PREPARATION AND CHARACTERIZATION OF ALUMINIUM METAL MATRIX COMPOSITE REINFORCED WITH Al₂O₃-SiO₂-SiC SYNTHESIZED IN PLASMA REACTOR BY CARBO THERMAL REACTION OF FLY ASH

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ABSTRACT

With the rising problem of fly ash disposal globally, constant attempts are being made to promote utilization of fly ash in different areas. One such identified area is Aluminium Metal Matrix reinforced with fly ash (ALFA) composite. Research papers suggest potentiality in this area. Some Researchers have observed that the properties of ALFA composite vary with composition of fly ash. In the present investigation fly ash is chosen containing 5% carbon in it. Fly ash is characterized chemically, micro structurally and with XRD. These are then treated specially in high temperature plasma reactor in neutral atmosphere. Treatment has caused partial conversion of SiO₂ to SiC with the presence of other phases such as Al₂O₃, SiO₂ and Carbon. SEM, XRD, EDAX analyses have corroborated the above findings. Both the hardness and tensile properties such as UTS, YS, Stiffness are more for ALFA treated composite in comparison with ALFA untreated composite. Fractographs of ALFA treated sample shows appearance of dimples in different areas with large deformations at places around particles. Fractographs of broken tensile samples of ALFA untreated shows presence of fine dimples with areas having river pattern appearance in the fractured surface. One of the spots reveals shearing of the particle. The result of the tensile test, thus corroborate the SEM finding from fractographs. Abrasion studies of composites prepared with untreated and treated fly ash shows the abrasion resistance is more for ALFA treated composite than ALFA untreated composite. However, abrasion is more pronounced for both the composites beyond 3Kg load. It is observed that abrasion rate increases rapidly for ALFA untreated than ALFA treated composite. Effect of variables (such as load, speed, time) on abrasion of ALFA untreated and treated composites are quantified in the form of regression equations. These equations are statistically checked and corrected by ’t’ test. The validity of the equations are established using F test and with random experiments. These equations are useful to predict the abrasion resistance of two composites accurately in the range of variation of variables.

KEYWORDS: Plasma Synthesized MMC Composite, Flyash, Stir Casting, Wear, Statistical Design Experiment

INTRODUCTION

Metal matrix composites have gained importance over monolithic alloys owing to their attractive properties such as high strength to weight ratio, stiffness and bulk density (1-4). The improved fatigue resistance has also been observed for composites made with conventional alloys (5). Recent market survey report, published by BCC research Co.USA, has revealed that composites made with lighter metals such as Al, Mg, Ti have substituted many conventional heat treated ferrous and non ferrous alloys used both in cast or wrought condition by automobile, aero space, electronic Industries (6).
Aluminium metal matrix composites (AMC) have become more popular due to their abundance, less cost, low melting point, high thermal conductivity and simpler during handling. Common additives are Al₂O₃, SiC, SiO₂, BN etc. The melting and casting route for the preparation of these materials is comparatively easier and properties of composites developed by this process are isotropic in nature. Stir casting is a useful technique adapted for producing aluminium matrix composite. Because of poor wettability of ceramic particulates such as SiC, Al₂O₃ in the melt, there is considerable drainage of these materials during production of composites by melting route. This increases the cost of production and therefore, makes the product yet costlier. Results of published literature suggest that the use of fly ash as reinforcing agent is beneficial and can reduce the cost appreciably. Presence of hollow micro sphere, called cenosphere. Aluminium fly ash composite (ALFA) lighter and enhances the stiffness, strength as well as abrasion resistance. Fly ash contains fine particles of SiO₂, Al₂O₃ in major quantities with the presence of oxides of Fe, K, Na, P, Mn etc. in minor quantities. However, the composition of fly ash is found to vary from one source to the other. Final properties of AMCs largely depend on chemical composition of the constituents, i.e. reinforcing agent and their amount, the volume fraction, size, shape and their distribution in the matrix.

