

# **A Comparative Study of Al6061 Based Composites Reinforced with SiC and Red Mud by Taguchi Technique**

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**ABSTRACT:** In today's world aluminium matrix composite (AMC) has wide range of application in different sectors like aerospace, automobile, sport and so on. Effort has been made to increase the wear resistance, strength to weight ratio, toughness etc. and to decrease the processing cost of the AMC. There are so much work has been done in the field of AMCs but still there is a lot scope of improvement. In this experimental work wear properties of AMC reinforced with SiC and red mud with varying weight percentage (2.5%, 5%, and 7.5 %) has been compared. Composite was fabricated by liquid metallurgy process and T6 heat treatment process was applied on the sample. To perform the wear test L9 orthogonal array (OA) was selected. Reinforcement weight percentage, normal load, sliding distance and sliding speed are selected as experimental factor and weight loss as response value. Main effect plot of S/N ratio and mean has been plotted. Interaction between different factors has shown by interaction plot. ANOVA analysis is done to check the factor contribution. To get the optimum response value regression equation is formulated.

**KEYWORDS:** AMC, S/N ratio, ANOVA, DRAMC

## **I. INTRODUCTION**

The recent development in the field of engineering system demands the materials having excellent set of properties. Metal matrix composite gives wide range of tailored properties which are needed in field of science and technology such as high strength to weight ratio, high specific stiffness, high wear resistance, high corrosion resistance, low coefficient of thermal expansion etc. [1-5]. Metal matrix composites are used in many industries like aerospace, sport, electronics etc. but the concern is the cost of the composite [6]. In automobile industry we need material which has less weight but high strength so that the fuel efficiency can be increased [1]. Aluminium matrix composites provide such combination of properties by which these demands can be met. AMCs have improved mechanical and tribological properties than the conventional monolithic materials [2, 6, 7]. In AMC right combination of matrix material and reinforcement is very significant because it decides the properties of AMC. To prepare the composite, different types of fabrication techniques are used which can be basically classified into two categories which are liquid phase fabrication method and solid state fabrication method. Selection of processing technique is very important to prepare the AMC because it effects the reinforcement distribution, interaction between matrix material and reinforcement of the composite and its cost as well. Stir casting technique is one which is cost effective and we can get the desired shape also by this process. For producing AMCs discontinuously reinforced reinforcement in the form particulates is advantageous which is reported in literatures [1, 2, 8]. However in the development of discontinuously reinforced AMCs (DRAMCs) the cost and availability of synthetic reinforcement is a major problem. Which can be solved by adopting alternative of synthetic reinforcement such as fly ash, bamboo leaf ash, rice husk ash etc. and it was found by researchers that AMCs reinforced with agro waste and industrial waste have shown better performance compared to their matrix alloy. Another problem faced by DRAMCs is reduced mechanical property such as poor ductility, inferior fracture toughness and uncertainty to decide the corrosion behaviour [9, 10]. To improve the performance of DRAMC

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the size of the reinforcement particle were decreased up to Nano size but again it which increased the ductility and fracture toughness of the DRAMC but it increased the cost of the composite [11]. Another approach developed to improve the properties of AMC was hybrid composite by selecting at least two combination of reinforcement with matrix material [12]. Red mud which is an industrial waste of aluminium industry and hazardous for environment is used as reinforcement to prepare the AMC. Another AMC was reinforced with SiC, which is hard material of low density. In this comparative study weight loss in wear test of AMCs reinforced with red mud and SiC has been observed. Wear which is an important aspect of tribology has been studied in this paper with the help pin on disc wear machine. By design of experiment (DOE) we can get to know the effect of different factors for response but performing experiment with every possible combination of factors increases the cost of the experimentation process and time consuming also this is where Taguchi technique helps. L9 orthogonal array was selected to conduct the wear experiment.

## II. MATERIALS

Al6061 was used as matrix material which is a heat treatable alloy of 6000 series with medium to high strength capabilities. Al6061 is easily available and possess high toughness, weldable with good surface finish. In table no. 1 chemical composition of Al6061 is shown. Al6061 was purchased in the form of bars.

