International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Issue 06, Volume 6 (June 2019) - Special Issue www.ijirae.com
SPECIAL ISSUE - 4th National Conference - "RTME – 2019"

EVALUATION OF MACHINING PARAMETERS & SURFACE ROUGHNESS OF AL4600/SIC METAL MATRIX COMPOSITE BY TAGUCHI EXPERIMENTAL DESIGN TECHNIQUE.

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Manuscript History
Number: **IJIRAE/RS/Vol.06/Issue06/Special Issue/SI.JNAE10094**
Received: 28, May 2019
Final Correction: 05, June 2019
Final Accepted: 10, June 2019
Published: **June 2019**
Editor: Dr.A.Arul L.S, Chief Editor, IJIRAE, AM Publications, India

Abstract—The paper presents the results of experimental investigation on mechanical properties, machining Characteristics & Surface Roughness of an Aluminum Metal Matrix Composite (Al/SiC). Composite is prepared by using stir casting technique. The influence of reinforcement ratios of 0, 4 and 8 wt. % of SiC on mechanical Properties is discussed. Machining of composite by using turning operation and its characteristics that influence the cutting force and surface roughness such as feed rate, depth of cut and cutting speed was studied. It was observed that increase of reinforcement element addition produced better mechanical properties. Experimental results revel that the cutting forces increases with increase in weight percentage and Flank wear and decreases with increase in the cutting speed. It was observed that the cutting speed, Flank wear and the feed rate at constant depth of cut affects the surface roughness during dry turning operation of cast MMCs. Taguchi L27 orthogonal array technique is considered with four factors i.e. Material, cutting speed, feed & artificially induced tool wear, each at 3 different levels, has been employed. The experimental results reveal that cutting speed is most influencing parameter when cutting force Fx is considered. Similarly when surface roughness is considered tool wear plays the most influencing factor.

Keywords— MMC, Stir Casting, Mechanical Properties, Taguchi.

I. INTRODUCTION

Particle reinforced aluminium metal matrix composites (MMCs) have developed in the last few years, in order to reduce the weight of components in structural applications and to improve their mechanical properties and physical properties.Due to the advancement in the material technology to produce desired materials from various industrial applications and fast changing scenario in the production of lighter and stronger materials, composite materials are gaining wide acceptance due to their unusual characteristics of behavior with their high strength to weight ratios. The most widely used material in these industries is aluminum and their alloys because of their light weight.

To make these alloys of aluminum further versatile and flexible for varieties of application, during which these materials is expected to behave as expected and provide a long life under different environments, the composites have emerged as the single most material, which can provide a better service and better quality. The composite material is non-homogeneous and anisotropic, the cutting behavior of this material is quite different from that of homogeneous material like steel. Also, a number of reinforcement materials are significantly harder and highly abrasive than the commonly used tool materials. Thus, machining of MMCs presents a significant challenge. Despite the superior mechanical and thermal properties of MMCs, their poor machinability and high machining costs have been the main deterrent to their substitution of metal parts. With the advent of the excessive usage of MMCs, the study of their machinability aspects have become a prospective research area of significant interest.

By using the design of experimental (DOE) method, number of experiments can be reduced, which will reduce the time of experimentation. The relation between the most influencing factor and its interrelation among all the other factors are found with the limited number of experiments by using DOE based on Taguchi orthogonal array. To develop a better understanding of product or process performance, Taguchi method uses definite sequences for the experiments, which is simple, proficient and methodical multi-step statistical technique. This method used to determine the relationship between the output parameters and number of control factors. Considering the importance on use of MMC owing to its high strength & hardness, the present work aims at studying hardness, machinability and surface roughness of Al4600/SiCp composite by using Taguchi experimental design technique.

II LITERATURE SURVEY

Tamer Ozben,et al.[1] has studied the mechanical and machinability of silicon carbide particle(SiC-P) reinforced aluminium metal matrix composites. In this study 5,10& 15 wt% of SiCp on mechanical properties examined. The effect of machining parameters eg. Cutting speed, feed rate and depth of cut on tool wear and surface roughness was studied.

Parvin et al. [2] studied on the influence of Al2O3 particle size on the mechanical properties of sintered Al- Al2O3 composites prepared by using powder metallurgy technique. In this study 10 wt% of Al2O3 powder with 3 different particle sizes 3, 12, and 48μm were used in the production of samples. Samples were cold pressed to 440MPa, and sintered at 5500C for 45 mints under argon atmosphere in an electric furnace. Result showed that relative density of composites increased with increasing Al2O3 particle size up to 12μm, however raising the particle size up to 48μm led to abrupt reduction in relative density. The hardness of the Al- Al2O3 composites increased in the presence of fine Al2O3 particle and also shows the yield strength and compression strength increased in the presence of fine Al2O3 particles.

