Studies on Drilling Characteristics of Heat Treated Aluminium A356/Silicon Carbide Reinforced Metal Matrix Composites and Optimization of Parameters using Taguchi Technique

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Abstract - *The main objective of the present work is to fabricate SiC particles reinforced Aluminium metal matrix composite (Al-0, 10 and 20 wt. % SiC MMC) and optimization of drilling process parameters using Taguchi technique in the heat treated MMC specimen. The A356-SiCp reinforced composite has been fabricated by liquid metal stir casting technique. The microstructural evaluation indicated that the maximum reinforcement concentration was found at the 20 wt. % SiC reinforced specimen. The composite specimens were heat treated and Ti-Al-N coated carbide tool was used for the drilling studies. The effect of drilling parameters such as cutting speed, feed, point angle and weight percentage of SiC (0, 10 and 20 wt. %) on the surface roughness and thrust force were analysed using Taguchi technique. Analysis of variance (ANOVA) was also employed to study which drilling parameters significantly influence the drilling process. The results revealed that speed, feed, point angle and zone distance had the highest significance on the drilling process.*

Key Words: Metal Matrix Composites, Heat treatment, Drilling, Taguchi Technique, ANOVA.

1. INTRODUCTION

The purpose of Aluminium alloy is necessity in aerospace and automobile industries due to its properties of high strength to weight ratio, outstanding corrosion resistance, easy machinability and low cost [1]. Several researchers reviewed the properties obtained from MMC and documented widely. The various properties of MMC and the influence of properties by the developing route of MMC have also been reported by a number of investigators. The properties such as improved specific modulus, high strength and resistance to wear, fatigue, creep and corrosion are obtained by applying various reinforcements to the matrix alloy. The tensile and compressive strength are the majority quoted measurement due to their importance in industrial applications [2]. Currently, manufacturing industries are in front of challenges from machining the latest difficulties to machine materials like composites and ceramics. These advanced materials have excellent properties like high strength even at high temperatures and wear resistance compared to other materials and it provides better options for component design. So, machining is required to achieve the desired dimension, tolerance and surface finish for components made from these materials to meet the advanced applications [3]. Ramesh Kumar et al (2019) had done machining on hybrid Aluminium composite using HSS drill bits. The influence of parameters like cutting speed, feed, depth of cut and percentage of reinforcement on the thrust force, surface roughness and circularity were studied. The result showed that cutting speed is highly influencing the drilling [4]. Vinoth Babu et al (2017) conducted the machining study on Aluminium alloy and Aluminium based MMC with carbide tools. The effects of surface roughness and thrust force are studied. It was found that the surface finish is mainly affected by point angle during the drilling of MMC. The parameters such as speed, feed, point angle and weight percentage of reinforcement influence the surface roughness [5]. Vinoth Babu et al (2012) used Taguchi method to get the optimal machining parameters of speed, feed, point angle and zone for getting better surface roughness in drilling operations of functionally graded material using carbide drills. The Taguchi method is suitable for only to found the optimal parameter settings for a single performance characteristic and the approach becomes unsuitable when multiple performance characteristics with contradictory goals are measured [6]

The aim of the present study is to fabricate Aluminium reinforced with SiC metal matrix composite (Al-MMC) by liquid metal stir casting technique and optimizes the drilling parameters for heat treated Al-MMC using Taguchi technique.

2. MATERIALS AND METHODS

2.1 Raw materials and its composition

Aluminium alloy A356 is used as a base material for the fabrication of homogeneous MMC because of its heavy engineering applications due to its strength, workability and weldability. The elements of Aluminium alloy A356 and its weight percentage are shown in table 1.

Table -1: Elements of aluminium ally A356 and its weight percentage

Element	Si	Mg	Cu	Fe	Zn	Al
Wt. %	7.0	0.35	0.2	0.2	0.1	Balance

The reinforcing material used for the present fabrication of metal matrix composite is green variety silicon carbide (0, 10 and 20 wt. % SiC) with an average size of 23 µm because of its high wear resistance. The density of silicon carbide is 3.21 g/cm^3.

2.2 Fabrication of Composite

Aluminium alloy A356 reinforced with silicon carbide (0, 10 and 20 wt. % SiC) metal matrix composite was fabricated by liquid stir casting technique. Initially, Aluminium alloy is melted in a crucible made up of clay graphite using resistance heated furnaces with 10 kg capacity. The melt is stirred by mechanical means using an impeller driven by an electrical motor. The rotational speed of the stirrer is controlled to around 350 rpm. The stirring speed is controlled by a dynodrive motor. The SiC particles are preheated to about 600^{o}C prior to the addition. The preheated particles are added to the melt with a known feed rate of around 1 gm/sec and melt temperature of 740^{o}C. Before powder addition, 1% Mg is added at 730^{o}C to compensate for the loss of Mg in the melt due to oxidation. The particles are added to the molten metal in the crucible via manual powder addition mechanism. After the powder addition, a baffle is introduced in the crucible for uniform mixing of the composite and the stirring is done for 15 minutes after which degassing should be done.

