Machining Studies on Hybrid AMCs used for Automotive Applications

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ABSTRACT

The main advantages of composite materials are its high specific strength, good resistance to heat and abrasion. In this investigation, the aluminium matrix was reinforced with fly ash particulates (5 wt.%) and varying percentage of Silicon Carbide. LM-13 grade of Aluminium alloy was used as the matrix material and the synthesis of the composite specimens was carried out with through the stir casting route. These LM-13 Aluminium alloy/Silicon Carbide/fly ash hybrid metal matrix composites can be used in the manufacture of automotive components such as piston, cylinder liners and drive shafts. The composite workpieces were turned using a CNC lathe and the turning operation was carried out at various levels of input parameters such as speed, feed, depth of cut and weight percentage of Silicon Carbide. S/N ratio analysis and ANOVA were used to study the contribution of these turning parameters on surface roughness and material removal rate of the composites. MINITAB 17.1 software was used to analyze the results. It was determined from the analysis that the factor feed had the major effect on the surface roughness as well as material removal rate. Regression equations were developed to calculate the output parameters for different set of turning parameters.

Keywords: Aluminium Matrix Composites, Surface Roughness, Material Removal Rate, Design of Experiments, S/N ratio analysis.

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INTRODUCTION

In the last two decades, research has shifted from monolithic alloys to composites to meet the global demand for light weight, high performance, wear and heat resistant materials [1]. The composite material has characteristics that are different from the characteristics of its constituents. In Aluminium Matrix Composites (AMCs), one of the constituent is aluminium alloy, which functions as the matrix phase and the other constituent which is dispersed in the matrix is the reinforcement.

The major advantages of AMCs are:

- ✓ Improved strength
- ✓ Improved stiffness

- ✓ Reduced density (weight)
- ✓ Improved thermal conductivity
- ✓ Controlled thermal expansion coefficient
- ✓ Improved abrasion and wear resistance [2]

AMCs are being used increasingly in numerous automotive, aerospace, structural and functional applications in different engineering sectors. They give improved performance and also have economical and environmental benefits. The AMCs are used in hot reciprocating parts such as pistons, where hot strength and resistance to thermal stresses are a prerequisite. The unique thermal properties of AMCs such as metallic conductivity with coefficient of expansion that can be tailored down to zero, add to their prospects in aerospace and avionics [3].

LM-13 grade Aluminium alloy was chosen as the matrix in this research work. LM-13 alloy is mainly used for applications where thermal stresses are high, since it can withstand higher temperatures and has good wear resistance. Particulate reinforcements are generally preferred in comparison to fibre reinforcements since they are easy to manufacture, cheaper and allow secondary forming operations [4]. AMCs which are reinforced with Silicon Carbide (SiC) have enhanced specific strength, lower thermal expansion coefficient, higher thermal conductivity and wear resistance [5,6]. The chief constituents of fly ash particulates are the oxides like silica, alumina and iron oxides. Fly ash has a low density and it is generally mixed with aluminium to reduce the overall weight and density of the composites. The cost of fly ash is also much lower than most other reinforcing materials and as well as the matrix aluminium. Therefore the usage of the low cost fly ash particulates in aluminium alloy has the potential to reduce the cost of AMC products.

In this research work, Aluminium matrix was reinforced with SiC and fly ash particulates. The hybrid composite was prepared with the help of stir casting equipment. The reason for using stir casting was to achieve uniform distribution of materials and also due to the fact that it is economical [7]. The hybrid composites were then subjected to turning operations with various levels of process parameters such as speed, feed, depth of cut and wt.% of SiC. Carbide tipped tool was used for the turning operations, since the AMCs are comparatively harder than conventional materials and also due to the fact that these tools have the capacity to withstand the high temperatures encountered during the high speed turning operation [8]. Material Removal Rate (MRR) and Surface Roughness (SR) were considered as the output parameters in order to evaluate the machining quality in this study.