In Sourav Kayala et al. [3]. This paper silicon carbide particulate reinforced Al 4600 alloy matrix composites were fabricated by green sand molding process by varying the particulate addition by weight fraction on percentage basis. Tensile properties and hardness tests studies were conducted to determine the tensile strength, modulus of elasticity and the hardness of the as cast MMCs. The experimental result reveals that the tensile properties and hardness of the as cast composites increases with the increasing the weight percentage of silicon carbide particulates in the matrix metal.

T.Sasimurugan et al. [4]. In this study, Aluminium metal matrix composites are finding increased applications in many areas. Adding of the third element to the metal matrix make the composite hybrid. The experimental studies were carried out on a lathe. The composites were prepared using the liquid metallurgy technique, in which 3, 6 and 9 wt % of particulates SiC and Al_2O_3 were dispersed in the base matrix. The obtained cast composites were carefully machined. The characteristics that influence the surface roughness such as feed rate, depth of cut and cutting speed were studied, which made the analysis come to a conclusion that the surface roughness is increases with the increase of feed rate and it reduces the surface roughness with the increase of cutting speed.

A.Manna et.al. [5] Studied the machinability of silicon carbide particulate aluminium metal matrix composite during turning using fixed rhombic tools. The influence of machining parameters, e.g. cutting speed, feed and depth of cut on the cutting force and surface finish criteria were investigated during the experimentation. The turning operations were performed considering 0.5 mm/rev constant feed and 0.5mm depth of cut. The test results show that the value of both surface roughness heights Ra and Rt are low at high cutting speed and comparatively high at low cutting speed. Cutting speed zone between 60 and 150 m/min is recommended for machining of Al/SiC-MMC, where cutting forces are more or less independent of cutting speed.

Rabindra Behera et al. [6] described the influence of machining parameters such as cutting forces and surface roughness on the machinability of AL 4600/ SiCp metal matrix composites at different weight fraction of SiCp. Machining tests were carried out at different cutting speed (i.e., 30, 68 and103 m/min) and different depth of cuts (i.e., 0.5, 1.0 and 1.5mm) at constant feed rate i.e., 0.05 mm/rev to study the machinability of as cast composites.

It was observed that the depth of cut and the cutting speed at constant feed rate affects the surface roughness and the cutting forces during dry turning operation of cast MMCs. It was also observed that higher weight percentage of SiCp reinforcement imparts a higher surface roughness and needs high cutting forces. This experimental analysis and test results on the machinability of Al/SiC-MMC will provide essential guidelines to the manufacturers. Srinivasan et al. [7] Studied on the machinability evaluation through the response surface methodology in machining of homogenized 10% micron Al2O3 LM25 Al MMC manufactured through stir casting method. Metal Matrix Composites (MMC) have become a leading material among composite materials and in particular, particle reinforced aluminum MMCs have received considerable attention due to their excellent engineering properties. These materials are known as the difficult-to-machine materials because of the hardness and abrasive nature of reinforcement element like Alumina (Al2O3).The combined effects of three machining parameters including cutting speed (s), feed rate (f) and depth of cut (d) on the basis of three performance characteristics of tool wear (VB), surface Roughness (Ra) and cutting Force (Fz) were reported.

III OBJECTIVES

- To study the Mechanical properties e.g. Hardness
- To study the influence of different cutting parameters, like cutting speed, depth of cut and feed rate on the machinability characteristics like cutting forces, tool wear, and surface finish during turning of Al-SiC MMC.
- Prediction of surface roughness, using multiple regression technique and comparison with the experimental values.