Fig -1: Al - 0,10 and 20 wt. % SiC MMC

Degassing is done to avoid the hydrogen entrapment. Degassing is done by passing N_2 gas to the molten metal through the sulphuric acid. Sulphuric acid will act as a purifier, and the N_2 gas will remove the H_2 from the molten metal. Degassing is done for about 20 minutes till the temperature reaches 760^{o}C. Then the molten metal is poured into the mould of dimension 60 mm diameter and 150 mm length. After that, the molten melt was allowed to cool for 6 to 7 hours in the room temperature. The fabricated drilling workpiece specimen is machined to the size of 50 x 55 x 15 mm as shown in figure 1. The microstructural examination was done on the fabricated MMC.

2.3 Drilling Operation

Drilling operations were performed on the heat treated MMC using Hartford CNC vertical machining centre. The Ti-Al-N coated 5 mm diameter carbide tool was selected for the drilling studies. The surface roughness of drilled holes was found using the Mitutoyo SJ 201 surfestanalyzer. The thrust force was measured by Kisteler piezo dynamometer which is connected with the CNC drilling machine.

2.4 Selection of control parameters and their levels

Taguchi's Design of Experiment is a method used to evaluate the design parameters. This method gives high quality product design with a minimum number of experiments at low time and cost. So this method was used to study the influence of control parameters on the thrust force and surface roughness. The experiment used four control parameters such as speed, feed, point angle and weight percentage of SiC. The control parameters and their levels are given in table 2. The L9 orthogonal array was chosen for the experimentation.

Table -2: Control parameters and their levels

Symbol	Control Parameters	Level 1	Level 2	Level 3	Unit
A	Speed	1000	2000	3000	rpm
B	Feed	0.05	0.15	0.25	mm/rev
C	Point angle	90	120	140	degree
D	Weight percentage of SiC	0	10	20	wt.%

3. RESULTS AND DISCUSSION

3.1 Microstructural Examination

Figure 2 show the microstructure of fabricated three heat treated composites. The microstructure (Figure 2a) observed at the first fabricated specimen shows the absence of volume percentage of SiC particle because of the absence of SiC. The microstructure (Figure 2c) observed at the third fabricated specimen shows the maximum volume percentage of SiC particle because of the addition of 20 wt.% of SiC. The microstructure (Figure 2b) observed at the second fabricated specimen shows moderate volume percentage of SiC particle between the first and third specimen because of the addition of 10 wt.% of SiC.

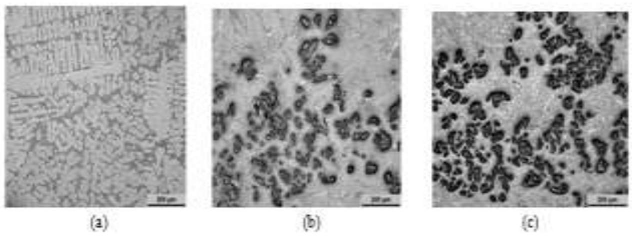

Fig - 2a: Microstructure of 356 Al alloy;
Fig - 2b: Microstructure of 356Al-10% SiC composite;
Fig – 2c: Microstructure of 356Al-20% SiC composite

3.2 Experimental Details

The holes are drilled in the heat treated MMC specimen and the experimental results are shown in table 2. The typical heat treated machined specimens are shown in figure 3.

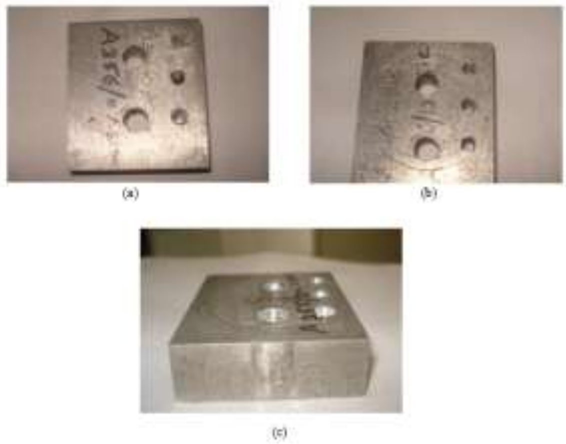

Fig - 3a: Drilled specimen of A 356 base alloy;
Fig - 3b: Drilled specimen of A356 + 10% SiC;
Fig - 3c: Drilled specimen of A356 + 20 % SiC