**Table 1: Chemical composition of Al6061 [13]**

0.15-0.40	0.15 Max.	0.8-1.2	0.7 Max.	0.4-0.8	0.25 Max.	0.04-0.35	0.06	0.15 Max.	0.15total, 0.05Max each	Balance
Cu	Mn	Mg	Fe	Si	Zn	Cr	Ni	Ti	others	Al

SiC (silicon carbide) also known as carborundum was used in the form of powder. SiC as reinforcement. It possess high hardness, low density, high strength and low thermal expansion coefficient. Because of these properties it is used in bearing application. Mechanical and physical properties of SiC are shown in table no. 2.

**Table 2: Mechanical properties of SiC [13]**

Liquidus temperature	615°c
Solidus temperature	555°c
Density (g/cm <sup>3</sup> )	2.685
Tensile Strength (MPa)	230
Hardness (BHN)	75
Toughness (Joule)	6
Fatigue strength(1 x 10 <sup>7</sup> MPa)	120

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During the production of alumina from bauxite red mud is generated found as a caustic insoluble waste of Bayer's process used as reinforcement. Because red mud is generated in mass disposal of it also a crucial problem. Red mud is used as reinforcement in this study to prepare the AMC. Table 3 shows the properties of red mud. For this study red mud was purchased from Renukoot (U.P.) of 100-200 mesh size.

**Table 4: The chemical constituents (%) and trace elements (ppm) of red mud [14]**

SiO <sub>2</sub>	12.2	Cu	39
Al <sub>2</sub> O <sub>3</sub>	10.5	Zn	55
MgO	0.53	Pb	128
CaO	11.66	Sr	585
Na <sub>2</sub> O	6.09	As	85
Fe <sub>2</sub> O <sub>3</sub>	31.63	Cr	506
TiO <sub>2</sub>	5.9	Co	38
P <sub>2</sub> O <sub>5</sub>	0.55	Ni	122
MnO	0.34	Ga	22
K <sub>2</sub> O	0.05	Sc	48
–	–	Y	28

### III. METHODOLOGY

**Fabrication process:** AMC reinforced with SiC and red mud was prepared separately in varying weight percentage as (2.5%, 5% and 7.5%) by stir casting technique. Muffle furnace was used to melt the matrix material first at 850°C and mechanical stirrer was used to create the vortex. Reinforcement material is preheated separately at 450°C to avoid the moisture. Reinforcement was added in loose form into the graphite crucible. 1% Mg was added to increase the wettability of the reinforcement. After adding the reinforcement stirrer was applied into the molten material for 10 minutes to attain the homogenous mixture of reinforcement. Stirrer has three blades with the gap of angle 120°. Molten AMC was poured into mild steel mould.

**Wear test:** To conduct the wear test, samples of AMC were prepared on lathe machine in cylindrical shape. Sample sizes were kept as 10×30 mm. Before the wear test performed, AMCs samples were subjected to T6 heat treatment process. To achieve the avg. surface roughness less than 800 nm contact surface of AMC were polished by emery of different grit size from 200 to 1000 and finally with the nylon cloth. Pin on disc wear machine was attached with a computer and an electronic controller by which sliding speed can be controlled and wear can be measured. Levels of different parameter used are given in table no. 4. Weight loss of samples were measured on the electronic digital weighing machine of precision 0.0001 gm. Wear load on pin on disc wear machine was applied through pulley and lever mechanism.

**Experimental design:** To conduct the experiment L9 orthogonal array was selected with four factors and three levels of each. In table no. 4 experimental factors are shown with the value of their levels. Weight loss during wear test is considered as response value in the experiment. The advantage of using Taguchi is that influence of each factor and how these factors are interacting with each other can be known.

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Table 4: Factor levels

Factor	Type	Levels	Values
Wt. %	Fixed	3	2.5, 5, 7.5
LOAD(kgf)	Fixed	3	1.5, 3.0, 4.5
Sliding Distance (SD)	Fixed	3	2000, 4000, 6000
SPEED (m/s)	Fixed	3	0.5, 1.0, 1.5

## IV. RESULTS AND DISCUSSION

**Microstructural analysis:** SEM (Scanning electron microscopy) images were taken of machined samples of AMC reinforced with red mud and SiC. It is evident from the images which are shown in fig.1 (a) and (b) that clustering of reinforcement particles are present in both the composite at some places which is due to poor interaction between matrix material and reinforcement. Cracks are present on the surface which is due to machining of the sample material. Both images show that homogenous distribution of reinforcement particle is not attained..

