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RESEARCH

# Characterization, Fabrication and Dry Sliding Wear Analysis of Hybrid Aluminium 6061 Composite

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## ABSTRACT

*In the present study, wear behavior of Al6061 hybrid composite having silicon carbide and red mud as the reinforcements have been studied. This hybrid composite was fabricated using the stir casting technique. Effect of variation of magnesium content, red mud content, aging time, red mud particle size, applied load, displacement and speed were studied. Scanning electron microscopy confirmed the fairly uniform distribution of the reinforcement particles and provided wear patterns of this composite. Energy dispersive spectroscopy showed different constituents present in this hybrid composite. Wear loss decreased with an increase in magnesium content and aging time while it decreased with an increase in red mud content up to 4% (wt%) and particle size up to 150 mesh (105 µm). Wear loss increased with an increase in load, sliding speed and sliding distance. Load and sliding distance have a significant effect on the wear loss. Optimum values for minimum weight loss were calculated and were confirmed by confirmation experiments. Load and sliding distance have been found to have significant effect on wear loss. So this fabricated composite can be utilized in various applications like in Marine frames, Aircraft and truck frames, Chemical equipment, aircraft landing mats etc.*

## 1. INTRODUCTION

Aluminium alloy 6061 has been widely used as a matrix material in the development of composite. Al6061 alloy has been used in various industrial and automobile sectors due to its various properties like high strength to weight ratio, corrosion resistance, high temperature strength etc. [1]. Various attempts are made by researchers at enhancing its properties by using it as a matrix material with different reinforcements and determining the optimum results. As a result, there has been a huge development in metal matrix composites that has good mechanical properties and has been a good replacement for the traditional materials [2]. To meet the demands of an evolving world the focus of research is to produce the materials that have good mechanical properties at low costs. Various conventional reinforcement that have been added to these matrix materials include oxides and carbides of boron, aluminium, titanium etc. Kala et al. in their study reported that aluminium alloys and pure aluminium when reinforced with ceramic particles such as alumina, SiC, B4C etc. they showed an appreciable increase in mechanical properties such as tensile strength, hardness and yield strength. Addition of graphite resulted in an increase in tensile strength but hardness decreased. Organic reinforcements also increased the mechanical properties along with the tribological behaviour of the composite [3]. But these reinforcements are costly and so researchers are thus emphasizing on use of other reinforcements such as rice husk ash, fly ash, red mud etc. which are mainly waste products [4]. Thus, it also acts as effective utilization of wastes. Red mud is the waste product of aluminium extraction unit that mainly consists of oxides of iron, aluminum, titanium, sodium etc... There also have been emphasis on development of hybrid composites that uses more than one reinforcement material in the development of composite. The main idea of this hybrid composite is to use the properties of all contents of the material at one place making it a superior material than base material. Stir casting has been most common fabrication method used in the production of the composite. Other methods of fabrication used are spray deposition, powder metallurgy, squeeze casting, compo casting etc [5,6].

Tribological study includes the study of wear which is the most prominent in the material when there is relative movement of material having physical contact. There is the loss of material observed due to this rubbing action. The factors that influence the amount of wear are studied under the tribological properties. These include load of action, time, sliding speed, sliding distance, lubrication etc. This wear is the surface harm caused due to rubbing action causing removal of material from that surface cause different types of grooves on the surface there by degrading the performance of the material. Research has been emphasized on reducing the wear by developing different types of composites and tribologically testing these materials for getting optimum parameters for minimum wear. Literature suggested that presence of fine particle reinforcements resulted in the decrease of wear rate. Authors reported the decline in the wear rate of material due to presence of oxides on the material, which prevent direct contact of material during rubbing. Wear rate was reduced due to presence of hard oxides on the top surface and also on the amount of reinforcements present in the matrix material greatly improve its wear performance over the matrix material. Both abrasive wear and adhesive wear were reported as most prominent wear material in aluminum matrix composites [7-9]. Walczak et al. in their study studied tribological characteristics of aluminium composite having silicon carbide (SiC) as the reinforcement. Weight percentage of silicon carbide was fixed to 20% and it was found that resistance to wear of composite is 14% more than the unreinforced alloy. Also, resistance to wear increased by almost 27% with effect of heat treatment [10]. Ahmad et al. evaluated the wear behavior of aluminium composite having alumina particles as the reinforcement. It was found that the wear rate of the composite increased with increase in load while the coefficient of friction decreased at high loads. In their results, they also concluded that aluminium matrix composite experienced a combination of different types of wear under different loading conditions [11].