Design of Experiments (DOE) is a powerful analysis tool for modelling and analysing the influence of multiple control factors on the performance output. DOE approach using Taguchi technique can be used so that the process can be optimized and optimal combination of the factors for a given response can be measured [9,10]. Similar approach was used by researchers in the electric discharge machining studies of hybrid AMCs [11]. Taguchi's Signal-to-Noise (S/N) ratios, which are logarithmic functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results. It helps in predicting the extent to which the parameters affect the response. Analysis of Variance (ANOVA) was used to determine the influence of individual machining parameters on the responses and as well as their interactions. Regression analysis helps in predicting the value of the response when the parameters are varied within a certain range.

EXPERIMENTAL DETAILS

Materials Used

In this research work, LM-13 Aluminium alloy has been used as the matrix, and SiC and fly ash particulates were used as reinforcements. The chemical composition of LM-13 alloy is listed in Table 1. SiC was used owing to better strength and thermal properties whereas fly ash was used for its lower density.

Table 1. Chemical composition of LM-13 alloy

Element	% by weight
Copper	0.7-1.5
Iron	1.0
Lead	0.1
Magnesium	0.8-1.5
Manganese	0.5
Nickel	1.5
Silicon	10.0-13
Tin	0.1
Titanium	0.2
Zinc	0.1
Aluminium	Remainder

Preparation and Machining of Composite Specimens

Nine composite specimens of 20mm length and 75mm diameter were fabricated with three different weight percentage of SiC (0 wt.%, 5 wt.% and 10 wt.%) and a constant 5 wt.% fly ash. A total of 27 specimens were prepared using stir casting equipment so that they could be utilized for the 27 different experiments. Table 2 shows the composition of the various composite specimens. These composite specimens (workpieces) were then subjected to turning operation in a CNC lathe at various speeds, feeds and depth of cut for duration of 2 minutes 45 seconds.

Table 2. Composition of the AMC specimens

Number of AMC specimens	LM-13 Aluminium alloy (wt.%)	Fly ash (wt.%)	Silicon Carbide (wt.%)
9	95%	5%	0%
9	90%	5%	5%
9	85%	5%	10%

Measurement of Output Parameters

Surface Roughness (SR) and Material Removal Rate (MRR) of the machined samples are the performance characteristics which are used to evaluate the machining quality in this study. SR was measured in micrometers (μm) with the help of a surface roughness meter. The initial weight of the samples was measured using an accurate weighing scale and the final weight was measured after the turning operation. The machining time was kept constant for all the samples. The difference between the initial and final mass gave the mass loss in gram. MRR for each experiment was calculated using the following expression:

$$MRR = \frac{initial mass of\ workpiece - final mass of\ workpiece}{machining time} \qquad (1)$$

The unit in which MRR is measured is g/min.

Design of Experiments

The sequence in which the experiments were to be conducted was determined based on Taguchi's Method. This is essentially a 4-Factor and 3-Level design as it has 4 input variables with 3 different levels. The input variables are Composition, Speed, Feed and Depth of Cut whereas the responses are MRR and SR. The various levels of input parameters are shown in Table 3. An L27 orthogonal array was selected for this work and it has 27 rows and 13 columns. A total of 27 experiments were carried out with different combinations of input parameters by utilizing Taguchi’s orthogonal array. MINITAB 17.1 software was used for the analyses of the experimental data. Signal-to-noise (S/N) ratio measures how the response varies relative to the nominal or target value under different noise conditions. The objective of determining S/N ratio is to develop processes that are insensitive to noise.

For MRR, 'Larger is Better' characteristic is chosen to determine S/N Ratio:

$$\frac{S}{N} = -10\log[\frac{1}{n}(\sum\frac{1}{y^2})] \qquad (2)$$

where y is the observed data (MRR) and n is the number of observations.

For SR, 'Smaller is Better' characteristic is chosen to determine S/N Ratio:

$$\frac{S}{N} = -10\log[\frac{1}{n}(\sum y^2)] \qquad (3)$$

where y is the observed data (SR) and n is the number of observations.