Under different operating conditions with variable compositions of coal used by Power plants, fly ash generated contains carbon varying from 0.5 to 5% or even more. Systematic studies have not been carried out to find the effect of carbon in fly ash on the properties of (ALFA) composite. It is, therefore, necessary to study such an effect in the ALFA composite. Carbon being a brittle and amorphous constituent in fly ash Vis-a-Vis ALFA composite, it will be fractured or be fragmented during loading or by other deformation processes and thereby may lead to de-cohesion and spilling off from the matrix phase. The beneficial effect of particulates in the matrix will thus be reduced leading to poor mechanical & chemical properties of composites. Prior heating of fly ash to a temperature of 800°C in oxidizing atmosphere before using in the Aluminium melt will result in the removal of carbon by oxidation. However, with suitable heat treatment or with plasma synthesis of fly ash under neutral atmosphere, it is possible to develop an important ternary in-situ ceramic composite comprising of SiO₂, SiC, Al₂O₃. If any un-reacted carbon is present, it will convert to graphite, a crystalline phase which will improve properties such as machinability. In the present investigation, high carbon fly ash is treated under controlled atmosphere in a furnace, having temperature of 1500°C/1600°C. Alternatively; fly ash is treated in a plasma reactor under neutral atmosphere for producing in-situ ceramic composite. In either case SiO₂ in fly ash will react with carbon to form silicon carbide and thus is expected to result better properties in the ALFA composite. These treated materials are used in molten aluminium for producing ALFA composite. For the comparison purpose, ALFA composite is also prepared with untreated fly ash. The effect of different parameters on abrasion properties is quantified in the form of regression equations by adapting statistical design of experiments.

**Statistical Design Experiments**

In statistical design experiments, different factors affecting the properties are varied simultaneously. The base level, around which the factors are varied, is usually chosen either from the literature or from own results obtained by single factor experiments. Number of experiments depend on the range of variation of variables and the number of variables used in the experiments. It is calculated using a relation \( P^n \), where \( P \) is the range of variation of variables, \( n \) is number of variables. In the present work, variation range is kept at two levels i.e. \( P = 2 \) and the number of variables used are 3. In effect, 8 experiments are required for construction of the design matrix. For statistical analysis and better accuracy, each experiment is replicated thrice. The regression equation developed by using the data of design matrix is polynomial in nature and relate to properties (\( Y \)) with variables (\( X \)) in the form of equation as stated below;

\[ Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{12}X_1X_2 + b_{23}X_2X_3 + b_{13}X_1X_3 + b_{123}X_1X_2X_3 \]  

(1)
b₀, b₁, b₂, b₃,……… are constants and quantify main effect of the variables & b₁₂, b₂₃, b₁₃,……… are represent interaction coefficients. All the constants related to variables are not significant, which may arise from error in experiments. Therefore, the equations need be corrected by applying ’t’ test. Further, adequacy of the corrected equations is checked by Fiscer(F) test. For computation of ∆bj and F values, following expressions are used;

\[ \Delta b_j = \pm t \times S_{bj} \] (2)

\[ \Delta b_j \] is the confidence interval and can be computed from the equation (2)

\[ S_{bj} = \frac{S^2_y}{N} \] (3)

\[ S^2_y = \frac{\sum_i^N \sum_j^n (y_i - \bar{y}_j)^2}{N(n-1)} \] (4)

N= total number of experiments, n= number of replicate made at each level, \( \bar{y} \) = average response of n replicates. The value of \( t_{a,n} \) is obtained from table (reference). The confidence interval setup by the upper and lower limits(\( bj \pm \Delta bj \)) are the marginal values. The coefficients of equations having the value less than \( \pm \Delta bj \) value are to be ignored. The new equations are formed after neglecting the insignificant coefficients. The adequacy of equations is checked by variation ratio test. For this purpose, the residual variance of adequacy is calculated using the following relations;

\[ F_{\text{calculated}} = \frac{S^2_{ad}}{S^2_y} \] (5)

\[ S^2_{ad} = \frac{\sum_i^N \Delta y_i^2}{f} \] (6)

\( \Delta y_i \) = difference between the experimental and calculated properties.