Wear behavior of Al6061 hybrid composite having silicon carbide and red mud as the reinforcements has not been much reported in the literature. Effect of various parameters like magnesium content, red mud content, aging time, red mud particle size, load, displacement and speed on the wear behavior has not been much reported. In the present research wear behavior of hybrid Al6061 composite having silicon carbide and red mud as the reinforcements has been tested with aim of utilizing the waste products as the reinforcements to increase its scope for its use in various applications. Effect of various parameters on this wear behavior has also been studied.

## 2. ENGINEERING DESIGN AND FORMULATION

The design for performing the wear test was based on the taguchi design. Appropriate orthogonal array was used for performing the test. Complete planning of experiments needs to be carried out for better results. In this work design of experiments (DOE) has been used to systematically conduct the experiments and analyze the input and output factors. Taguchi design of DOE suggests the use of the suitable orthogonal array for conducting the experiments and on the orthogonal array and further analyzing the corresponding results by using analysis of variance (ANOVA) [12,13].

In this study the aim was to fabricate and study the wear properties of hybrid aluminium 6061 composite having silicon carbide and red mud as the reinforcements. After analysis of previous data, these parameters were selected. The composition of silicon carbide was fixed to 10% by weight of the total composition and also the same size of silicon carbide that is 150 mesh (105μm) was used as data has been reported on the variation of silicon carbide as reinforcement while less work has been reported on the red mud as reinforcement. From the literature, it has been seen that reinforcement size and composition significantly affects the properties of the composite, therefore, red mud percentage composition and size were selected as design parameters. Also, the use of magnesium was considered by various researchers in making a composite but its composition variation was very less reported, so magnesium percentage was taken as another parameter. Effect of heat treatment on composite was also less reported so aging time was considered as a factor. A total of seven parameters were taken for designing the experiments namely magnesium percentage, aging time, red mud particle size and red mud percentage (wt%), Load, sliding speed and Sliding distance [14-16].

The parameters were selected after studying the work of different authors and feasibility of execution. All the parameters were varied at three levels except for the magnesium percentage which has been taken at two levels. (Table 1). Based on parameters suitable orthogonal array was selected using MINITAB 18 software. The mixed level design was selected as the need to vary magnesium percentage at two levels and other parameters at three levels occurred. So L18 ($2^1$*$3^7$) orthogonal array was selected for this experimental design. Wear properties was studied based on this design.

## 3. MATERIALS AND METHODS

Two different reinforcements that have been used in this thesis work are silicon carbide and red mud. Silicon carbide is a hard-ceramic reinforcement and most commonly used reinforcement. Silicon carbide of size 150 mesh (105 μm) was purchased from Om enterprise, Surat. The red mud is an industrial waste of alumina extraction plant. Red mud contains oxides of iron, aluminium, silicon, calcium, sodium, titanium, calcium and lead as well as a group of some minor elements like potassium, crypton, vanadium, barium, copper, manganese, lead, zinc, phosphorous, sulphur, arsenic etc. [17]. This industrial waste was used as second reinforcement in the thesis and has been procured form HINDALCO Plant, Renukoot. It was sieve into different mesh sizes that are 100 (149 μm), 150 (105 μm) and 200 (74μm) (BSS 410/1969). Magnesium turnings was also added to study its wettability characteristics of reinforcements and matrix material.

**Table 1.** Process Parameters and their levels for Taguchi Design of Experiments.

| Sr. no. | Process Parameter | Level I | Level II | Level III |
|---|---|---|---|---|
| 1. | Magnesium content (wt.%) | 1% | 2% | ~ |
| 2. | Aging time (in hours) | 8hr | 16hr | 24hr |
| 3. | Red mud particles size (Mesh size) | 100 | 150 | 200 |
| 4. | Red mud content (wt.%) | 2% | 4% | 6% |
| 5. | Load | 1kg | 2kg | 3kg |
| 6. | Sliding Speed | 0.5m/s | 1m/s | 1.5m/s |
| 7. | Sliding distance | 2000m | 4000m | 6000m |

Stir casting technique was done using a Muffle furnance for fabrication of hybrid composite as per the experimental design [18].

All the raw material was weighed according to weight percentage tabulated in the orthogonal array. Pieces of Aluminium 6061 were placed in a crucible and then that crucible was kept inside the muffle furnace. Temperature of the furnace was set to 800°C. After aluminium 6061 melts, the reinforcements having suitable weight composition according to the design were added. Uniform stirring was done with help of stirrer to have a good mixing of the constituents in the furnace. Heat treatment has been applied in order to improve their properties. All the samples were given T6 heat treatment where the samples are maintained at 520°C in furnace for two hours followed by the water quenching. This was done in order to obtain uniformity of structure and better properties [19]. After this, the samples were dried before further treatment. Next step of heat treatment was the aging of samples. Aging has been carried out at 160 °C [20,21]. Aging time was kept at 8 hrs, 16 hrs, and 24 hrs. Aging time for the samples was done according to our L18 orthogonal array. After this heat treatment, the samples were allowed to cool inside the furnace. Aging was done in order to provide superior surface properties.