Table 3. Machining Parameters and their levels

Level	Composition (Wt. % of SiC)	Depth of Cut (mm)	Feed (mm/rev)	Speed (rpm)
1	0	0.5	0.125	500
2	5	0.75	0.250	750
3	10	1.00	0.375	1000

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RESULTS AND DISCUSSION

Signal-to-Noise (S/N) Ratio Analysis

Taguchi method uses a special set of arrays called orthogonal arrays which stipulate the way of conducting the minimal number of experiments that would give the full information of all the factors that affect the performance parameter. The experiments were conducted based on the L_{27} Taguchi orthogonal array design. The system has 4 parameters and each of them has 3 levels. Testing all the possible combinations of these parameters will result in a set of $81(3^4)$ test cases. But instead of testing the system for all combination of parameters, we can use an orthogonal array to select only a subset of these combinations. The experimental results for MRR and SR are shown in Table 4. The experimental results were then converted into S/N ratios so that the effects of various parameters on the responses could be plotted and ranked according to the degree to which they affect the response. The S/N ratios for MRR and SR are shown in Table 4.

Table 4. Orthogonal array and experimental results

Experiment Number	Composition (wt.% of SiC)	Depth of Cut (mm)	Feed (mm/ rev)	Speed (rpm)	MRR (g/min)	S/N Ratio for MRR (dB)	Surface Roughness (µm)	S/N Ratio for SR (dB)
1	0	0.5	0.125	500	2.992	9.5192	1.8466	-5.3274
2	0	0.5	0.25	750	8.241	18.3199	4.8666	-13.7445
3	0	0.5	0.375	1000	14.659	23.3223	7.88	-17.9305
4	0	0.75	0.125	750	6.181	15.8217	2.02	-6.1070
5	0	0.75	0.25	1000	15.023	23.5353	6.62	-16.4172
6	0	0.75	0.375	500	12.097	21.6538	5.86	-15.358
7	0	1	0.125	1000	10.917	20.7625	1.8766	-5.4674
8	0	1	0.25	500	10.880	20.7329	4.972	-13.930
9	0	1	0.375	750	19.181	25.6574	7.7933	-17.8344
10	5	0.5	0.125	500	3.058	9.7113	1.78	-5.0084
11	5	0.5	0.25	750	8.534	18.6232	2.96	-9.4258
12	5	0.5	0.375	1000	13.817	22.8088	6.085	-15.6852
13	5	0.75	0.125	750	6.374	16.0886	1.6766	-4.4885
14	5	0.75	0.25	1000	14.030	22.9415	3.7866	-11.565
15	5	0.75	0.375	500	12.081	21.6424	5.89	-15.4023
16	5	1	0.125	1000	11.359	21.1073	1.66	-4.4021
17	5	1	0.25	500	10.862	20.7186	3.8533	-11.7167
18	5	1	0.375	750	19.618	25.8532	6.6233	-16.4215
19	10	0.5	0.125	500	5.9699	15.5193	2.16	-6.6890

20	10	0.5	0.25	750	14.517	23.2378	3.3266	-10.44
21	10	0.5	0.375	1000	14.783	23.3955	4.8933	-13.792
22	10	0.75	0.125	750	7.796	17.8378	2.2066	-6.8744
23	10	0.75	0.25	1000	13.517	22.6179	3.91	-11.8435
24	10	0.75	0.375	500	11.455	21.1799	4.9933	-13.9678
25	10	1	0.125	1000	10.770	20.6448	2.3	-7.2345
26	10	1	0.25	500	10.758	20.6352	3.9633	-11.9611
27	10	1	0.375	750	19.349	25.7335	4.9466	-13.8861

The main effects plots for MRR and SR were obtained by S/N ratio analysis using MINITAB software. Figure 1 represents a four in one graph, where means of MRR is plotted in the Y-axis and the different levels of Composition, Feed, Depth of Cut (DOC) and Speed are plotted in the X-axis. This enables us to make a comparative view of the effect of these parameters on responses and hence list out their effects. It can be observed from the plot that there is an increase in the MRR when the wt.% of SiC is increased from 5% to 10%. However the MRR remains almost unchanged when the wt.% of SiC is increased from 0% to 5%. MRR is also found to be directly proportional to the other factors like DOC, Feed and Speed. It was found out that an increase in DOC, Feed and Speed produced a corresponding increase in MRR. Table 5 shows the response table for MRR. It was found out using S/N ratio analysis that the Feed has the maximum influence on MRR, followed by Speed, DOC and Composition.