IV METHODOLOGY

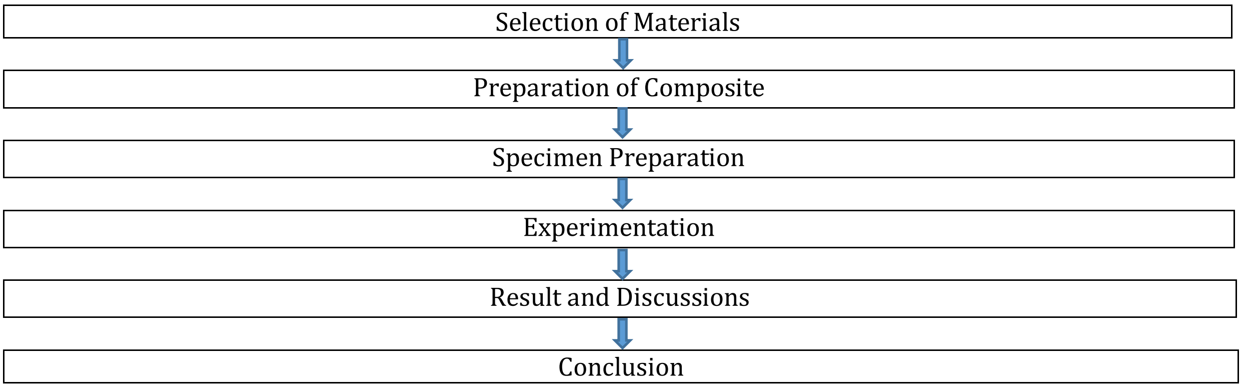

Figure 1 Flow chart for experimental Procedure

The flow chart of experimental procedure is as shown in the Fig.1.

V EXPERIMENTAL PROCEDURE

A. Selection of materials

i) Matrix Material: Al 4600 (as per IS 617(1994))

Aluminum alloy Al 4600 (as per IS617 (1994) is having good machinability. It exhibits excellent resistance to corrosion under both ordinary atmospheric and marine conditions. For the severest conditions, this property can be further enhanced by anodic treatment. It is equally adaptable for sand casting and aluminium die casting (gravity die casting and pressure die casting). Chemical composition is as shown in the table 1

Table 1 Chemical composition of Al 4600

Cu	Si	Mg	Zn	Fe	Mn	Ni	Ti	Pb	Al
0.1	10.0-13.0	0.1	0.1	0.6	0.5	0.1	0.1	0.1	BAL

ii) Reinforcement Material: silicon carbide (36 grit/483 micron)

Silicon carbide also known as carborundum, SiC is the chemical compound made up of carbon and silicon. It was produced by a high temp electro-chemical reaction of sand with raw petroleum coke which contains carbon in it. Silicon carbide is an excellent abrasive material and has been produced and made into grinding wheels and other abrasive products for over hundred years. Presently material has been developed into high quality technical grade ceramic with very good mechanical properties such as Exceptional hardness, High strength, Low density, High elastic modulus, High thermal shock resistance, Superior chemical inertness, High thermal conductivity, Low thermal expansion. It is shown in the fig 2.

Figure 2 Reinforcement Material (Sic)

B. Preparation of Composites

Composites are prepared by stir casting method. Base metal aluminum alloy is heated and melted in a crucible and heated to about 750 degree centigrade in the electric resistance furnace . Degassing is carried out with hexa-chloroethane tablet. Then the stirrer was immersed gently into the molten metal bath and stirrer was rotated at a speed of 0 to 500 rpm to create a vortex in the liquid metal. Preheated SiC is added to the melt through the side of the vortex. After completion of addition of SiC the stirrer was continued for 5 minutes and stopped was quickly withdrawn. The composite melt was then poured at a preheated temperature into a cast-iron permanent mould. The cast composite is as shown in the fig 3

Figure 3 The cast composite

C) Specimen preparation

Specimens are prepared for Hardness, machining specimen for surface roughness & microstructure study with 0%, 4% & 8% of silicon carbide added by weight to the base alloy Al4600.

i) Hardness test specimen
ii) Machining specimen for Surface roughness
iii) Microstructure study.

i) Hardness test specimen

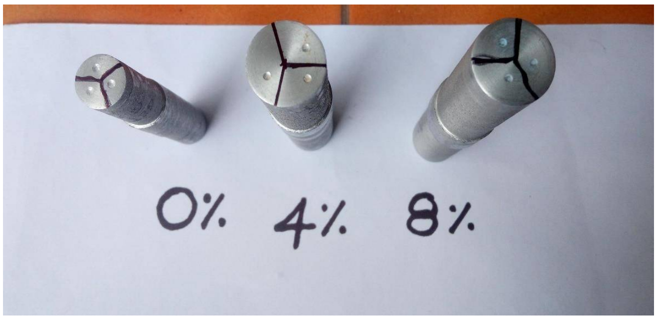

Figure 4 Hardness test specimen

After casting process the aluminum alloy Al4600/SiC composite rods were machined on the lathe machine to form specimens that were suitable for hardness test is as shown in the fig 4.

ii) Machining specimen for Surface roughness

The casted specimen is taken. The extra projections on the on the specimen is removed using hacksaw and lathe. The specimen is machined to particular dimensions as per the specifications as shown in the figure 5

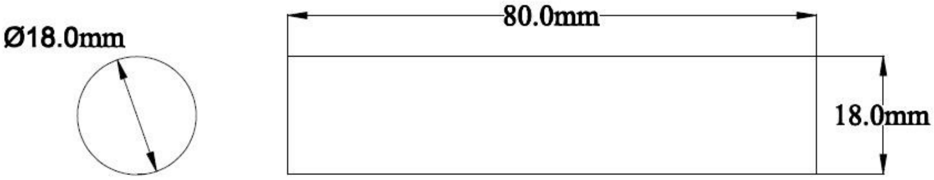

Figure 5 Geometry of Machining Specimen

iii) Microstructure study.