Degree of freedom (f) = N – K,

N = Total number of experiments, K = Number of significant coefficient of regression equation.

If \( F_{\text{calculated}} < F_{\text{obtained}} \) from standard statistical table, the model is adequate and the equation may be used to predict the property correctly, within the range of variation of variables.

**EXPERIMENTAL**

**Characterization of Fly Ash**

As received fly ash is screened out below 240 mesh size. The average particle size of screened material is determined by sieve analysis, particle size analyzer (Malvern instruments Ltd). The composition of fly ash is chemically analyzed and is characterized by XRD

**Plasma Synthesize of Fly Ash**

Fly ash is mixed with activated charcoal amounting 20% of weight of the SiO₂ present in the fly ash. This is done with a view to converting some part of SiO₂ into SiC. The mixture is treated in a plasma reactor under neutral atmosphere. Treated fly ash is then characterized using XRD, SEM, EDAX.
Preparation of ALFA Composite

Aluminum 99.8% purity is used for the preparation of the ALFA composite. Fly ash is to be heated to 700°C before pouring in to the melt of aluminum. This is done for enhancing the wettability. The aluminum ingots, before melting, are properly cleaned to eliminate the surface impurities. The melting furnace used is pit-type resistance-heating system with a bottom pouring arrangement (Figure 1).

The molten metal is stirred with a BN coated stainless steel rotor at a speed of 600-650 rpm. A vortex is created in the melt because of stirring where preheated (700±2°C) fly ash is poured centrally into the vortex. The rotor is moved down slowly, from top to bottom by maintaining clearance of 12 mm from the bottom. The rotor is then pushed back slowly to its initial position. The pouring temperature of the liquid is kept around 700°C. Casting is made in cylindrical, as well as rectangular metal moulds.

Metallographic and Hardness Tests

Metallographic samples are prepared from central portion of the ingots. These samples are observed under image process analyzer (XJL 17). Hardness Tests are performed using Rockwell Hardness Tester, HRF scale.

Tensile Test

Tensile test is conducted using Universal testing machine, the dimensions of test specimen is shown in (Figure 2). Mechanical properties such as Tensile Strength, % of elongation, yield strength are determined.

Wear Test

Treated and untreated ALFA composite are tested for Abrasion resistance using pin on disc wear testing machine (DUCOM 201 LE) under atmospheric air condition. The test samples having the dimensions of 8 mm diameter and 40 mm length, (as shown in Figure 3) are slid against the low alloy steel disc (material EN-31-HRS 60 W 61 equal to 4340) of dia 215 mm, and Hardness Re 62. Weight loss is measured and tabulated in design matrix under variable loads (30, 50, 70N), speeds (0.4, 1.0, 1.6 m/s), timings. (600, 900, 1200 sec). Tangential force and hence the coefficient of friction is measured continuously with an electric sensor attached to the machine and are recorded. The worn out samples are cleaned with acetone and are weighed in the balance. Each test is performed thrice for making the statistical analysis.

Hot Working of the Composite

Treated and untreated ALFA strip composites are soaked to a temperature of 450±5°C for 3hrs and are then hot forged. Initial thickness of the strips are 20mm. Working is done in steps ie 10% in each step first the thickness is reduced to 8mm in between each step the strips are soaked for a half an hour before the forging is resumed. Strips are reduced, because of 8mm for the preparation of DUCOM samples following hot forging a few strips are also hot rolled to a thickness of 2mm. Hot rolling is also carried out in steps before rolling operation. Strips are soaked at 480°C for half an hour and rolling is carried. in between each step before rolling annealing is done for an half an hour. Thin sheets are used for tensile test.