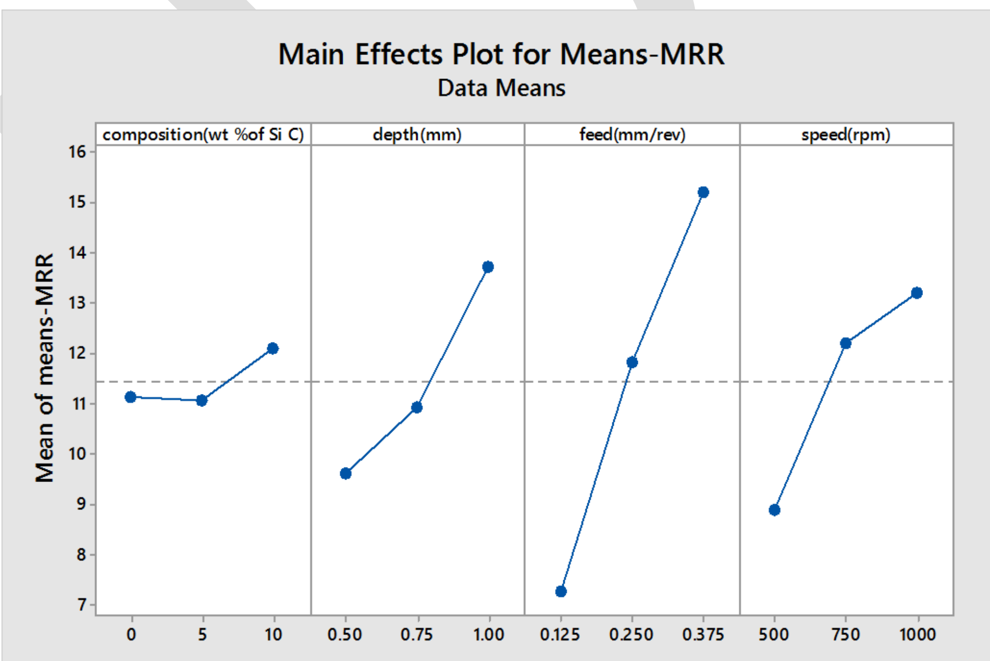

Fig 1: Plot for MRR vs Turning Parameters

Table 5. Rank of turning parameters for MRR

Level	**Composition (wt.% of SiC)**	**Depth of Cut (mm)**	**Feed (mm/rev)**	**Speed (rpm)**
1	19.93	18.27	16.33	17.92
2	19.94	20.37	21.26	20.80
3	21.20	22.43	23.47	22.35
Delta	1.28	4.15	7.14	4.42
Rank	4	3	1	2

Figure 2 represents a four in one graph, where means of SR is plotted in the Y-axis and the different levels of Composition, Feed, DOC and Speed are plotted in the X-axis. It can be noticed that the SR of the composites is almost constant when the wt.% of SiC is increased from 0% to 5%. However, there is an increase in the SR when the wt.% of SiC is increased from 5% to 10%. SR is also found to be directly proportional to the other factors like DOC, Feed and Speed. It was found out that an increase in DOC, Feed and Speed produced a corresponding increase in SR. Table 6 shows the response table for MRR. It was found out using S/N ratio analysis that the Feed has the maximum influence on SR, followed by Composition, Speed and DOC.