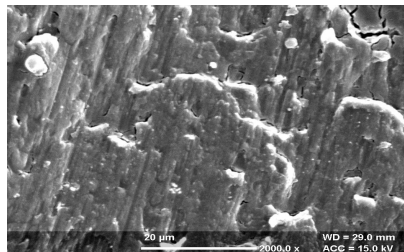


Fig. 1(a)

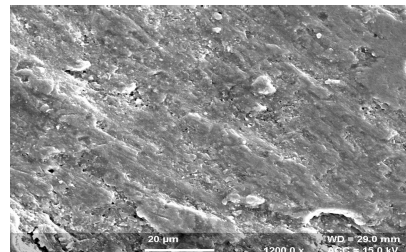


Fig. 1 (b)

Fig. 1: SEM images of reinforced with (a) SiC (b) red mud

**Statistical analysis:** For the wear analysis S/N ratio is chosen as smaller the better. In fig no. 2 and 3 main effects plot for data means is shown for both the composite. Response table for composites reinforced with SiC and red mud red are shown in table no. 5 and 6 respectively.

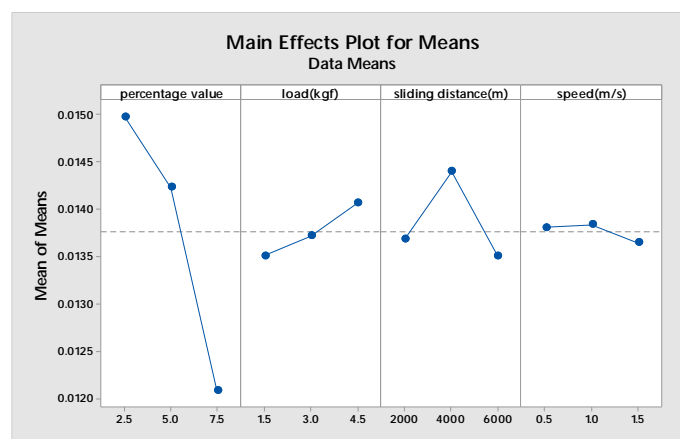


Fig. 2: Main effects plot of SiC reinforced AMC

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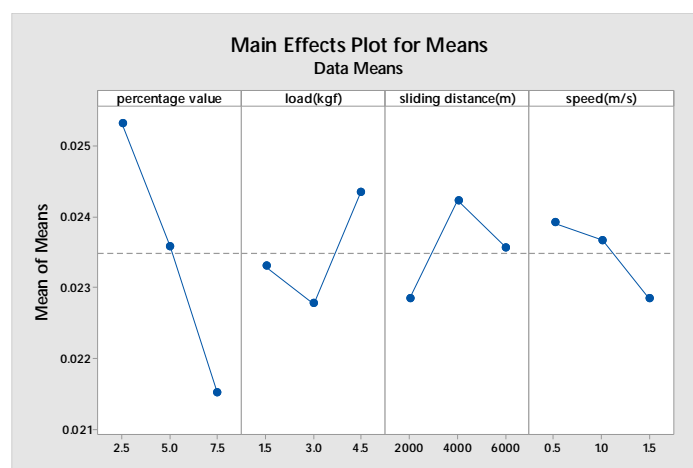
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This can be infer from the main effects plot for means that weight loss of AMC is decreasing as we are increasing the weight percentage of SiC in the composite. On the other hand by increasing the normal load weight loss is increasing. This is evident from fig. 2 that at first weight loss increases with the sliding distance but after 2<sup>nd</sup> level of sliding distance mean value of weight loss gradually decreases. In table 5 delta values are shown which is the difference of highest and lowest value of S/N ratio for any particular and that is how ranking of factors are decided. For SiCp dispersed AMC weight percentage has most influence on the response followed by sliding distance, normal load and sliding speed.

**Table 5: Response table for S/N ratio (SiC)**

Level	Wt.%	Load(kg-f)	SD (m)	speed(m/s)
1	36.49	37.42	37.32	37.22
2	36.93	37.3	36.84	37.22
3	38.36	37.07	37.43	37.34
Delta	1.87	0.35	0.59	0.13
Rank	1	3	2	4

In fig. 3 main effects plot for data means it can be observed that effect of normal load is not similar as in the case of SiC reinforced composite. Mean value of weight loss first decreases but the slope of means line becomes positive after 2<sup>nd</sup> level of this particular factor. Weight percentage of reinforcement has the almost similar effect on the means value of weight loss for red mud reinforced composite. Response table for S/N ratio shows that percentage value of reinforcement has the highest influence on the response followed by load applied, sliding distance and sliding speed has the least effect on the weight loss during wear test.