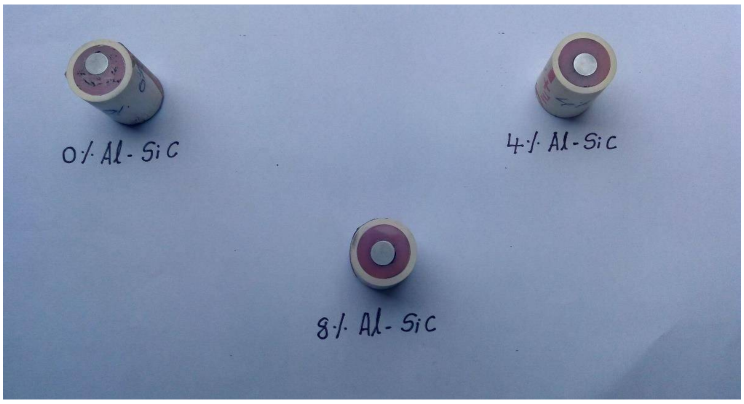

Figure 6 Microstructure Test Specimens

The Microstructure Test Specimens are prepared with the cast specimen is as shown in the figure 6.

D) Experimentation

i) Hardness test

- The indenter is pressed into the sample by an accurately controlled test force.
- The force is maintained for a specific dwell time, normally 10 to15 seconds.
- After the dwell time is complete, the indenter is removed leaving a round indent in the sample.
- The size of the indent is determined optically by measuring two diagonals of the round indent using either a portable microscope or one that is integrated with the load application device.
- The Brinell hardness number is a function of the test force divided by the curved surface area of the indent. The indentation is considered to be spherical with a radius equal to half the diameter of the ball. The average of two diagonals is used in the following formula to calculate the Brinell hardness.

ii) Machining of composite to study Surface roughness

Figure 7 Lathe Machine

The lathe used for carrying out the turning operation is Enterprise 1330. This lathe has 8 spindle speeds ranging from 54 to 1200 rpm. The lathe machine used for the present work is as shown in the figure 7. Tungsten carbide tool has been selected for carrying out the machining operation of Al-SiC metal matrix composite. The figure 8 shows the tungsten carbide tool inserts. These tool inserts are artificially ground to induce an artificial flank wear to conduct the Experiment.

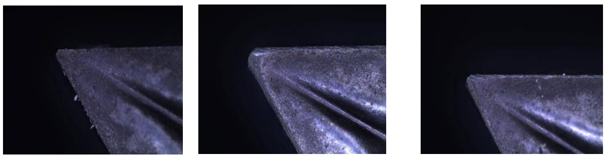

Figure 8 Tungsten carbide tool with 0, 0.1 & 0.2mm flank wear.

E) Taguchi method

Taguchi method is a standardizes approach for determining the best combination of inputs to produce a product or service. It is done through design of experiments. It provides a method for quantitatively identifying just the right ingredients that go together to make a high quantity product or service. In this experiment we have 4 different control parameters i.e. Material (Al 4600/SiC), Cutting speed (m/min), Feed rate (mm/rev) & Tool wear (flank wear, mm) each at three different levels. Codes and levels of these three factors are listed in table 1

Table 2 Levels for various control factors

Code	Control Factors	Level		
		1	2	3
A	Material (Al+ SiC) (%)	0	4	8
B	Cutting speed (m/min)	13	28.27	43.82
C	Feed rate (mm/rev)	0.2	0.3	0.4
D	Tool wear (Flank wear)(mm)	0	0.1	0.2

F) Regression Analysis

Regression analysis method is used for the estimation of surface roughness. The objective of regression analysis is to develop a model that explains as much as possible, the Variability in a dependent variable, using several independent variables. Operating Parameters like speed, depth of cut, feed rate and time are considered as the independent Parameters for constructing the regression model. The variation of measured and Estimated Surface roughness with feed rate and speed has been presented in the form Graphs for comparison.

VI) RESULTS AND DISCUSSIONS

i) Hardness test results are as shown in the table 3.