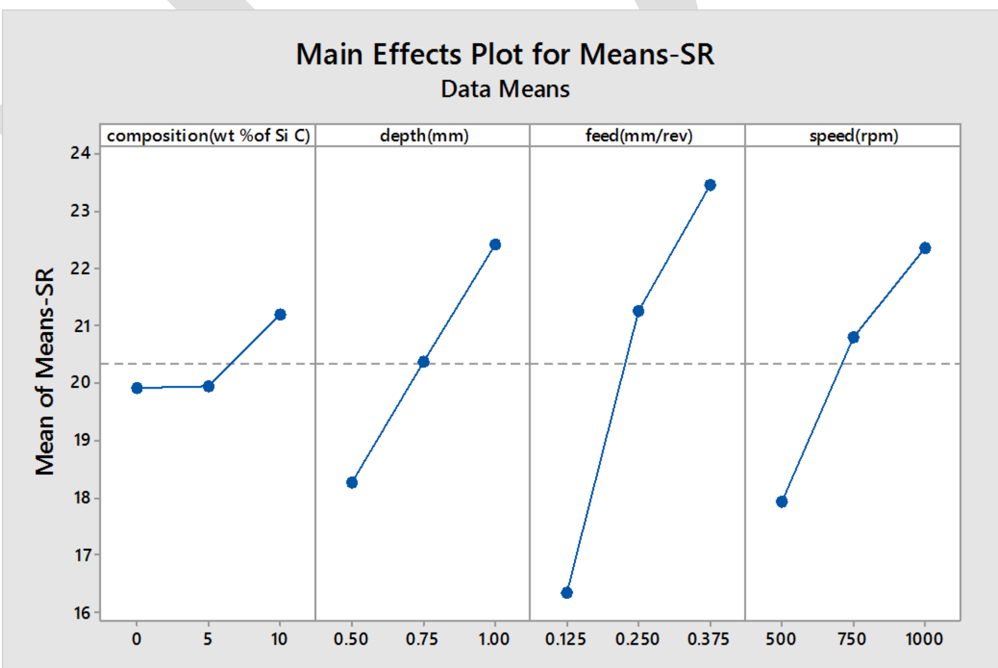

Fig 2: Plot for SR vs Turning Parameters

Table 6. Rank of turning parameters for SR

Level	Composition (wt.% of SiC)	Depth of Cut (mm)	Feed (mm/rev)	Speed (rpm)
1	-12.457	-10.894	-5.733	-11.040
2	-10.457	-11.336	-12.338	-11.025
3	-10.743	-11.428	-15.586	-11.593
Delta	2.000	0.535	9.853	0.568
Rank	2	4	1	3

Analysis of Variance (ANOVA)

The relative contribution of each parameter to multiple responses was identified with the help of ANOVA. Basically, ANOVA compares two types of variances: the variance within each sample and the variance between different samples. It uses a mathematical technique known as the sum of squares to quantitatively examine the deviation of the average mean of the factors that affect the response from the overall experimental mean response. The ratio of individual sum of squares of a particular independent variable to the total sum of squares of all the variables gives the percentage contribution of the independent variable on the response. The significance of the individual control factors is quantified by comparing the variance between the control factor effects against the variance in the experimental data due to random experimental error, and this is given by the F-test. Table 7 shows the results of the ANOVA for the MRR. The percentage contribution of the factors to the response MRR was calculated and is displayed in the last column of the table. From the ANOVA results it can be inferred that the factor contributing the most towards MRR is Feed (56.33%), followed by Speed (17.89%), DOC (15.66%) and Composition (1.17%).

Table 7. Analysis of variance for MRR, using adjusted SS for tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage Contribution
Composition (Wt.% of SiC)	2	5.961	5.961	2.981	0.96	0.433	1.17
Depth of Cut (mm)	2	79.774	79.774	39.887	12.91	0.007	15.66
Feed (mm/rev)	2	286.946	286.946	143.473	46.42	0.000	56.33
Speed (rpm)	2	91.130	91.130	45.565	14.74	0.005	17.89
Composition*DOC	4	14.940	14.940	3.735	1.21	0.397	2.93

Composition*Feed	4	3.539	3.539	0.885	0.29	0.877	0.6947
Composition*Speed	4	8.561	8.561	2.140	0.69	0.624	1.6806
Error	6	18.544	18.544	3.091			3.6404
Total	26	509.394					100

Table 8 shows the results of the ANOVA for the SR of the composites. The percentage contribution of the factors to the response, SR was also calculated and displayed in the table. From the results obtained in the table it can be observed that the factor contributing the most towards SR is Feed (79.25%) followed by Composition (8%) and then Composition*Feed (7.05%) and Composition*Speed (1.61%).