## 4. WEAR TEST

Wear of hybrid aluminium 6061 composites were performed on the pin-on-disk wear testing machine (Model: -TR-20LE-PHM-CHM-400 from-Ducom, Bangalore) at tribology lab UIET, PU Chandigarh (Fig. 1). Results were measured as the weight loss after the wear. Samples of the size of 10 cm diameter and 30 cm height were prepared based on ASTM G99-05 standard at CITCO, Chandigarh [22]. The cross-sectional surface of the samples was mechanically rubbed using emery papers and velvet cloth. Equipment for wear test consists of a steel disc (hardness value 60 HRc and surface roughness 1.6 Ra). Specimens were fixed in a way to contact its cross-sectional area to the disc while the disc was provided with some sliding speed based and suitable load through the counterweight mechanism. Duration for this testing was specified and set prior to set digitally setting it in the machine. Values of these sliding speed, load, and time were selected on the basis of the values taken in the orthogonal array. Track diameter of the equipment was also set prior to testing and in this case, it was set to 100mm. This is a diameter that on which the specimen slides on the rotating disc. Difference between initial and final weight of the specimens were evaluated and analyzed.

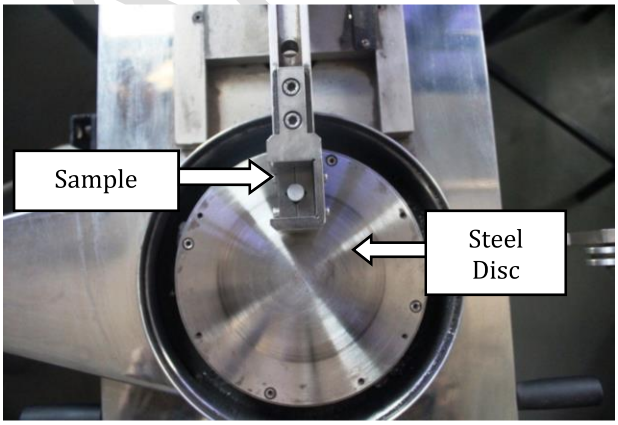

**Fig. 1**. Dry sliding wear of a sample.

## 5. CALCULATIONS

The design for performing the wear test was based on the Taguchi design. In this taguchi based design the results are signal to noise ratio as the quality attributes for calculating the deviation of results from the desired values [23,24]. There are three types of S/N investigations that is the smaller the better, nominal is better and larger is better. Here in the case of wear smaller is better criterion has been used as it requires less wear in the material. So higher value of S/N ratio suggests that it has high signal and less noise that is better experimentation result. After this delta analysis for the wear was done in order to check for the rank in which these parameters are affecting the wear rate. After this ANOVA analysis was carried out in order to check the significance of parameters and percentage contribution of each parameter on weight loss due to wear. Total of 18 experiments were done with repeatability. The confirmation experiment was done to check it with the theoretical result for confidence interval.

## 6. RESULT AND DISCUSSIONS

The result for mean weight loss due to wear along with corresponding S/N ratios have been tabulated in the table 2. P (1-7) signifies the corresponding parameters such as P (1-7) signifies Magnesium content (wt. %), Aging time (in hours), Red mud particles size (Mesh size), Red mud content (wt. %), Load, Sliding Speed and Sliding distance respectively. Weight loss due to wear for each sample have been calculated by weighing each sample before and after the wear test. This data for different experiments and their consecutive trials have been tabulated to find the mean weight loss due to wear for each experiment.

Mean loss due to wear has been tabulated by calculating the mean sum of wear for each trial of experiment as per specified in orthogonal array and then S/N ratios corresponding to the outcomes have been calculated through MINITAB software. Values of these mean weight loss due to wear and S/N ratios are further analyzed to know the tribolgical properties of this hybrid composite and conclusions were drawn accordingly.

Delta analysis for wear loss was done using Minitab 18 software. The higher the value of delta the more is its influence. For this analysis, the mean value of each parameter at each level was calculated and then the minimum mean value was subtracted from the maximum mean value, and difference is called delta (Δ). The wider the difference between the values, the larger is the effect of the parameter on the weight loss due to wear. It has been observed that the sliding distance has the largest effect while magnesium content has the least effect on weight loss due to wear (Table 3).

Analysis of variance (ANOVA) was employed to observe the significance of parameters affecting the weight loss due to wear. The load and sliding distance were found significant during ANOVA analysis. ANOVA table for weight loss due to wear is shown in table 4.