**Fig. 3: Main effects plot of red mud reinforced AMC**

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**Table 6: Response table for S/N ratio (red mud)**

Level	Wt.%	Load(kg-f)	SD	Speed(m/s)
1	31.93	32.67	32.87	32.43
2	32.55	32.9	32.32	32.53
3	33.36	32.28	32.57	32.88
Delta	1.43	0.62	0.55	0.45
Rank	1	2	3	4

ANOVA (analysis of variance) is done to test the percentage contribution of different factors in the wear test of both the composite is shown in the table 7 and 8. For SiC reinforced composite weight percentage of reinforcement is the most significant factors and same is the case with red mud reinforced composite.

**Table 7: ANOVA table of SiC reinforced AMC**

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	0.000013	0.000003	12.29	0.016
Wt. %	1	0.000012	0.000012	46.51	0.002
Load(kg-f)	1	0	0	1.6	0.274
SD (m)	1	0	0	0.06	0.824
Speed(m/s)	1	0	0	0.12	0.748
Error	4	0.000001	0		
Total	8	0.000014			

**Table 8: ANOVA table for red mud reinforced AMC**

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	0.000027	0.000007	9.58	0.025
Wt. %	1	0.000023	0.000023	33.15	0.005
Load (Kg-f)	1	0.000001	0.000001	1.65	0.269
SD (m)	1	0.000002	0.000002	2.19	0.213
Speed(m/s)	1	0.000001	0.000001	1.75	0.257
Error	4	0.000003	0.000001		
Total	8	0.000029			

Contour plots are shown in fig. 4 and 5, from contour plots we can observe the effect of two factors involved in experimentation on response value in one picture. In fig. 4 (a) for SiC reinforced AMC which is a contour plot between weight loss against load and percentage value of reinforcement we can see that weight loss is highest in the region where the values weight percentage of reinforcement is less than 3 % and load value is more than 2.5 Kg-f. In fig. 4 (b) which is contour plot of weight loss against sliding distance and speed, response value is lowest in the region

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where sliding speed is highest and sliding distance is less than 3000 m. In fig. 5(a) and (b) we observe that contour plot pattern is quite similar for both the composite but the difference is the distinguished region for SiC reinforced AMC are more compare to contour plots of red mud reinforced composite. From contour plots ( fig. 5) of red mud reinforced composite we can see that weight loss is maximum in the region where the values of percentage reinforcement is minimum and sample is subjected to higher load.

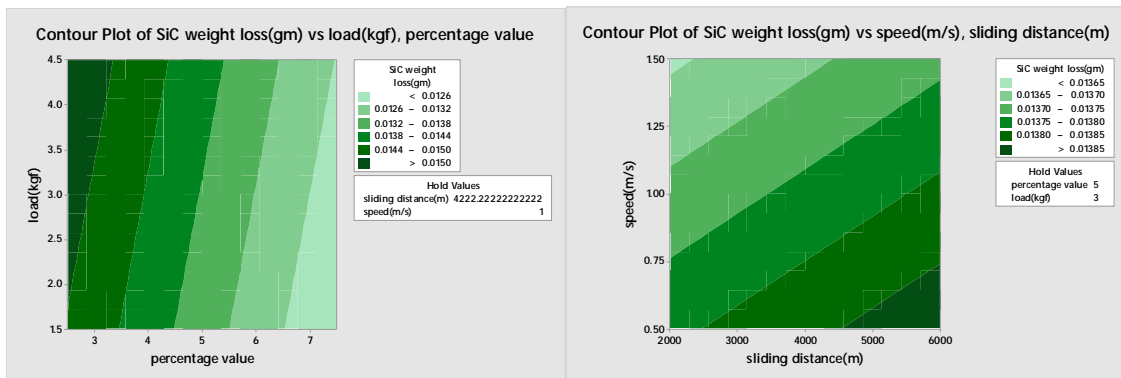


Fig. 4 (a)

Fig. 4 (b)