RESULTS AND DISCUSSIONS

Characterization of Fly Ash (Chemical)

Chemical analysis (Table 1) shows presence of compounds such as SiO₂, Al₂O₃, Fe₂O₃ as major constituents in fly ash. Since Fe₂O₃ is detrimental to the properties of ALFA composite, therefore pre-treatment of Fly ash in a magnetic separator under wet condition has enabled reducing Fe₂O₃ content to appreciably to a lower value (i.e., 5 - 0.5 %).
X-ray analysis of treated fly ash (figure 4) indicates that thermal treatment of fly ash under neutral atmosphere has converted partially SiO$_2$ to SiC by the following reaction:

$$\text{SiO}_2 + 3\text{C} \rightarrow \text{SiC} + 2\text{CO}.$$  

It is suggested that SiO$_2$ may be reduced to Si by Aluminum melt. Reduced Si in turn may react with carbon present in the fly ash to form SiC, a stable thermodynamic phase. The formation of SiC is observed by several workers by treating rice husk which contains SiO$_2$ & Carbon in it. SiC particulates formed in the treated fly ash will provide added advantage, i.e., it will reduce thermal distortions, if added in the Al melt as reported by some authors. The diffraction pattern has confirmed presence of other phases such as Al$_2$O$_3$ and C.

Many researchers have established the importance of shape, size and distribution of powders. Therefore, size analysis of fly ash is thought to be very important. Both statistical analysis and Particle analysis with laser particle size analyzer have found out that the average particle size of fly ash is 36.08μm. However, there are fine particulates in the sizes, ranging between 5-10μm. Scanning electron micrographs of powder (figure 5) have shown size and shape and distribution of particles. Shape of particles are rough, irregular but not spherical. Rough and small particles increase the wettability. EDAX analysis of heat treated fly ash powder shows the presence of elements such as Al, C, Si. O this evidences the presence of SiO$_2$, Al$_2$O$_3$ and SiC compounds in the treated material as has been observed in XRD pattern (Figure 4). Some un-reacted carbon is observed in Scanning electron micrographs (Figure 5a) as is confirmed by EDAX analysis (Figure 5b).

**Microstructure Characterization of ALFA Composite**

Figure 6(a,b,c),7 (a,b,c) are optical micro graphs and volume fractions of fly ash particles(untreated and treated respectively) in the aluminum matrix. The distribution of particles in the microstructure are seen to be uniform. On etching, fine grain structures are resulted. Grain boundaries are also thickened owing to segregation of particles. Nucleation of grains in the liquid aluminum begins heterogeneously at the interfaces of incoherent and fine particles. During the growth of grains the particles are pushed to their boundaries. Segregation of fine particulates at the high energy high angle grain boundaries lowers the surface tension force and this brings stability to the microstructure. Figure 8b shows fly ash particles segregation at the grain boundary of ALFA composite. Scanning electron micro graph along EDAX analysis confirms the presence of un reacted carbon in the matrix (Figure 8a&b).

A notable difference is observed in optical micro graphs of ALFA(un treated)and ALFA (treated)composites. During plasma treatment of fly ash particles have clustered as a result of reaction between SiO$_2$ and C forming SiC in the neighborhood of Al$_2$O$_3$ particles, with the presence of un reacted carbon. This has caused the particles formulated cluster in the treated samples which are and thickened at the grain boundaries (Figure 8c). Volume fractions measured for un treated and treated ALFA composites are 18% and 16% respectively. Therefore, not much difference in volume percentage in the microstructures.