Table.3 Hardness test results

Reinforcement Ratio	BHN
AL 4600-base	54
AL 4600-4 wt%SiC	58
AL 4600-8 wt%SiC	64

From the table 3 it is observed that the hardness of the composite is increasing with the increase of reinforcing particulate content. The hardness value of the composite is higher than that of its matrix alloy. This increase in hardness of the composite may be attributed due to the reason that the reinforcement materials used is much harder than that of the matrix material.

ii) Analysis of surface roughness.

Table 4: Experiments based on Taguchi L27 orthogonal array

Sl.No	Material Wt % SiC	Cutting speed in (m/min)	feed rate in (mm/rev)	Tool Wear (Flank Wear) (mm)
1	0	13	0.2	0
2	0	13	0.3	0.1
3	0	13	0.4	0.2
4	0	28.27	0.2	0.1
5	0	28.27	0.3	0.2
6	0	28.27	0.4	0
7	0	43.82	0.2	0.2

8	0	43.82	0.3	0
9	0	43.82	0.4	0.1
10	4	13	0.2	0
11	4	13	0.3	0.1
12	4	13	0.4	0.2
13	4	28.27	0.2	0.1
14	4	28.27	0.3	0.2
15	4	28.27	0.4	0
16	4	43.82	0.2	0.2
17	4	43.82	0.3	0
18	4	43.82	0.4	0.1
19	8	13	0.2	0
20	8	13	0.3	0.1
21	8	13	0.4	0.2
22	8	28.27	0.2	0.1
23	8	28.27	0.3	0.2
24	8	28.27	0.4	0
25	8	43.82	0.2	0.2
26	8	43.82	0.3	0
27	8	43.82	0.4	0.1

Table 5: Experimental data using Taguchi L27 orthogonal array for base alloy and composite

Sl.No	Cutting force FX (N)	Mean of cutting Force Fx(N)	Signal to Noise (S/N) Ratio	Experimental Ra (µm)	Mean Ra (µm)	Signal to Noise (S/N) Ratio
1	186.39	186.3	-45.40	11.92	11.92	-21.5
2	107.91	107.9	-40.66	14.05	14.05	-22.9
3	112.81	112.8	-41.04	15.37	15.37	-23.7
4	230.53	230.5	-47.25	14.58	14.58	-23.2
5	196.2	196.2	-45.85	13.04	13.04	-22.3
6	142.24	142.2	-43.06	13.79	13.79	-22.7
7	132.43	132.4	-42.43	13.23	13.23	-22.4
8	122.62	122.6	-41.77	12.08	12.08	-21.6
9	107.91	107.9	-40.66	10.43	10.43	-20.3
10	132.43	132.4	-42.43	7.16	7.16	-17.0
11	259.96	259.9	-48.29	9.01	9.01	-19.0
12	284.43	284.4	-49.07	13.64	13.64	-22.6
13	103	103.0	-40.25	12.33	12.33	-21.8
14	103	103.0	-40.25	12.53	12.53	-21.9
15	93.195	93.19	-39.38	12	12.00	-21.5
16	142.24	142.2	-43.06	8.88	8.88	-18.9
17	93.195	93.19	-39.38	11.72	11.72	-21.3
18	137.34	137.3	-42.75	9.45	9.45	-19.5
19	122.62	122.2	-41.77	9.01	9.01	-19.0
20	210.91	210.9	-46.48	9.81	9.81	-19.8
21	240.24	240.2	-47.61	11.2	11.20	-20.9
22	188.29	188.2	-45.49	11.68	11.68	-21.3
23	196.2	196.2	-45.85	12.8	12.80	-22.1
24	112.81	112.8	-41.04	10.74	10.74	-20.6
25	188.29	188.2	-45.49	8.87	8.87	-18.9
26	122.62	122.6	-41.77	8.14	8.14	-18.2
27	132.43	132.4	-42.43	6.97	6.97	-16.8

Tables 4 & 5 shows the Taguchi L27 orthogonal array of the experiment layout, obtained results of cutting Force(Fx) and surface roughness for all the experimental condition is summarized. Analysis regarding the influence of each control factor on the Cutting Force(Fx) and surface roughness is performed by Minitab 18 software package.

Since cutting Force(Fx) during machining & surface roughness is a 'lower the better' type of a quality characteristic (because objective is to minimise the surface roughness) therefore, the S/N ratio for 'lower the better' type of response was used which is given by the following equation: S/N = -10log[$\sum_{i=0}^{n}\frac{y_i^2}{n}$]

Where, n is the number of observations, y is result of the experiments. Regardless of the category of the quality characteristics, the desired value of S/N ratio is always intended to be the lower one. The mean value of the cutting force (Fx) and surface roughness for each machining parameters at different levels were calculated. These average mean values of surface roughness (Ra) & signal to noise (S/N) ratio of cutting force (Fx), for each machining parameters at levels 1, 2, 3 are given in table 6, & 7, respectively. Similarly, average mean values & S/N ratio of surface roughness, for each machining parameters at levels 1, 2, 3 are given in table 8, & 9, respectively. Delta refers to the difference between maximum and minimum of mean cutting force (Fx) or S/N ratios for a particular control factor. The higher the value of the delta, the more significant will be the control factor.