Table 8. Analysis of variance for SR, using adjusted SS for tests

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**Percentage Contribution**
Composition (Wt.% of SiC)	2	7.8937	7.8937	3.9469	8.47	0.018	8.00
Depth of Cut (mm)	2	0.2669	0.2669	0.1334	0.29	0.761	0.27
Feed (mm/rev)	2	78.1686	78.1686	39.0840	83.84	0	79.25
Speed (rpm)	2	0.7988	0.7988	0.3994	0.86	0.471	0.81
Composition*DOC	4	0.1638	0.1638	0.0409	0.09	0.983	0.17
Composition*Feed	4	6.9582	6.9582	1.7396	3.73	0.074	7.05
Composition*Speed	4	1.5897	1.5897	0.3974	0.85	0.541	1.61
Error	6	2.7972	2.7972	0.4662			2.84
Total	26	98.6370					100

Regression Analysis

Regression analysis is used for modelling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables. The dependent variable is the 'response' and the independent variable is the input parameter. Regression analysis shows the change in the typical value of a dependent variable when any one of the independent variables is varied, while the other independent variables are held fixed. The regression equations for predicting the MRR and SR were developed using MINITAB software. The regression equations (4) and (5) can be used to predict the values of MRR and SR for different set of input turning parameters. The residual plots for MRR and SR are shown in Figures 3 & 4, where goodness of fit can be observed.

The regression equation for MRR (g/min) =

- 13.8 + 0.918 Composition + 11.4 Depth of Cut + 35.0 Feed + 0.00985 Speed - 0.632 Composition*Depth of Cut - 0.639 Composition*Feed - 0.000250 Composition*Speed (4)

The regression equation for SR (µm) =

- 2.43 + 0.278 Composition + 0.226 Depth of Cut + 21.7 Feed + 0.00206 Speed + 0.052 Composition*Depth of Cut - 1.02 Composition*Feed - 0.000247 Composition*Speed (5)

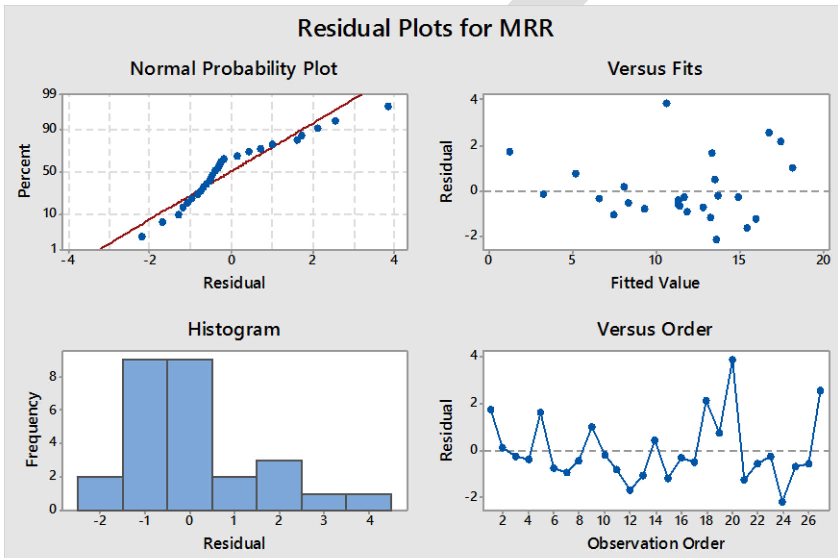

Fig 3: Residual plot for MRR

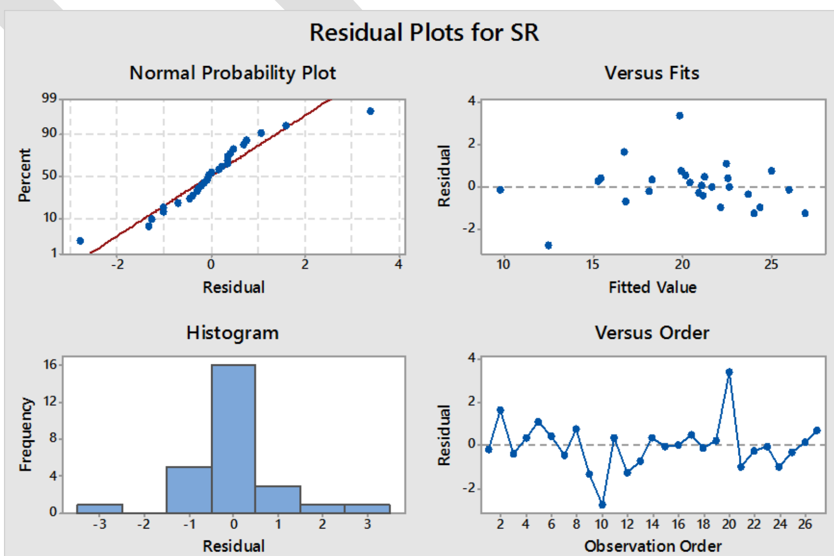

Fig 4: Residual plot for SR

CONCLUSION

1. LM-13 Aluminium alloy/SiC/fly ash hybrid metal matrix composites were successfully fabricated through the stir casting procedure and they can be used in the manufacture of automotive components such as piston, cylinder liners and drive shafts.