**Mechanical Properties**

- **Hardness Measurement**

  Difference in the hardness of the composite prepared with treated and untreated fly ash has been observed. While the hardness for ALFA composite with untreated fly ash is measured to be HRF 22, the hardness of ALFA composite with treated fly ash is HRF 29. This difference is attributed to the difference in composition, morphology, nature, distribution of particles resulted from plasma treatment of fly ash as discussed in the preceding paragraph of the text.
• Tensile Properties

Stress-Strain curves for untreated and treated ALFA composites are shown in (Figure 9). For ALFA composite (untreated), UTS, YS are much less as compared to the values of ALFA composite (treated) as shown in table 2. The stiffness for ALFA composite (treated) is larger in comparison to the stiffness of ALFA composite prepared with untreated fly ash composite. The percentage of elongation of two materials is 47%, 44% respectively.

The energy absorbed by both the materials till they rupture (area under stress strain curves) widely vary. This also suggests a rough estimation of a fracture toughness values of the two materials. Fractographs of tensile samples corroborate the tensile values. Fractographs of broken tensile samples of ALFA composites (treated/untreated) are shown in figures 10, 11. For untreated samples there is a mixed mode of fracture (Figure 10a, b, c). Corresponding fractured sample of the treated materials show presence of dimples with a few areas of crater indicating large deformation of material around spherical particles when viewed at higher magnification (Figure 11a, b, c). The topography of the fractured surface in case of ALFA composite (untreated) has an even surface with river pattern appearance. However appearance of fine dimples in greater areas of ALFA composite (treated) indicate higher toughness of the later composite. Scanning electron micrographs of the fractured sample of ALFA (untreated/treated) composite at higher magnification. While ALFA (untreated) samples shows tearing of facets of particulates with wide opening but ALFA (treated) shows large deformation in the matrix around particulates.

Wear Properties

For automobile industries, higher abrasion resistance for composite is a mandatory requirement, especially when applied for brake system. Therefore, it is thought to find out abrasion rate for the novel composite prepared with Aluminum and thermally treated fly ash. For comparison purpose, composites prepared with Aluminum and as received fly ash (untreated) is taken as a reference material. Volume fractions of the reinforcing agents for both the ALFA composites have been kept 16% & 18% respectively. Since the applied load has effect on the abrasion or loss of material, therefore materials are subjected to variable loads (ie 1 kg & 5 kg). Figure 12a, b are direct plots from DUCOM tester. For 1 kg load abrasion occurs almost at the same rate for both the composites. However ALFA (untreated) is seen to abrade more as compared to ALFA (treated). When the load is increased from 1kg to 5kg it is observed that there is appreciable change in the abrasion rate for the two composites. In general abrasion is more at higher load for both the composites as shown in figure 12a and figure 12b. However abrasion rate is higher for ALFA untreated than the corresponding ALFA treated composite. Figure 13 is a plot of wear rate Vs load for ALFA (untreated & treated) composites. Wear rate of pure Aluminum is superimposed on the diagram for comparative studies. Pure aluminum abrades steadily at higher rate. In case of ALFA composites (treated and untreated) abrasion rates are increased with load at much slower pace. However, abrasion of ALFA (untreated) composite increases at faster rate beyond 30 N load than the ALFA (treated) composite. SEM photographs of untreated and treated ALFA composite samples are shown in Figure 15(a) & 15(b). The comparison of wear debris and the surface roughness of both the composites clearly indicate the extent of abrasion occurred under similar condition of wear test. The surface roughness of untreated sample with higher depth of penetration by the pin is distinctly visible in untreated ALFA composite material (Figure 15a). Figure 12a, b corroborate the quantitative values of wear of the two materials, obtained in the test. Thus the fly ash treatment in plasma reactor has given added advantage as regard to abrasion resistance of the ALFA composite. Thermo mechanically treated ALFA composite prepared with fly ash (untreated, treated) are also tested for abrasion resistance. Due to thermo mechanical operation, the inter phase between particle and the matrix gets modified and mechanically bonding is established. Therefore, it is expected that abrasion resistance for both treated and untreated fly ash in aluminum matrix will be more for thermo mechanically treated
composites Figure 14 shows comparative graphs of wear under similar variables (load-3kg, speed-1.6m/sec, time -20min) for untreated and treated ALFA composites in as cast and forged condition.