**Table 2.** Mean weight loss due to wear has been tabulated along with corresponding S/N ratios.

| Ex. no | P-1 | P-2 | P-3 | P-4 | P-5 | P-6 | P-7 | Mean Wt. Loss (g) | S/N RATIO |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 8 | 100 | 2 | 1 | 0.5 | 2000 | 0.005 | 46.020 |
| 2 | 1 | 8 | 150 | 4 | 2 | 1 | 4000 | 0.015 | 36.478 |
| 3 | 1 | 8 | 200 | 6 | 3 | 1.5 | 6000 | 0.062 | 24.152 |
| 4 | 1 | 16 | 100 | 2 | 2 | 1 | 6000 | 0.043 | 27.330 |
| 5 | 1 | 16 | 150 | 4 | 3 | 1.5 | 2000 | 0.02 | 33.979 |
| 6 | 1 | 16 | 200 | 6 | 1 | 0.5 | 4000 | 0.014 | 37.077 |
| 7 | 1 | 24 | 100 | 4 | 1 | 1.5 | 4000 | 0.006 | 44.437 |
| 8 | 1 | 24 | 150 | 6 | 2 | 0.5 | 6000 | 0.021 | 33.555 |
| 9 | 1 | 24 | 200 | 2 | 3 | 1 | 2000 | 0.012 | 38.416 |
| 10 | 2 | 8 | 100 | 6 | 3 | 1 | 4000 | 0.05 | 26.020 |
| 11 | 2 | 8 | 150 | 2 | 1 | 1.5 | 6000 | 0.026 | 31.700 |
| 12 | 2 | 8 | 200 | 4 | 2 | 0.5 | 2000 | 0.006 | 44.437 |
| 13 | 2 | 16 | 100 | 4 | 3 | 0.5 | 6000 | 0.034 | 29.370 |
| 14 | 2 | 16 | 150 | 6 | 1 | 1 | 2000 | 0.005 | 46.020 |
| 15 | 2 | 16 | 200 | 2 | 2 | 1.5 | 4000 | 0.026 | 31.700 |
| 16 | 2 | 24 | 100 | 6 | 2 | 1.5 | 2000 | 0.014 | 37.077 |
| 17 | 2 | 24 | 150 | 2 | 3 | 0.5 | 4000 | 0.016 | 35.917 |
| 18 | 2 | 24 | 200 | 4 | 1 | 1 | 6000 | 0.016 | 35.917 |

**Table 3**: Response table for means for the weight loss due to wear.

| Level | P-1 | P-2 | P-3 | P-4 | P-5 | P-6 | P-7 |
|---|---|---|---|---|---|---|---|
| 1 | 0.02200 | 0.02733 | 0.02533 | 0.02133 | 0.01200 | 0.01600 | 0.01033 |
| 2 | 0.02144 | 0.02367 | 0.01717 | 0.01617 | 0.02083 | 0.02350 | 0.02117 |
| 3 | ~ | 0.01417 | 0.02267 | 0.02767 | 0.03233 | 0.02567 | 0.03367 |
| Delta | 0.00056 | 0.01317 | 0.00817 | 0.01150 | 0.02033 | 0.00967 | 0.02333 |
| Rank | 7 | 3 | 6 | 4 | 2 | 5 | 1 |

**Table 4**: ANOVA table for the weight loss due to wear

| Source | dof | Sum of Squares | Mean squares | F Ratio | P value | % age Contribution |
|---|---|---|---|---|---|---|
| Mg content | 1 | 0.600 | 0.600 | 0.05 | 0.831 | 0.079 |
| Aging time | 2 | 37.638 | 18.819 | 1.63 | 0.303 | 4.993 |
| Red mud particle size | 2 | 5.122 | 2.561 | 0.22 | 0.810 | 0.679 |
| Red mud content | 2 | 36.882 | 18.441 | 1.60 | 0.309 | 4.893 |
| Load | 2 | 238.615 | 119.307 | 10.34 | 0.026 | 31.667 |
| Speed | 2 | 47.643 | 23.821 | 2.07 | 0.242 | 6.321 |
| Sliding distance | 2 | 341.145 | 170.573 | 14.79 | 0.014 | 45.258 |
| Residual Error | 4 | 46.136 | 11.534 | | | 6.12 |
| Total | 17 | 753.779 | | | | |

## 7. ESTIMATION OF OPTIMUM LOSS DUE TO WEAR AND CONFIRMATION TEST

For finding out the optimum weight loss due to wear of the composite theoretically the parameters with significance were selected from the table. As weight loss due to wear is "smaller the better" type characteristic of the Taguchi approach showed the minimum values of constituting significant parameters were selected and these values were substituted into the mathematical relation for the calculation of mean weight loss due to wear. The mean value of the obtained weight loss due to wear has been calculated by the relation [25].

$$W_{wl} = \underline{LD_1} + \underline{SD_1} - \underline{T_{wl}} \quad (1)$$

Where, $\underline{LD_1}$ is average weight loss due to wear at the first level that is corresponding to a load of 1kg (0.012g), $\underline{SD_1}$ is average weight loss due to wear at the first level that is corresponding to a sliding distance of 2000m (0.01033g), $\underline{T_{wl}}$ is the average weight loss due to wear 0.0217 g.

