Tribological Performance of Al-MMC Reinforced with Treated Fly Ash using Response Surface Methodology

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Abstract

Objectives: To fabricate Aluminium Metal matrix Composite (AMC) reinforced with treated fly ash (TFA) and untreated fly ash (UFA) by stir casting route with percentage of volume ≈ 15%. Methods/Statistical Analysis: Fly ash particulates are treated in plasma reactor; Al-TFA composite has been compared with Al-UFA and Al-Si alloy. In treated fly ash (TF) composite, carbon is present in the form of graphite which enhanced wear resistance. The experiments are designed based on response surface methodology (RSM). In this study, sliding time, sliding distance and load as input parameters whereas weight loss (g) and coefficient of friction (COF) are response. Findings: X-ray studies corroborate the presence of SiC in TFA. Mechanical (i.e. Hardness, Tensile and Impact strength) and Physical (i.e. density) properties of Al-TFA composite exhibited better than Al-UFA and Base matrix. In this study, sliding time, sliding distance and load as input parameters whereas WL (g) and COF are response. Analysis of variance (ANOVA) is performed on Al-TFA composite to known the effect of parameters on response. From ANOVA of TFA disclosed that load is the most significant factor then sliding time and distance on WL. Similarly, on COF, the collective effect of load and sliding distance is the highest influencing parameter. The significant of optimum for WL (g) and COF is 0.007 and 0.183 respectively. Moreover, a confirmation test is conducted to validate the regression equation and the worn-out surfaces are examined by Scanning Electron Microscopic (SEM). Application/Improvements: Al-TFA composite exhibited better mechanical and tribological properties than Al-UFA composite.

Keywords: AMCs, ANOVA, Coefficient of Friction, Fly Ash, RSM, Weight Loss

1. Introduction

Metal matrix composites (MMCs) are potential applications in different areas due to their unique property combinations. The present scenario demand for materials with specific modules, specific strength, high temperature resistance, stiffness, and better resistance of wear. Aluminium Composites (AMC) and their alloys are important engineering materials for tribological and mechanical applications due to their low density, low thermal coefficient of expansion conductivity and improved machinability used for applications like automobile, mineral processing, and aerospace industries. The selection of matrix with reinforcement materials has become an interesting area for manufacturing science in MMGs. Aluminium - silicon alloys present a great...
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Industrial potential in many applications. It is due to its good castability. Al-Si alloys are of particular importance to many engineering applications due to its outstanding characteristics and properties such strength to weight ratio, superior corrosion resistance, good castability, and low hot tearing tendency. The major drawback of this material is that; show the inferior standard of tribological properties. Therefore, it is desired by the researcher to extend a new material with superior tribological properties and contest on the ratio of strength to weight. The specified above problem has been overcome by addition of hard and soft phase particulates (reinforcement) such as SiC, B4C, TiC, MgO, Al2O3, TiB2, BN and TiO2 in Al-Si alloy to enhance the composite properties i.e. mechanical and wear resistance. Stir casting is a useful technique adapted for producing AMC. 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. Therefore, makes the product yet costlier. Many researchers advocate that the use of fly ash as reinforcing agent is favourable and can reduce the cost appreciably.

Fly ash is potential discontinuous dispersions used in MMCs, because of inexpensive and low-density with plenty availability in thermal power plants. The addition of fly ash particle to base matrix, which will improve physical, mechanical and tribological properties. In consideration of adequate availability and cheap, the Fly ash (FA) is widely make use in aerospace sectors and automotive parts. Gupta and Ling reported on the behaviour of mechanical and microstructure about Al-Si alloys fabricated with various volume of Si i.e. 7, 10 and 19% by disintegrated melt deposition technique. The observation from the microstructures, while increasing of Si, porosity also increases. Moreover, the aging study reported that in all Si composites have similar aging kinetics which, resulting in increasing of mechanical properties. A composite contains SiC-Al2O3-C from fly ash. Generally, The Indian fly ash contains the chemical elements like SiO2, Al2O3, Fe2O3, and CaO etc. Presences of carbon along with SiO2 compound the translation of SiO2 towards SiC via plasma reactor (thermal treatment) and fabricated an AMC.

Currently, industrial units are facing a problem on wear and machinability performance of materials and tools, which lead to the replacement of components frequently especially due to abrasion. The hard phase particles were penetrated into soft material, which causes Abrasive wear. Many researches has been done on the tribological performance of AMCs contain distinct refinement phases i.e. silicon carbide (SiC), alumina (Al2O3), in the form of fiber or whisker. The wear mechanisms of composites were held at a various operative combination of speed, distance, and applied load. From the reports, the wear mechanism of composite contains various kinds of wear such as Mild, mixing or oxidative, delamination and severe wear have been observed. The interface between matrix and particulates (reinforcement) have significant influences on abrasion resistance. However, a few novelists were applied mathematical models to optimize the process parameters on wear behaviour of AMCs. Moreover, they enclose with establish parameters of process such as percentage of filler (% of wt.) , velocity of counter face (m/s), pressure (N/mm2), sliding distance (m) and sliding time (see) are major. In general, abrasion rate increases with increasing of applied load due to eroded surface, plastic deformation and ploughing of matrix.