2. It was determined from S/N ratio analysis that the factor which has the maximum effect on MRR is Feed, followed by Speed, DOC and Composition. It was also found out that the factor which has the predominant effect on SR is Feed, followed by Composition, Speed and finally DOC.

3. It was determined based on ANOVA that Feed has the predominant influence on MRR, followed by Speed, DOC and Composition. It was also found out that the SR is influenced by Feed followed by Composition, Composition*Feed and then finally Composition*Speed.

4. Regression equations were developed to calculate the output parameters for different set of turning parameters.

REFERENCES

[1] N.Radhika, R.Subramanian and S.Venkat Prasat, “Tribological Behaviour of Aluminium/Alumina/Graphite Hybrid Metal Matrix Composite using Taguchi’s Techniques”, Journal of Minerals & Materials Characterization & Engineering, Vol. 10, No. 5, pp. 427-443, 2011.

[2] M.K.Surappa, “Aluminium matrix composites: Challenges and opportunities", Sadhana, Vol. 28, Parts 1 & 2, pp. 319–334, 2003.

[3] Gowri Shankar M.C, Jayashree P.K, Raviraj Shettya, Achutha Kinia and Sharma S.S., “Individual and Combined Effect of Reinforcements on Stir Cast Aluminium Metal Matrix Composites”, International Journal of Current Engineering and Technology, Vol.3, Iss.1, 2013.

[4] S. Venkat Prasat, R. Subramanian, N. Radhika and B. Anandavel, “Dry sliding wear and friction studies on AlSi10Mg–fly ash–graphite hybrid metal matrix composites using Taguchi method”, Tribology - Materials, Surfaces & Interfaces, Vol. 5, No. 2, pp. 72-81, 2011.

[5] I. B. Singh, M Singh, S Das, Anil K. Gupta, "A Comparative Corrosion Studies of LM13 alloy, LM13-10%SiC composite and cast iron in NaCl solution", India Journal of Chemical Technology,Vol.19, pp.385-391, 2012.

[6] Manoj Singla, D. Deepak Dwivedi, Lakhvir Singh, Vikas Chawla , "Development of Aluminium Based Silicon Carbide Particulate Metal Matrix Composite", Journal of Minerals & Materials Characterization & Engineering, Vol. 8, No.6, pp 455-467, 2009.

[7] Rajeshkumar Gangaram Bhandare, Parshuram M. Sonawane, "Preparation of Aluminium Matrix Composite by Using Stir Casting Method", International Journal of Engineering and Advanced Technology, Volume. 3, Issue-2, 2013.

[8] Sahib Singh, Kapil Singh, R.K. Bhushan “Machining Response in Turning Aluminium Composite LM13 With 15% SiC”, International Journal of Enhanced Research in Science Technology & Engineering, Vol. 1, 2012.

[9] Krishankant, Jatin Taneja, Mohit Bector, Rajesh Kumar, "Application of Taguchi Method for Optimizing Turning Process by the effects of Machining Parameters", International Journal of Engineering and Advanced Technology, Vol. 2, Issue 1, 2012.

[10] Kamal, Anish and M.P.Garg, “Experimental investigation of Material removal rate in CNC turning using Taguchi method”, International Journal of Engineering Research and Applications, Vol. 2, Issue 2, pp.1581-1590, 2012.

[11] S. Venkat Prasat, R. Subramanian, N. Praveen and L. Arun, "Electric Discharge Machining of AlSi10Mg/Fly Ash/Graphite Hybrid Metal Matrix Composites", European Journal of Scientific Research, Vol.59, No.4, pp. 485-498, 2011.