On substitution of these values in equation (1), we have $W_{wl}$ = 0.00063
Predicted confidence interval for weight loss due to wear can be calculated using by substituting the following values in equation. $V_e$= 0.000022; Total degree of freedom in mean estimation = 4; N= 18; $N_{eff}$= 18/ (1 + 4) = 3.6; $F_{0.05}$ (1, 4) = 7.71.

The confidence interval = ±0.0002167366g. Therefore, the 95% confidence interval for predicted optimum value of weight loss due to wear is =0.00063±0.0002167366g .The values of parameters for obtaining optimum value of weight loss due to wear are given as: Magnesium content: 1%; Aging time: 24 hr; particle size: 150 mesh; reinforcement content: 4%; Load: 1kg; Sliding speed: 0.5m/s; Sliding distance: 2000m.

The value of weight loss due to wear obtained after confirmation experiment are shown in table 5. These values obtained after the confirmation experiment were compared with the predicted values and found that the values obtained are within limits of confidence interval.

**Table 5**: Experimental and predicted values of weight loss due to wear.

| Response Characteristics | Optimum level | Predicted Value | C.I. at 95% | Experimental value |
|---|---|---|---|---|
| Weight loss due to wear | $MC_2$, $AT_3$, $PS_2$, $RP_2$, $L_1$, $SS_1$, $SD_1$ | 0.00063 g | ±0.0002167 | 0.64 |

## 8. MORPHOLOGICAL ANALYSIS AND EFFECT ON PARAMETERS

Scanning electron microscopy used to study the wear spectroscopy carried out to know the constituents of the hybrid composite. From the analysis the presence of calcium (Ca), silicon (Si), oxygen (O), iron (Fe), carbon (C), zinc (Zn), sodium (Na), magnesium (Mg), vanadium (W), titanium (Ti), potassium (K) etc. were observed in the surface of hybrid composites. These images have been taken for each variation of the level of percentage reinforcement and particle size. It is deduced been seen that hybrid composite based on silicon carbide and red mud can be successfully fabricated using stir casting technique. Images of EDS spectrum are shown in figures 2,3,4 and 5 along with the area of the selected spectrum.

Also, from the SEM images it was observed that the reinforcement particles were fairly uniform distributed in the Al6061 matrix. SEM of worn out surfaces carried out revealed that abrasive wear was more prominent at lower loads while adhesive wear occurred more at higher loads as shown in figures 6, 7 and 8. From the images we can also conclude that there are deeper grooves for larger sliding distance.