Quantitative effect of variables such as load, speed, time is found out in the form of regression equation by applying statistical design of experiments. Table no.(3) shows range of variation of variables in the coded form as well as their natural values (shown in brackets). Table (4) shows treatment combination with responses for ALFA untreated composite and similar results with treatment combinations are shown in table.5 for ALFA treated composite. Each experiment is replicated thrice. The two tables (table.4,5) depict responses in terms of weight loss for the two composites(ALFA untreated & treated) responses. Treating data of the table.4 and 5 response surfaces are obtained in the form of regression equations connecting weight loss with load, speed, time and are shown in equations7,8 of Untreated and treated ALFA composites respectively. All the coefficients obtained in the equations may not be significant and may occur due to error in the experiments(personal or machine).

ALFA Untreated Composite

\[ Y_1(\text{Weightloss}) = 16.24975 + 1.5X_1 + 10.3325X_2 + 9.91675X_3 + 0.25X_1X_2 + 5.83325X_2X_3 + 0.3335X_1X_3 - 0.4165X_1X_2X_3 \]

(7)

ALFA Treated Composite

\[ Y_2(\text{Weightloss}) = 9.4577 + 2.45837X_1 + 6.54187X_2 + 4.20837X_3 + 1.5416X_1X_2 + 2.7916X_2X_3 \]

(8)

Insignificant coefficients in equations 7 and 8 are found out by applying T test using relations expressed in equation(2). ±\(\Delta b_j\) Values computed are shown in table (6). Any value of coefficient in equations7 and 8 is departing from ±1.41823 and ±2.1761 for untreated and treated composites respectively are eliminated from the equations and the corrected equations are shown in equations 9,10.

\[ y_1(\text{Weight loss}) = 16.24975 + 1.5X_1 + 10.3325X_2 + 9.91675X_3 + 5.83325X_2X_3 \]

(9)

\[ y_2\text{Weight loss} = 9.4577 + 2.45837X_1 + 6.54187X_2 + 4.20837X_3 + 2.7916X_2X_3 \]

(10)

Adequacy of these equations are checked by Fisher ‘F’ test, as described in the earlier section (Eq-4,5 and 6). The analysis of the results shows that ‘F’ values calculated from the corrected equations is always less than Fisher ‘F’ value obtained from standard statistical table reference \(^{(25)}\). Therefore, it can be calculated that the equations are adequate and can predict results in the range of variables with 95% confidence. Further, the accuracy of equations are checked through random experiments and the results are shown in table.6.

These equations are strictly valid in the range of variation of variables. Equations 9 and 10 reveal that the abrasion has occurred more for ALFA composite prepared with untreated fly ash. The applied load has however relatively less effect than the two other variables(comparison of coefficients attached to\(X_1,X_2,X_3\) of equations 9,10). Both the load and speed have prominent effect on the abrasion rate of both the composites(viz coefficients of equations attached to both the equations).

However, the effect of speed and time on abrasion of ALFA composite is twofold in comparison to ALFA composite (treated). The combined effect of speed and time is also more severe (two fold for the ALFA untreated composite compared to ALFA treated composite). These equations are thus helpful for quantifying effect of variables on abrasion of two composites prepared.
CONCLUSIONS