This study entails to the determination of physical and mechanical performance of Al-Si (LM) based AMCs reinforced with thermally treated fly ash, untreated fly ash and pure alloy. Moreover, determined the optimal condition of dry sliding wear behaviour on Al-Si alloy based MMC reinforced with thermally treated fly ash. The experiments are designed based on face centred composite (FCC) and held on pin-on-disc set-up. The effect of wear behaviour on AMC, the process parameters utilize such as applied load (N), sliding time (see), and speed (ms⁻¹) whereas WL (g) and COF (μ) are responses. Confirmation tests have been done to validate the actual results. Finally, the worn-out surfaces are studied using SEM in order to understand the various wear mechanisms involved.

2. Experimental Details

2.1 Materials

These investigation deals, Al-Si (LM) alloy is used as the matrix Table 1. The fly ash as reinforcement, acquired since thermal power plant, is screened below 240 mesh size. Well, judged amount of activated carbon is added to the fly ash for converting SiO2 to SiC before treating it in a plasma reactor. The total mixture is placed in a plasma reactor and treated below atmosphere (argon) condition.
Untreated and treated fly ashes are then analyzed by SEM, EDS and characterized with XRD.

**Table 1.** Composition of Al-Si alloy

| Element | Si   | Co | Fe  | Cu  | Mn  | Ti  |
|---------|------|----|-----|-----|-----|-----|
| % of Wt.| 12.3 | 0.02 | 0.44 | 0.08 | 0.16 | 0.07 |
|         | Zn   | Ni | Sn  | Cr  | Ca  | V   |
|         | 0.09 | 0.03 | 0.06 | 0.02 | 0.01 | 0.01 |
|         |      |    |     |     | Bal |     |

### 2.2 Preparation of Al-MMC

Initially, Al-Si ingot surfaces are properly cleaned and cut along weighed in essential quantities, to be charged into a bottom poured furnace which maintains at 550 °C. The reinforcement of fly ashes (treated and untreated) has been preheated to 650 °C ± 5 °C up to 3 hours before pouring into the molten metal of Al-Si Alloy. Argon gas is passing in the molten melt to avoid porosity to escape gases easily from the melt. The reinforcement particles are injected into molten metal at a constant velocity and for uniform distribution, stirred with an electrical motor contain a stirrer, coated with boron nitride and maintain a uniform speed of 620 rpm up to 9 min. At the time of stirring a vortex is observed and the reinforcement (fly ash) poured into it. Afterwards, the molten temperature is increased up to 700 °C than molten metal poured into a cast iron mould has a dimension of 250*20*45 mm³. Overall, two composites are prepared those Al-untreated (Al-UFA) and Al- treated fly ash (Al-TFA) with a volume percentage of 12%.

### 2.3 Testing Methods

Mechanical properties like tensile strength and hardness are measured by using Hounsfield computerized tensile testing machine (20 KN) and Vickers hardness tester of Model No.HVS-1000 respectively. The specimens used are highly finished surfaces. Finally, density is measured by Archimedes principle. The metallography study has been conducted by XJL-17. For determination of abrasion resistance of casted composites were tested by a tribo tester (pin-on-disc). The test specimens have a dimension of ø8 mm with a length of 35 mm, were sliding alongside with a counter face (EN-32A) of track ø65 mm.

To find Weight Loss (WL), considering the variation of initial and final weight. The coefficient of friction (COF) has been considered as per the slandered form of kinetic friction. The worn-out surfaces have been examined by SEM (model JEOL – JSM; 6480LV) with the attachment of EDAX.

### 2.4 Design Factors and Response Variables

The perceptible effect of input factors on responses has brought out by implementing statistical design of experiment. Theory of confounding is applied while designing the matrix. Although different method is applied to describe response surfaces accurately. FCC is advocated to be a suitable modelling technique to describe response surface accurately with least no of experiment and working with the idea of theory of confounding. The responses obtained are statically corrected so that with 95% confidence level the responses can be predicted accurately and lie in the sort of factors. In this work, a correlation has developed with three inputs (i.e. sliding time, sliding speed and load) used for two outputs i.e. WL (g) and COF. To estimate the behaviour of tribological factors influence on each response and to obtain correlations DX-9 has been used. The variable parameters are sliding time (T), sliding speed (S) and load (L), and their level is shown Table 2.