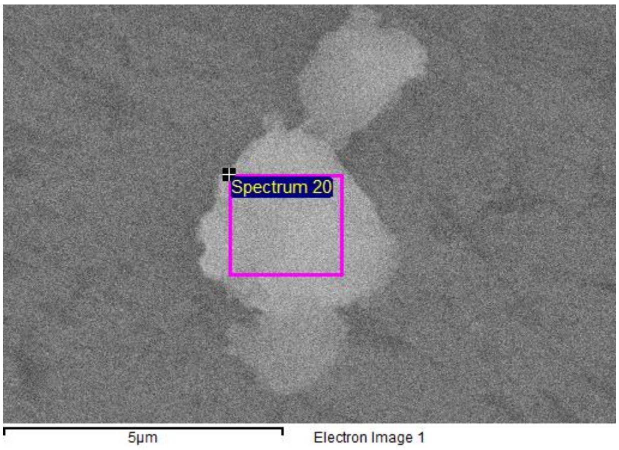

**Fig. 2.** Area of the selected spectrum of Al/SiC/4 wt. % red mud (mg 1%) hybrid composite.

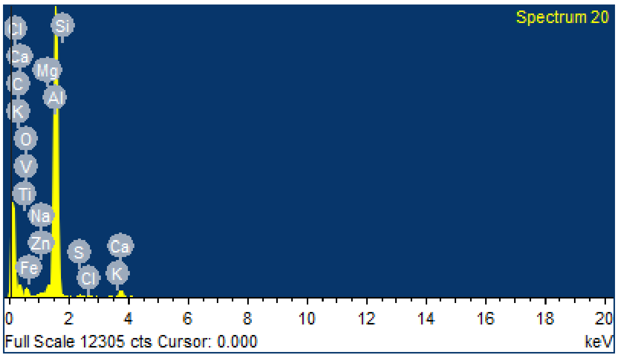

**Fig. 3.** EDS spectrum of Al/SiC/4 wt. % red mud (mg 1%) hybrid composite.

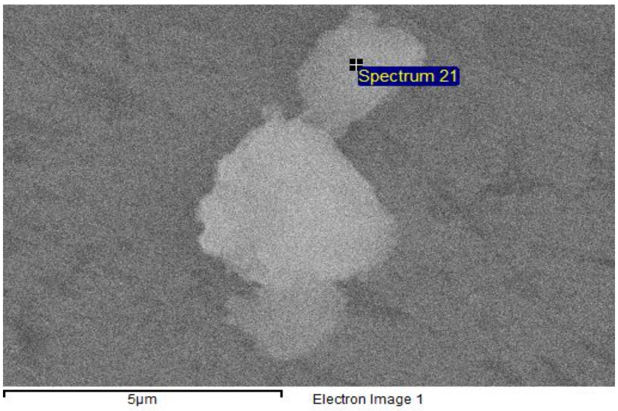

**Fig. 4.** Area of the selected spectrum of Al/SiC/4 wt. % red mud (mg 1%) hybrid composite.

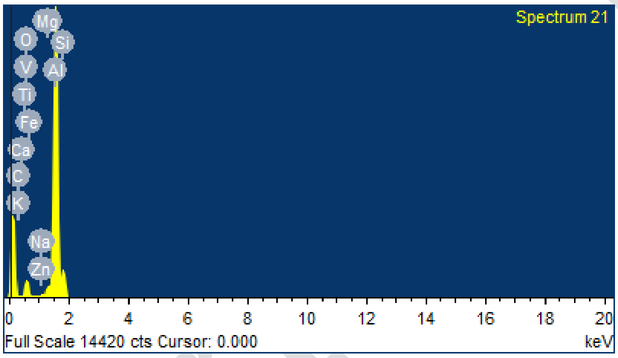

**Fig. 5.** EDS spectrum of Al/SiC/6 wt. % red mud (mg 2%) hybrid composite.

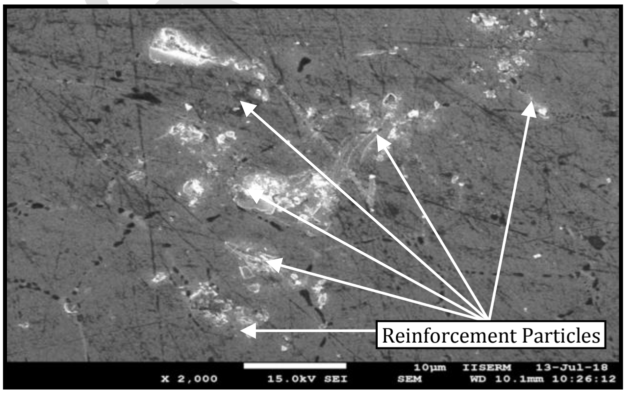

**Fig. 6.** SEM images of sample before wear for 2 % mg, 16 hr aging time, 150 mesh size6 % red mud.

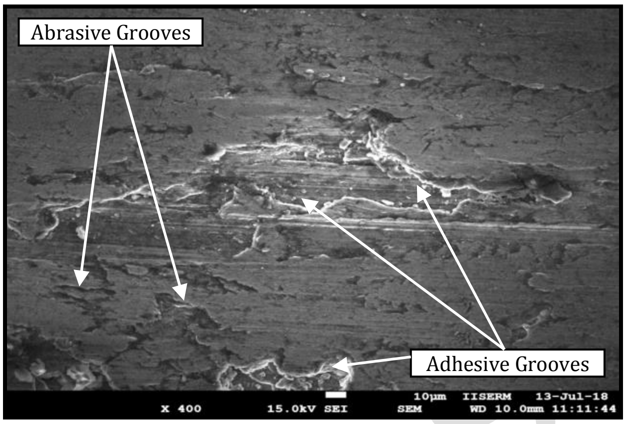

**Fig. 7.** SEM images of sample after wear for 1 % mg, 8 hr aging time, 200 mesh size, 6% red mud, 3kg load, 1.5m/s speed, 6000m sliding distance.