Table -3: Experimental results and their S/N ratio

Trial No	Parameter				Experimental Result		S/N ratio	
	Speed (rpm)	Feed (mm/rev)	Point angle (deg)	Weight percentage of SiC (wt.%)	Surface Roughness Ra (micron)	Thrust force F (N)	Surface Roughness (dB)	Thrust Force (dB)
1	1000	0.05	90	0	4.530	106	-13.12	-26.81
2	1000	0.15	120	10	1.740	83.2	-4.81	-21.60
3	1000	0.25	140	20	2.060	111.2	-6.27	-23.59
4	2000	0.05	120	20	2.420	55.38	-7.67	-20.04
5	2000	0.15	140	0	1.640	113.4	-3.69	-22.39
6	2000	0.25	90	10	2.450	174.3	-7.78	-26.30
7	3000	0.05	140	10	1.686	64.90	-3.75	-19.99
8	3000	0.15	90	20	3.396	109.1	-10.61	-25.68
9	3000	0.25	120	0	2.123	118.3	-6.53	-23.99

3.3 Signal-to-Noise (S/N) ratio Analysis

Signal to ratio gives the optimal process parameters that are influencing the surface roughness and thrust force in the drilling process of heat treated MMC. The S/N ratio is used to find the rank of influencing process parameters on the surface roughness and thrust force. "Smaller-the-better" quality characteristic is used to find the optimal process parameters that affect the surface roughness.

The rank of the process parameters based on the delta value is shown in table 4. S/N ratio shows that surface roughness was highly influenced by the point angle followed by weight percentage of SiC, feed and speed. Figure 4 shows the S/N ratio plot for surface roughness. The optimum process parameters to obtain minimum surface roughness are cutting speed of 2000 rpm, feed of 0.15 mm, point angle of 140^o and weight percentage of SiC of 10 wt.%

Table -4: S/N ratio response table for surface roughness

Factors	Level 1	Level 2	Level 3	Max-min	Rank
Speed	-8.070	-6.384	-6.970	1.686	4
Feed	-8.183	-6.375	-6.867	1.808	3
Point angle	-10.508	-6.342	-4.574	5.934	1
Weight percentage of SiC	-7.785	-5.448	-8.191	2.743	2

"Smaller-the-better" quality characteristic was used to found the optimal process parameters that affect the thrust force. Table 5 shows the rank of the process parameters that affect the thrust force based on the delta value. S/N ratio shows that the thrust force was heavily influenced by feed followed by point angle, weight percentage of SiC and speed. Figure 5 shows the S/N ratio plot for the thrust force. Cutting speed of 3000 rpm, feed of 0.05 mm, point angle of 120º and weight percentage of SiC of 20 wt.% was identified as the optimum process parameters to obtain minimum thrust force.

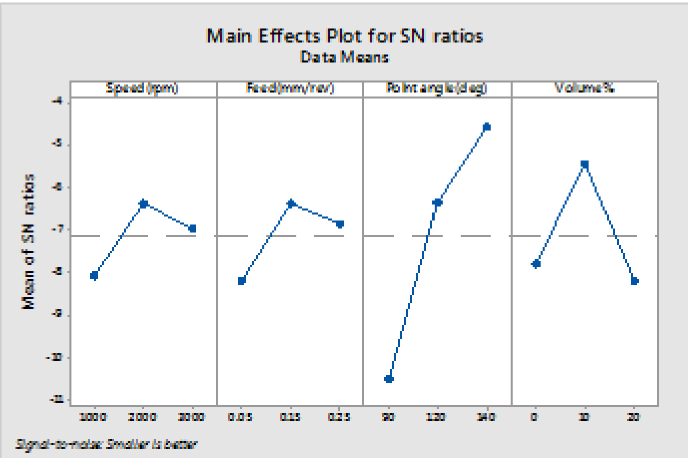

Fig – 4: Main effects S/N ratio plot for surface roughness.