- Fly ash consisting of SiO$_2$ in major quantities is partially converted to SiC by heat treatment in a plasma reactor.
- XRD, SEM & EDAX analysis have confirmed successful in situ conversion of a part of SiO$_2$ present in a fly ash to SiC with some untreated carbon added purposefully into the matrix.
- ALFA composites are prepared with untreated and treated fly ash having 18%, 16% of volume respectively. The micrographs show clustering of particles presumably at the grain boundaries.
- Both the hardness and tensile properties such as UTS, YS, Stiffness are more for ALFA treated composite in comparison with ALFA untreated composite. Fractographs of ALFA treated sample shows appearance of dimples in different areas with large deformations at places around particles. Fractographs of broken tensile samples of ALFA untreated shows presence of fine dimples with areas having river pattern appearance in the fractured surface. One of the spots reveals shearing of the particle. The result of the tensile test, thus corroborate the SEM finding from fractographs.
- Abrasion studies of composites prepared with untreated and treated fly ash shows the abrasion resistance is more for ALFA treated composite than ALFA untreated composite. However abrasion is more pronounced for both the composites beyond 3Kg load. It is observed that abrasion rate increases rapidly for ALFA untreated than ALFA treated composite.
- Effect of variables (such as load, speed, time) on abrasion of ALFA untreated and treated composites are quantified in the form of regression equations. These equations are statistically checked and corrected by ‘t’ test. The validity of the equations are established using F test and random experiments. These equations are useful to predict the abrasion resistance of two composites accurately in the range of variation variables.

ACKNOWLEDGMENTS

The authors wish to acknowledge the administration of GIET, Gunupur for providing support to carry out the work and to permit the authors to the publish scientific article in journal. The authors further wish to acknowledge the support provided by NML, Jamshedpur and IMMT Bhubaneswar to carry out the part of the work.

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APPENDICES

Table 1: Chemical Composition of Fly Ash

<table>
<thead>
<tr>
<th>Chemical Composition</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>C</th>
<th>Fe₂O₃</th>
<th>FeO</th>
<th>K₂O</th>
<th>CaO</th>
<th>MgO</th>
<th>Fe</th>
<th>Ti</th>
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</thead>
<tbody>
<tr>
<td>Weight%</td>
<td>68.41</td>
<td>20.73</td>
<td>5.6</td>
<td>4.97</td>
<td>0.45</td>
<td>0.95</td>
<td>0.62</td>
<td>0.46</td>
<td>2.77</td>
<td>2.04</td>
</tr>
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</table>
### Table 2: Tensile Properties of ALFA (Untreated, Treated) Composites

<table>
<thead>
<tr>
<th>Properties of ALFA Composites</th>
<th>Hardness</th>
<th>UTS(Mpa)</th>
<th>YS(Mpa)</th>
<th>% Elongation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>HRF22</td>
<td>66</td>
<td>57</td>
<td>47%</td>
</tr>
<tr>
<td>Treated</td>
<td>HRF29</td>
<td>150</td>
<td>114</td>
<td>44%</td>
</tr>
</tbody>
</table>

### Table 3: Range of Variation of Variables, Variation with Their Codes and Natural Values

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Level</th>
<th>Load(N) X₁ (Natural Values)</th>
<th>Speed(m/s) X₂ (Natural Values)</th>
<th>Time(min) X₃ (Natural Values)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Upper level (UL)</td>
<td>+1 (70)</td>
<td>+1 (1.6)</td>
<td>+1 (20)</td>
</tr>
<tr>
<td>2</td>
<td>Base Level</td>
<td>0 (50)</td>
<td>0 (1.0)</td>
<td>0 (15)</td>
</tr>
<tr>
<td>3</td>
<td>Lower Level (LL)</td>
<td>-1 (30)</td>
<td>-1 (0.4)</td>
<td>-1 (10)</td>
</tr>
</tbody>
</table>

\[ X_{\text{Coded Value}} = \frac{x - x_0}{\Delta x} \]

\( x_0 = \) base value, \( x \) is natural value, \( \Delta x = \) interval of variables

### Table 4: Design of Matrix with Response (Untreated ALFA Composite)

<table>
<thead>
<tr>
<th>Treatment Combination (X Variable)</th>
<th>Coded Values</th>
<th>Response Y₁</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X₁ Load</td>
<td>X₂ Speed</td>
</tr>
<tr>
<td>Sl. No.</td>
<td>(N)</td>
<td>(m/s)</td>
</tr>
<tr>
<td>1</td>
<td>+1</td>
<td>+1</td>
</tr>
<tr>
<td>2</td>
<td>-1</td>
<td>+1</td>
</tr>
<tr>
<td>3</td>
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<td>-1</td>
</tr>
<tr>
<td>4</td>
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</tr>
<tr>
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</tr>
<tr>
<td>6</td>
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<tr>
<td>7</td>
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<td>-1</td>
</tr>
<tr>
<td>8</td>
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### Table 5: Design of Matrix with Response (Treated ALFA Composite)