Fig. 4: Contour plots of SiC reinforced AMC

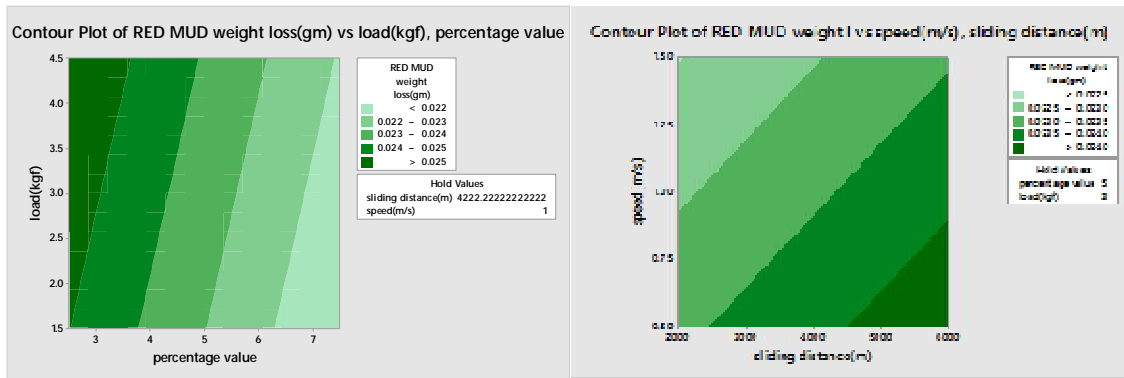


Fig. 5(a)

Fig. 5(b)

Fig. 5: Contour plots of red mud reinforced composite

To get the values of response (weight loss) at different values of factors regression equation is generated for both the composite by doing regression analysis.

$$\text{SiC weight loss(gm.)} = 0.016186 - 0.000583 \text{ percentage value} + 0.000180 \text{ load(kg-f)} + 0.000000 \text{ sliding distance(m)} - 0.000147 \text{ speed(m/s)}$$

$$\text{Red mud weight loss(gm.)} = 0.02644 - 0.000793 \text{ percentage value} + 0.000295 \text{ load(kg-f)} + 0.000000 \text{ sliding distance(m)} - 0.000911 \text{ speed(m/s)}$$

In fig. 6 comparison of response value which is weight loss during wear test under dry sliding condition done between composites reinforced with SiC and red mud in 9 different experiments designed by Taguchi technique. During wear test of both the composite factors levels were same for both the composite. It is evident from the graph (fig. 6) that

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weight loss value is more in every single experiment for red mud reinforced composite compare to SiC reinforced composite.

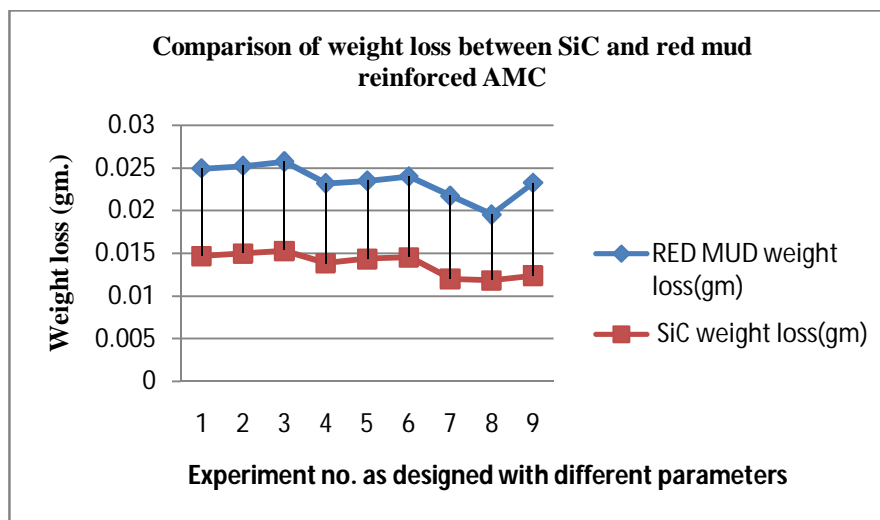


Fig. 6: Comparison of weight loss

## V. CONCLUSION

Through the experimental, microstructural study and statistical analysis of SiC and red mud reinforced composites following conclusion can be made.

1. AMCs are successfully fabricated by stir casting method with different reinforcement in varying weight percentage.
2. Microstructural study shows the non-homogenous distribution of distribution of reinforcement. Stirrer design can play a significant role in the distribution of reinforcement.
3. Reinforcement weight percentage is the most influential factor in the wear study for both composites.
4. Weight loss of red mud reinforced composite is more during wear test compare to SiC reinforced composites.

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