It is clear from table 6 & 7 that the tool wear is the most significant control factor followed by cutting speed in case of machining cutting force (Fx). Similarly, from table 8 & 9 that the control factor material is the most significant control factor followed by cutting speed in case of surface roughness (Ra). Main effect plots for mean & interaction plot in Fig.9 &10 shows, cutting force (Fx) is minimum at A1, B3, C3, D1. Similarly plots for main effects for S/N ratio in Fig 11&12 shows cutting force is minimum at A2, B3, C3,D1. Main effect plots for mean & interaction plot in fig 13 &14 shows surface roughness (Ra) is minimum at A3, B3,C1,D1. Similarly plots for main effects for S/N ratio analysis in Fig 15 & 16 shows surface roughness is minimum at A3,B3,C1, D1.

Table 6 Response table for Mean Cutting force (Fx)

Level	A	B	C	D
1	148.8	184.2	158.5	125.3
2	149.9	151.7	157.0	164.3
3	168.3	131.0	151.5	177.3
Delta	19.5	52	7.0	53.2
Rank	3	2	4	1

Graphs:

Fig.9 Main effects plot for mean cutting force (Fx)

Fig.10 Interaction plot for mean cutting force (Fx)

Table 7 Responce table for S/N Ratios of Cutting force (Fx)

Level	A	B	C	D
1	-43.13	-44.76	-43.74	-41.78
2	-42.77	-43.16	-43.37	-43.81
3	-44.22	-42.20	-43.01	-44.52
Delta	1.45	2.56	0.73	2.74
Rank	3	2	4	1

Graphs:

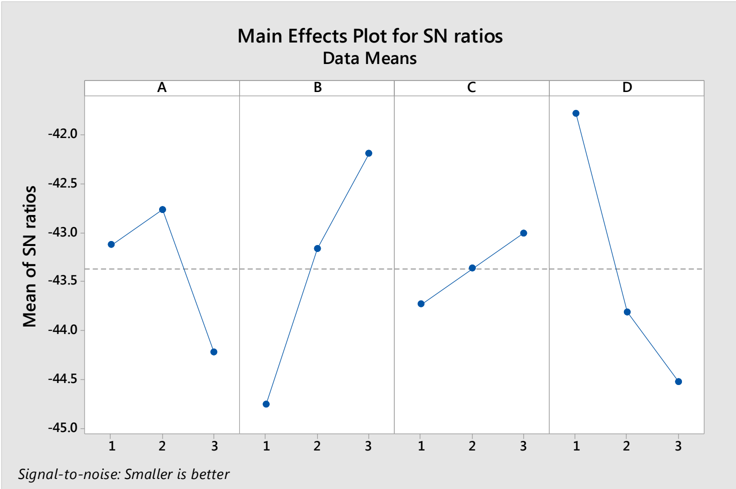

Fig.11 Main effects plot for S/N ratio of cutting force (Fx)

Fig.12 Interaction plot for S/N ratio of cutting force (Fx)

Table 8 Response table for Mean Surface roughness

Level	A	B	C	D
1	13.166	11.241	10.851	10.729
2	10.747	12.610	11.464	10.923
3	9.913	9.974	11.510	12.173
Delta	3.252	2.636	0.659	1.444
Rank	1	2	4	3

International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Issue 06, Volume 6 (June 2019) - Special Issue www.ijirae.com
SPECIAL ISSUE - 4th National Conference - "RTME – 2019"

Graphs:

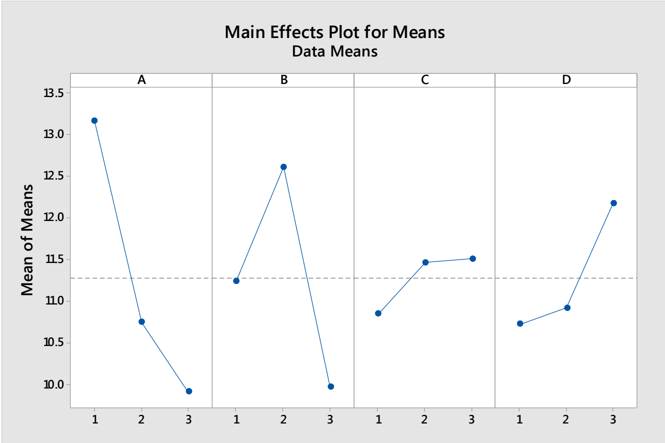

Fig.13 Main effects plot for mean Surface roughness

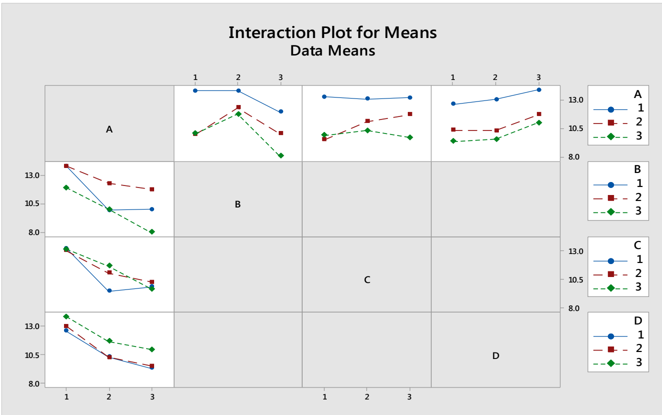

Fig.14 Interaction plot for mean Surface roughness

Table 9 Response table for S/N Ratios of Surface roughness

Level	A	B	C	D
1	-22.34	-20.78	-20.50	-20.44
2	-20.46	-21.98	-21.06	-20.56
3	-19.78	-19.81	-21.02	-21.58
Delta	2.55	2.17	0.56	1.14
Rank	1	2	4	3

Graphs:

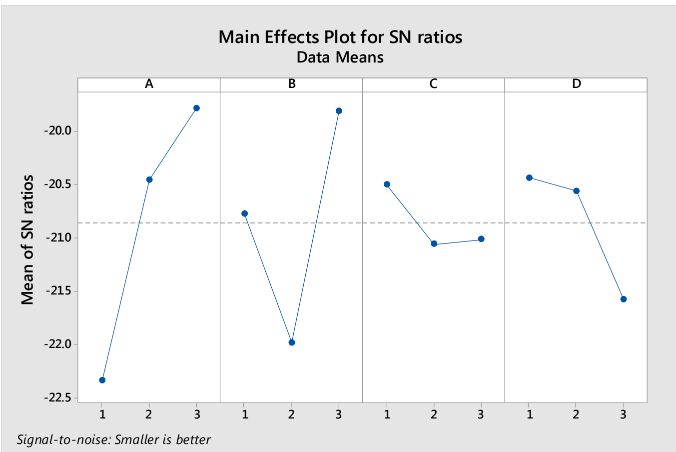

Fig.15 Main effects plot for S/N ratio of Surface roughness

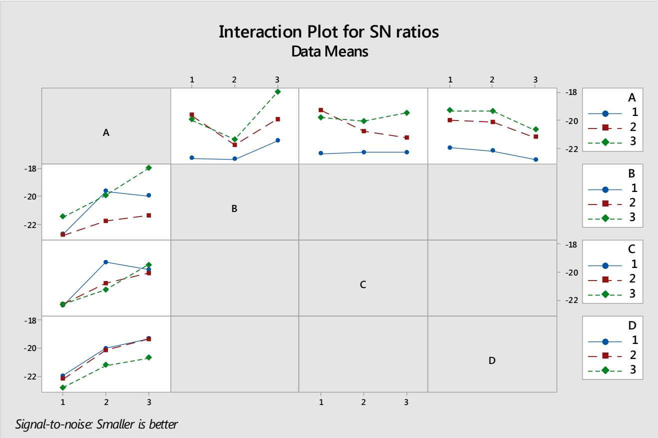

Fig.16 Interaction plot for S/N ratio of cutting force Fx

iii. Regression Analysis

Making use of the experimental data, a mathematical model has been developed, using Regression analysis. In this analysis surface roughness is considered as the dependent Variable and speed, feed, depth of cut and time are considered as the independent Variable. The first order polynomial model has been developed. The first-order Polynomial is given in the equation.

$$Y=A0+A1X1+A2X2+A3X3$$

After regression analysis the above equation is obtained as,

Regression Equation Ra =26.10 - 0.2544 Cutting speed - 13.70 Feed rate - 8.628 time

Y = 26.10 - 0.2544 (10.11) - 13.70 (0.2) - 8.628 (1.10)