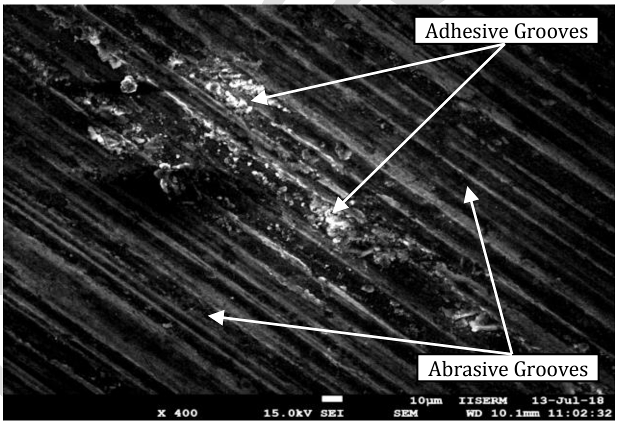

**Fig. 8.** SEM images of sample after wear for 2 % mg, 16 hr aging time, 150 mesh size, 6 % red mud, 1kg load, 1m/s speed, 2000m sliding distance.

Two samples were selected for XRD analysis one corresponding to experiment number 7 as per orthogonal array without aging and T6 heat treatment and second sample corresponding to same experiment number 7 having both T6 heat treatment and aging for 24 hours. XRD analysis was carried out at SAIF, Panjab University Chandigarh operated at 40 mA, 45 kV and data were analyzed at an angle (2 theta) from 10 to 100 degree and a step size of 0.0170. It has been found from the XRD spectra (Fig. 9, 10) that there has been presence of various distinct phases of $Al_2O_3$, $Fe_2O_3$, MgO , SiC and $TiO_2$ which has been in good agreement as per their respective JCPDS cards and respective planes (71-1123 for $Al_2O_3$ (110) 08-0479 for $Mg(CO)_3$ (110), 89-7100 for $Fe_2O_3$ (400 & 511) , 78-0430 for MgO (222) and 01-078-2486 for $TiO_2$ (224)) [26-33], So presence of these phases confirms the successful addition of reinforcements in our Al6061 matrix. Also, from the XRD patterns it has been seen that there is increase in intensity of peaks in a sample corresponding to heat treatments which implies that there is increase in crystallinity in the hybrid composite having the heat treatment thus enhancing the properties of our hybrid composite.

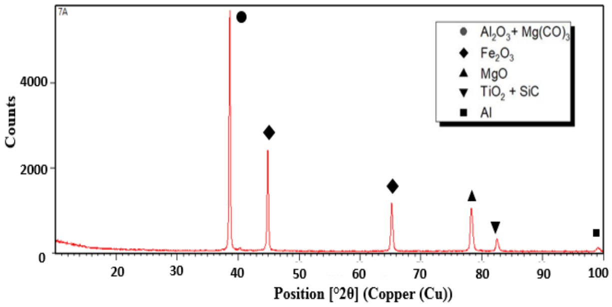

**Fig. 9.** XRD pattern for sample for 1% mg, 100 mesh size, 4% red mud without aging and T6 heat treatment.

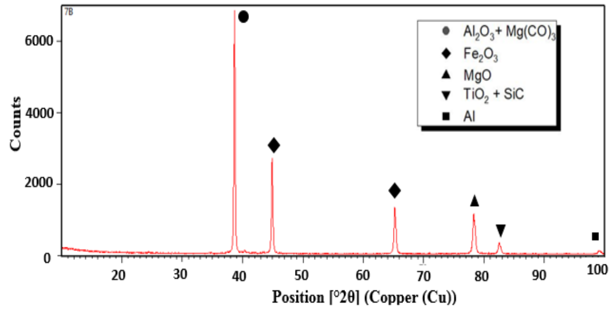

**Fig. 10.** XRD pattern for sample for 1% mg, 100 mesh size, 4% red mud, 24 hr aging time and T6 heat treatment.

## 9. EFFECT OF SELECTED PARAMETERS ON WEIGHT LOSS DUE TO WEAR

Effect of selected parameters on weight loss due to wear is shown in fig. 11. There was decrease in weight loss due to wear with an increase in magnesium content. This can be attributed to increase in hardness caused by better wettability with an increase in magnesium content. Proper wettability, may be attributed to good mixing of reinforcements and aluminium 6061 matrix making the material more resistant to wear due to the existence of more hard ceramic reinforcements. The higher value of S/N ratio at level 1 (1%) suggests strong signal and less noise thus it may be regarded as the optimum level of magnesium percentage for obtaining low wear loss. From the ANOVA analysis, it was seen that magnesium percentage (P=0.0831>0.05) has no significant effect on the weight loss due to wear. Magnesium percentage (0.08%) was the least influencing factor affecting the weight loss due to wear. The effect of aging time on the weight loss due to wear is shown in the figure 4. From the figure, there is a decrease in weight loss due to wear with an increase in aging time. This may be due to increase in the hardness of the composite with an increase in aging time. The higher value of S/N ratio at level 3 (24hr) suggests strong signal and less noise. Thus, it may be regarded as the optimum level of aging time for obtaining low wear loss. From the ANOVA analysis, particle size (P=0.303>0.05) has no significant effect on the weight loss due to wear. Particle size (0.04%) has the least influence on weight loss due to wear.

