2) & first level of reinforcement (D_1), the surface roughness is smallest.

At such parameter levels, the main effects plot of the S/ N ratio for surface roughness shown in Figure 7 is also the highest resulting in the optimum surface roughness value.

Accordingly, the combination of $A_3B_3C_2D_1$ (A_3=150mm/ min, B_3=3000 rpm, C_2= Carbide drill, D_1=3 %) is considered desirable for the smallest surface roughness within the variable range examined and also has the maximum S/ N ratio.

From the rank order of Table 5 it is clear that the feed has the highest effect on surface roughness followed by the drill material, reinforcement and speed.

Table 5. Response Table for Surface Roughness

Level	Feed	Speed	Drill	Reinforcement
1	-10.927	-9.916	-9.876	**-9.342**
2	-10.555	-10.369	**-9.486**	-10.646
3	**-8.712**	**-9.908**	-10.832	-10.206
Delta	2.214	0.461	1.346	1.303
Rank	1	4	2	3

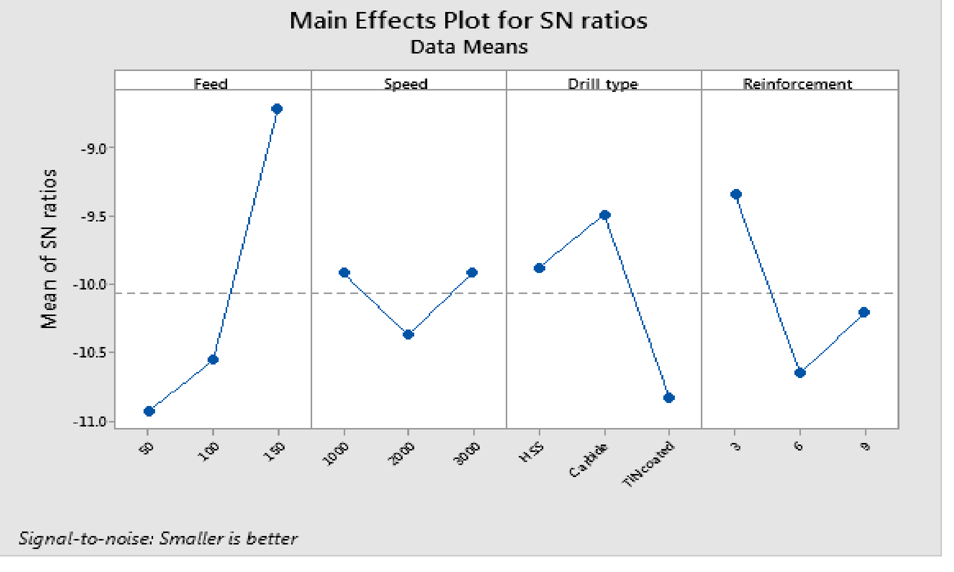

Fig. 7 Response Graphs for Surface Roughness

ANOVA is used to describe the optimal combinations of control parameters by analysing the comparative importance of variables in view of their relative contribution to the response [20]. Feed rate has a greater effect on the surface roughness. ANOVA Table 6 represents the amount of percentage contribution relative importance for each variable in regulating the response (surface roughness). The feed rate contributes (26.838%), followed by the interaction between Feed*Reinforcement (18.238%), the interaction between Feed*Speed (16.391%), drill (9.150%), reinforcement (8.393%), Feed*Drill (5.696%).

Table 6. ANOVA Table for Surface Roughness

Source	DF	SS	MS	F	p	Contribution %
Feed (A)	2	25.31	12.6549	5.77	0.04	26.838
Speed (B)	2	1.253	0.6267	0.29	0.761	1.329
Drill (C)	2	8.629	4.3146	1.97	0.22	9.150
Reinforcement (D)	2	7.915	3.9575	1.8	0.244	8.393
Feed*Speed (AB)	4	15.458	3.8646	1.76	0.255	16.391
Feed*Drill (AC)	4	5.372	1.3431	0.61	0.67	5.696
Feed*Reinforcement (AD)	4	17.2	4.3001	1.96	0.22	18.238
Residual Error	6	13.169	2.1949			13.964
Total	26	94.308				100

Similarly, from Table 7 it is obvious that, at the first level of feed (A_1), second level of spindle speed (B_2), second level of drill (C_2) and third level of reinforcement (D_3), the burr height is the smallest. At these variable levels, the main effects plot of the S/ N burr height ratio shown in Figure 8 is the optimum that results in the smallest burr height. Therefore, the combination of $A_1B_2C_2D_3$ (A_1= 50mm/ min, B_2=2000 rpm, C_2= Carbide drill, D_3=9 %) is considered to be ideal for the lowest Burr height within the parameter range investigated and has the highest S/ N ratio, too. From Table 7 rank order it is noticeable that the reinforcement has the greatest influence on Burr height followed by the spindle speed, drill and feed rate.