Y = 11.29μm

Where, Y= Surface roughness (μm), X1= Cutting speed (m/min), X2= Feed rate (mm/rev), X3= Cutting time (min) A0, A1, A2 and A3 are the Co-efficient of X1, X2, and X3. Same method is used for finding other predicted values. Table 10 shows comparisons of experimental and predicted surface roughness values of AL 4600 with 0 wt%, 4 Wt% & 8 wt % SiC, there are three parameters are considered such as speed, feed and Flank wear. By varying speed From 13.0- 28.27-43.82 m/min, feed rate at 0.2,0.3,0.4 mm/rev and Flank wear with 0mm, 0.1mm,0.2mm. Average surface roughness (Ra) values are measured with the aid of Tally surf surface Roughness Tester and predicted values calculated with the help of regression analysis in Minitab software.

Table 10: Comparison between Experimental and predicted Surface Roughness (R_A) values

Sl.No	Experimental values Ra (μm)	Predicted values Ra (μm)
1	11.92	11.29
2	14.05	15.28
3	15.37	15.2
4	14.58	14.62
5	13.04	13.71
6	13.79	13.12
7	13.23	12.27
8	12.08	11.5
9	10.43	11.1
10	7.16	8.31
11	9.01	9.63
12	13.64	12.56
13	12.33	12.16
14	12.53	11.69
15	12	11.01
16	8.88	9.19
17	11.72	10.99
18	9.45	8.45

19	9.01	8.05
20	9.81	9.2
21	11.2	12.91
22	11.68	12.33
23	12.8	11.86
24	10.74	11.01
25	8.87	9.62
26	8.14	8.85
27	6.97	8.45

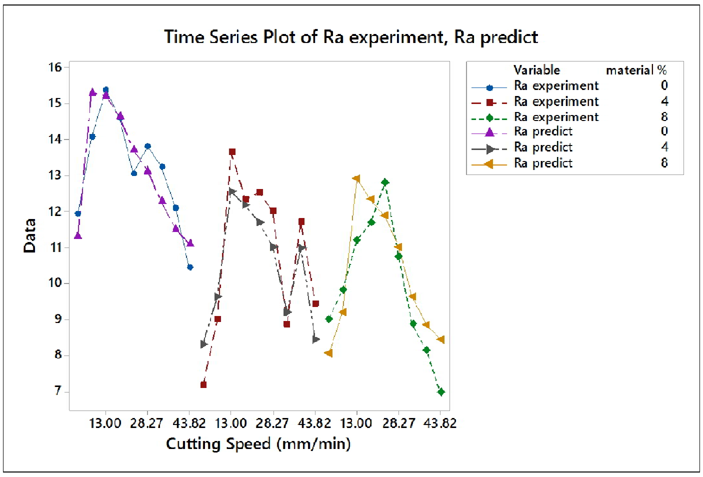

Figure 17 Time series plot for Experimental and Predicted Surface Roughness values v/s cutting speed

The Fig 17 shows the Time series plot for Experimental and Predicted Surface Roughness values v/s cutting speed. The Cutting Speed has major influence on the surface Roughness compared to the Feed rate, Flank wear and constant depth of cut, so graph is plotted for varying cutting speeds at (0%, 4%,8%) SiC reinforcement in the X axis v/s experimental and predicted surface roughness on the Y axis. In all the 3 variations the surface roughness decreases with increase in the Cutting speed. The difference in the Experimental and predicted Surface Roughness value is under 10% error.

VII. CONCLUSIONS

In this study, Hardness, & Design of experiment(DOE) by using Taguchi L27 orthogonal array has been adopted to investigate the effect of different parameters such as Material (Al4600 alloy & Composite Al4600/SiC), Cutting speed, feed & artificially induced tool wear on Cutting force Fx & Surface roughness (Ra). Based on the experimental results and their relevant analyses, the following conclusions may be drawn:

1. The Al4600 reinforced with SiC particulates that is Al4600/SiC metal matrix composition were successfully fabricated through liquid metallurgy route for 4% & 8% reinforcement.
2. The hardness of the composite is increases with the increase of reinforcing content
3. The experimental investigation was conducted to turn Al4600 alloy and Al4600/SiC composite using Tungsten carbide inserts at three levels of cutting parameters by using Taguchi technique to determine the optimum level of machining parameters. Among the four factors, tool wear is found to be most influencing factor followed by cutting speed, Material & feed rate, when cutting force is considered.
4. Surface roughness response table shows Material is found to be most influencing factor followed by cutting speed, tool wear & feed rate.
5. Experimental and predicted surface roughness from regression analysis shows, only 10% error in predicted values. From experimental surface roughness values it can be seen that, Surface roughness decreases with increase in the Cutting speed.

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