**Fig. 11.** Effect of parameters on the means of weight loss due to wear.

There is an increase in weight loss due to wear with the increase in particle size till the second level and then it declines with the further decrease in particle size. This can be due to firstly when particle size decreases there is decrease in contact stresses so the chances of pull out of reinforcement from matrix is lower. This leads to decrease in wear loss. But further decrease in particle size after level 2 (150 mesh) wear rate increases which may be due to dominance of different aspects like three-body abrasive wear which is attributed to increase the number of particles with decrease in particle size. The higher value of S/N ratio at level 2 (150 mesh) suggests strong signal and less noise; thus, it may be regarded as the optimum level of particle size for obtaining low wear loss. From the ANOVA analysis, particle size (P=0.810>0.05) has no significant effect on the weight loss due to wear. Percentage reinforcement (0.006%) has the least influence on the weight loss due to wear. The weight loss due to wear firstly decreased with an increase in red mud content up to the second level and then it increased with further increase in red mud content. This can be attributed to an increase in red mud content, as its hardness gets increased less wear is occurred. Whereas in later part the wear loss increased after the second level which may be due to the three body abrasive wear caused by the reinforcement particles as it pulls out of the surface and act as a catalyst. With increase in reinforcement percentage some reinforcement particles may get detached from the surface during wear leading to increase in wear. Similar results have been observed by Bhimaraj et al. for polyethylene terephthalate reinforced with alumina nanoparticles having different weight percentage [24]. The higher value of S/N ratio at level 2 (4%) suggests strong signal and less noise; thus, it may be regarded as the optimum level of percentage reinforcement for wear loss. From the ANOVA analysis, percentage reinforcement (P=0.310>0.05) has no significant effect on the weight loss due to wear. Percentage reinforcement (0.05%) showed least influence on the weight loss due to wear. There is an increase in weight loss due to wear with an increase in load. This may be due to increase in friction with increase in normal load, causing more wear. Similar results have been seen by Natarajan et al. for the wear behaviour of aluminium metal matrix composite and by Moustafa et al. for copper composite reinforced with different compositions of graphite [34,35]. The higher value of S/N ratio at level 1 (1kg) suggests strong signal and less noise; thus, it may be regarded as the optimum level of load for obtaining low wear loss. From the ANOVA analysis, particle size (P=0.026≤0.05) has a significant effect on the weight loss due to wear. Load (31.65%) is the second most influencing factor after sliding distance (45.257) that affects the weight loss due to wear.

There is an increase in weight loss due to wear with an increase in sliding speed. This may be due to an increase in contact area per unit time resulting in an increase in wear. A similar trend of results has been observed by Natarajan et al. for the wear behaviour of aluminium matrix composite and also by Ahamad et al for aluminium alloy reinforced with alumina particles [34, 11]. The higher value of S/N ratio at level 1 (0.5m/s) suggests strong signal and less noise; thus, it may be regarded as the optimum level of sliding speed for obtaining low wear loss. From the ANOVA analysis, sliding speed (P=0.242>0.05) has no significant effect on the weight loss due to wear. Sliding speed (0.06%) has the least influence on the weight loss due to wear. There was an increase in weight loss due to wear with an increase in sliding distance. This may be due to increase in contact area with an increase in sliding distance resulting in more area under erosion leading to an increase in wear. Similar results have been seen by Hassan et al. for Al-Mg–Cu alloys reinforced with silicon carbide and by Miyajima and Iwai for aluminium 2024 composite reinforced with silicon carbide and aluminium oxide [36, 37]. The higher value of S/N ratio at level 1 (2000m) suggests strong signal and less noise; thus, it may be regarded as the optimum level of magnesium percentage for obtaining low wear loss. From the ANOVA analysis, it can be concluded that sliding distance (P=0.014≤0.05) has a significant effect on the weight loss due to wear. Sliding distance (45.257%) has been the most influencing factor affecting the weight loss due to wear.

## 10. CONCLUSIONS

- Hybrid aluminium 6061 composites have been successfully fabricated using stir casting technique with fairly uniform distribution of the silicon carbide and red mud particles in the composite matrix.
- Weight loss due to wear was found to decrease with an increase in magnesium content and aging time. However, with the increase in particle size of red mud and red mud content the wear loss was observed to decrease till particle size of 150 mesh and red mud content of 4 %.
- Weight loss due to wear increases with an increase in load, sliding speed and sliding distance. SEM images of wear surfaces after the wear test has shown that both abrasive wear and adhesive wear occurred predominantly.
- From the analysis it was seen that load and sliding distance have significant effect on the weight loss due to wear.

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