<table>
<thead>
<tr>
<th>Treatment Combination (X Variable)</th>
<th>Coded Values</th>
<th>Response Y₂</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X₁ Load</td>
<td>X₂ Speed</td>
</tr>
<tr>
<td>Sl. No.</td>
<td>(N)</td>
<td>(m/s)</td>
</tr>
<tr>
<td>1</td>
<td>+1</td>
<td>+1</td>
</tr>
<tr>
<td>2</td>
<td>-1</td>
<td>+1</td>
</tr>
<tr>
<td>3</td>
<td>+1</td>
<td>-1</td>
</tr>
<tr>
<td>4</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>5</td>
<td>+1</td>
<td>+1</td>
</tr>
<tr>
<td>6</td>
<td>-1</td>
<td>+1</td>
</tr>
<tr>
<td>7</td>
<td>+1</td>
<td>-1</td>
</tr>
<tr>
<td>8</td>
<td>-1</td>
<td>-1</td>
</tr>
</tbody>
</table>

### Table 6: Confidence Interval \( \Delta b \) Values

<table>
<thead>
<tr>
<th>Un Treated</th>
<th>Treated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wear</td>
<td>Wear</td>
</tr>
<tr>
<td>± (1.41823)</td>
<td>± (2.1761)</td>
</tr>
</tbody>
</table>
Preparation and Characterization of Aluminium Metal Matrix Composite Reinforced with 
Al$_2$O$_3$-SiO$_2$-SiC Synthesized in Plasma Reactor by Carbo Thermal Reaction of Fly Ash

Figure 1: Bottom Pouring Furnace

![Bottom Pouring Furnace Image]

Gl=Gauge Length, Pl=Parallel Length

Figure 2: Tensile Test Specimen

![Tensile Test Specimen Image]

Figure 3: Wear Test Specimens

![Wear Test Specimens Image]

Figure 4: XRD Pattern of Plasma Treated Fly Ash Powder

![XRD Pattern Image]
Figure 5: Scanning Electron Micrographs and EDAX Analysis of Fly Ash Powder

Figure 6: Optical Micrograph of Untreated ALFA Composite and Volume Fractions

Figure 7: Optical Micrograph of Treated ALFA Composite and Volume Fractions

Figure 8: a, b, c, Scanning Electron Micrograph and EDAX Analysis of ALFA Composite
Preparation and Characterization of Aluminium Metal Matrix Composite Reinforced with Al₂O₃-SiO₂-SiC Synthesized in Plasma Reactor by Carbo Thermal Reaction of Fly Ash

Figure 9: Stress vs Strain Diagram

Figure 10: Scanning Electron Micro Graphs of Broken Tensile Specimen of Untreated ALFA Composite

Figure 11: Scanning Electron Micro Graphs of Broken Tensile Specimen of Treated ALFA Composite

Figure 12: (a, b): Wear (µm) vs Time(sec) Graphs of ALFA Composites (Untreated, Treated)
Figure 13: Wear Rate (µm/Sec) vs Load (N) Graphs of ALFA Composites (Untreated, Treated)

Figure 14: Wear (µm) Vs Time (sec) Graph of ALFA Composites (Untreated, Treated) as Cast and Forged (TMT)

Figure 15a: Worn Out Surface of ALFA Untreated Composite at Load (3kg), Speed (1.6m/sec), Time (20min)

Figure 15b: Worn Out Surface of ALFA Treated Composite at Load (3kg), Speed (1.6m/sec), Time (20min)