Table 7. Response Table for Burr height

Level	Feed	Speed	Drill	Reinforcement
1	**21.49**	20.99	19.72	14.59
2	20.74	**25.78**	**23.39**	21.52
3	21.16	16.62	20.29	**27.29**
Delta	0.75	9.16	3.67	12.7
Rank	4	2	3	1

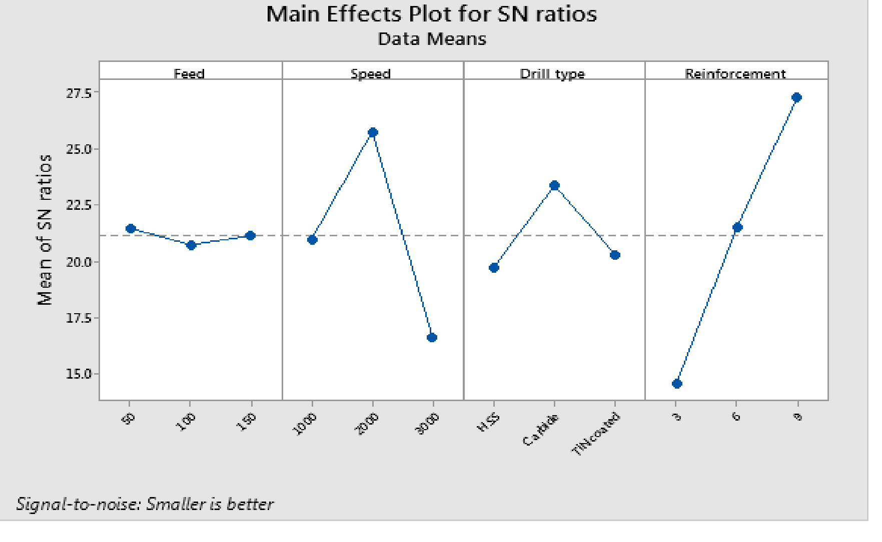

Fig. 8 Response Graphs for Burr Height

Similarly, ANOVA Table 8 reveals the importance of each factor in controlling the response (burr height). Among the selected drilling parameters, the reinforcement has the highest contribution on burr height (42.203%), followed by speed (21.892%), drill (4.069%), the interaction between the Feed*Speed (3.008%), Feed*Drill (1.512%), Feed*Reinforcement (0.315%) and finally feed (0.147).

Table 8. ANOVA Table for Burr Height

Source	DF	SS	MS	F	P	Contribution %
Feed (A)	2	2.53	1.263	0.02	0.984	0.147
Speed (B)	2	377.83	188.914	2.45	0.167	21.892
Drill (C)	2	70.22	35.112	0.45	0.655	4.069
Reinforcement (D)	2	728.39	364.195	4.71	0.059	42.203
Feed*Speed (AB)	4	51.91	12.978	0.17	0.947	3.008
Feed*Drill (AC)	4	26.1	6.526	0.08	0.984	1.512
Feed*Reinforcement (AD)	4	5.43	1.356	0.02	0.999	0.315
Residual Error	6	463.51	77.252			26.856
Total	26	1725.92				100

Confirmation Experiments

The optimum parameters are used to perform the confirmation experiments and also to predict the surface roughness and burr height values. Suitable variables for achieving minimal surface roughness are at level A_3, B_3, C_2, D_1 which is 150 mm/ min feed, 3000 rpm speed, carbide drill and 3% Fly ash. The predicted surface roughness value is 2.501μm and the experimental surface roughness value is 2.462μm. Similarly, the optimum parameters to achieve minimum burr height are A_1, B_3, C_3 and D_3 which are feed 50 mm/min, speed 3000 rpm, TiN Coated drill and 9% reinforcement. The predicted value of burr height is 0.008 mm and the experimental value is 0.024 mm.

4. CONCLUSIONS

i) Three different composites (LM6+ 3% Fly Ash, LM6+ 6% Fly Ash & LM6+ 9% Fly Ash) were produced using stir casting and drilling was done on these composite plates.
ii) Feed (26.838 %) has more influence on Surface Roughness followed by the interactions between Feed*Reinforcement (18.238%), Feed*Speed (16.391%), drill (9.150%), reinforcement (8.393%), Feed*Drill (5.696%).
iii) Percentage reinforcement has the highest contribution on burr height (42.203%), followed by speed (21.892%) and drill (4.069%).
iv) The confirmation experiments show that there is a considerable enhancement in the drilling operation by the use of Taguchi technique.

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