Table - 5: S/N ratio response table for thrust force

Factors	Level 1	Level 2	Level 3	Max-min	Rank
Speed	-39.94	-39.45	-39.49	0.50	4
Feed	-36.39	-40.08	-42.40	6.01	1
Point angle	-42.03	-37.43	-39.42	4.60	2
Weight percentage of SiC	-41.02	-39.82	-38.03	2.99	3

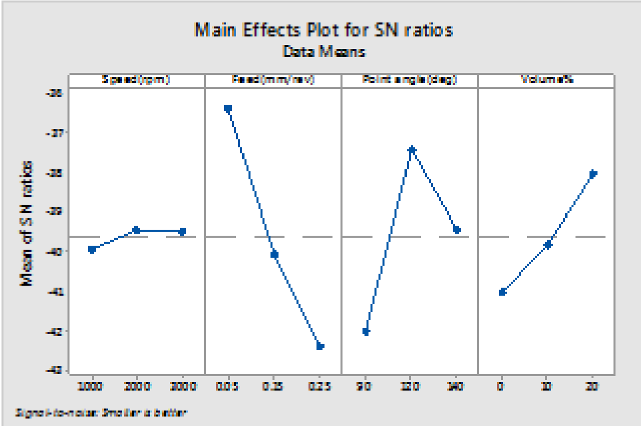

Fig – 5: Main effects S/N ratio plot for thrust force.

3.4 Analysis of Variance (ANOVA) and the effect of factors

ANOVA was carried out to find out the significance of the various process parameters on the experiments. Table 7 shows the result of ANOVA. This analysis was conducted for a confidence interval of 95% and a significant level of 5%. The result shows that point angle had a greater effect (66.21%) on the surface roughness followed by weight percentage of SiC (15.56%), feed (9.83%) and speed (8.44%).

Table – 7: Analysis of Variance table for Surface Roughness.

Factors	Degree of freedom	Sum of Squares	Mean Sum of Squares	Contribution %	Rank
Speed	2	0.6461	0.3208	8.44	4
Feed	2	0.7529	0.3765	9.83	3
Point angle	2	5.0670	2.5335	66.21	1
Weight percentage of SiC	2	1.1908	0.5954	15.56	2
Total	8	7.6523		100	

Table 8 shows the result of ANOVA for thrust force. The analysis shows that feed had a greater effect (54.71%) on the thrust force followed by point angle (33.41%), weight percentage of SiC (9.57%) and speed (2.29%).

Table - 8: Analysis of Variance table for thrust force.

Factors	Degree of freedom	Sum of Squares	Mean Sum of Squares	Contribution %	Rank
Speed	2	255.1	127.6	2.29	4
Feed	2	6088	3044	54.71	1
Point angle	2	3717.7	1858.9	33.41	2
Weight percentage of SiC	2	1065.1	532.5	9.57	3
Total	8	11125.9		100	

3.5 Confirmation Test

After selecting the optimum process parameters, the confirmation experiment is done with optimum process parameters. The predicted surface roughness was calculated using a linear regression model. The linear regression equation obtained using MINITAB 17 is given below.

Surface roughness = 7.54 – 0.000212 Speed – 3.09 Feed – 0.0358 Point angle – 0.0051 Weight percentage of SiC

The confirmation experiment was done with the combination of optimum process parameters and the optimum surface roughness was calculated. Table 9 shows the results of the confirmation experiment.

Table – 9: Results of the confirmation experiment for surface roughness.

Factor	Predicted surface roughness Micron	Experimental surface roughness Micron
Surface Roughness	1.5895	1.5899

The predicted thrust force is calculated by using a linear regression model. The linear regression equation obtained using MINITAB 17 is given below.

Thrust force = 156.5 – 0.00135 Speed + 318.5 Feed – 0.742 Point angle – 1.260 Weight percentage of SiC

The confirmation experiment was done with the combination of optimum process parameters and the optimum thrust force was calculated. Table 10 shows the results of the confirmation experiment.

Table- 10: Results of the confirmation experiment for thrust force.

Factor	Predicted thrust force N	Experimental thrust force N
Thrust force	54.135	54.255

4. CONCLUSIONS

Drilling operation is performed on the heat treated MMC using Ti-Al-N coated 5 mm diameter carbide tool. L9 orthogonal array table was used to study the effect of thrust force and surface roughness. Taguchi method was adopted to investigate the effects of process parameters such as speed, feed, point angle and weight percentage of SiC on thrust force and surface roughness of heat treated MMC. The major conclusions drawn from the results are as follows:

The optimum process parameters for higher surface roughness are the speed of 2000 rpm, feed of 0.15 mm, point angle of 140^{o} and weight percentage of SiC of 10 wt. % was identified and ANOVA analysis shows that that point angle had a greater effect (66.21%) on the surface roughness followed by weight percentage of SiC (15.56%), feed (9.83%) and speed (8.44%).

The optimum process parameters for higher thrust force are the speed of 3000 rpm, feed of 0.05 mm, point angle of 120^{o} and weight percentage of SiC of 20 wt. % was identified and ANOVA analysis shows that that feed had a greater effect (54.71%) on the thrust force followed by point angle (33.41%), weight percentage of SiC (9.57%) and speed (2.29%).

The confirmation experiment is conducted to verify the optimum parameters. It shows better performance.

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