**Table 2.** Process factors and their levels

| Parameters | Unit | Levels of factor |
|------------|------|-----------------|
| Time (T)   | Sec  | 1000 2000 3000 |
| Speed (V)  | m/s  | 1 2 3         |
| Load (L)   | N    | 10 30 50      |

### 3. Results and Discussion

#### 3.1 Mechanical properties of Al-MMC

The received and treated fly ash is conducted to chemical analysis as XRD shown in Figure 1 the presence of untreated fly ash chemical compounds like Al₂O₃, SiO₂ and Fe₂O₃ are major CaO and MgO are minor. In the treated fly ash Al₂O₃, SiC are major and SiO₂C and Fe₂O₃ are minor constitutes shown in Figure 1. The chemical compounds Al₂O₃ and SiO₂ are well known, which improves mechanical properties. From the reduction of iron oxide by the carbothermal process, SiO₂ is converted into SiC. SiC is a harder compound than SiO₂ and the unburnt carbon presents in the form of graphite which resulting greater properties than untreated fly ash. Figure 2 shows the untreated fly ash particles seen to be in the form of spherical. Later by the thermal treatment of fly ash, particulates are converted in the form of fibers or seen to be needles, which are shown...
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in Figure 2. Figure 3 shows the mechanical properties of Al-Si, Al-UFA and Al-TFA composites. Figure 3 represents hardness and tensile strength of composites. This revealed that, Al-TFA composite of hardness and tensile properties are enhanced 16.11% & 32.36% than the base alloy respectively. Similarly, properties of hardness and tensile strength are enhanced by 7.33% & 11.49% as compared to untreated composite respectively. This caused by inter particular displacement and stain hardened. The density of composites (Al-UFA and Al-TFA) is lesser than the base alloy due to cenosphere particles are introduced into matrix. Ceno spherical particles are lesser density than the precipitators and alloy density. By the thermal treatment of fly ash, particulates are converted in the form of fibers or seen to be needles, which are shown in Figure 2.

Figure 1. (a) XRD of untreated (b) XRD of treated fly ash.

Figure 2. SEM of (a) untreated (b) treated fly ash particulates.

Figure 3. Mechanical properties.

Similarly, Figure 3 indicated impact strength of composites; the recorded values revealed the highest amount of energy observed by the treated fly ash composite, which is due SiC particles combined with whiskers and irregular shapes the composite become more stable and improves thermal, physical and mechanical properties. The micro structures are used to quantify the morphological and material characteristic. The morphological study of Al-Si, Al-UFA and Al-TFA are shown in Figure 4. This microstructure revealed that Al-Si is presence of alpha aluminium dendrites and eutectic silicon and eutectic phase provide a better interfacial bonding between two compounds. The microstructure of Al-UFA and Al-TFA are shown in Figure 4. The reinforced particles are clearly able to be seen. The phases of alpha, eutectic and reinforcement are in greater bonding with all the compounds, which improves the properties of composites. Al-TFA has enhanced the properties due to morphological change, orientation and convert oxide particulates to fiber in composite.

Figure 4. Micro structures of (a) Al-Si alloy (b) Al-UFA (c) Al-TFA.

3.2 Development of Regression Model Equation

CCF has been used to develop an interaction among three operating variables i.e. sliding time, sliding
speed and load for weight loss and coefficient of friction. The detailed experimental range with levels of process variables is listed in Table 2. The design of the matrix along with the experimental results of responses is represented as Table 3. Experimental runs 15-20 are utilized as the center point to establish the error. Analysis of regression has functioned to known the factor behavior on responses i.e. WL and COF. The ultimate empirical interrelation between factors is shown in the form of coded for WL (Y1) and COF (F1) of Al-TFA are shown in Equations 1 and 2 respectively.

\[
y_1 = -0.02922 + 0.0035a + 0.0035b + 0.0088c - 0.00013ac + 0.00188bc \\
- 0.00505a^2 + 0.00495b^2 - 0.00555c^2
\]  

(1)

\[
f_1 = -0.19014 + 0.02461a + 0.01272b + 0.02252c - 0.00458ab - 0.01233ac + 0.0599bc \\
+ 0.01401a^2 + 0.01385b^2 + 0.07085c^2
\]  

(2)

The positive and negative sign represents synergistic and antagonistic effect of parameters respectively. The actual and the predicted values of responses are exposed in Figure 5 respectively. The values of experimental and predated for an exacting run. Moreover, the values of theoretical are estimated from the model equation. From Figure 5 the ideals of \( R^2 \) (0.982& 0.979) and \( R^2_{adj} \) (0.965 \& 0.960) is established for WL and COF of Al-TFA composite respectively. The forecasted \( R^2 \) is in reasonable agreement with the \( R^2_{adj} \). Adequate precision is trialed the signal to noise ratio. A desirable value of the signal to noise is greater than 4.

The ratio of WL and COF of Al-TFA are 28.72 and 22.401 respectively. Table 3 represents the correlation between three process variables by an inadequate experimental number, consisting a wide range along with influencing response are tabulated. ANOVA of Al-TFA for responses WL (Y₁) and COF (F₁) are signified in Tables 4 and 5 respectively. The fisher (F) -value of WL (Y₁) and COF (F₁) has been identified as 59.88 and 51.33 respectively, which entails to the relationship attain, is significant. A fisher assessment of probability is ≥ 0.05 specified a model term is significant. Thus, for weight loss(WL), the model terms T, V, L, TL, \( T^2 \), \( V^2 \), and \( L^2 \) are significant, whereas for the COF significant terms are T, V, L, VL, TL, and \( L^2 \).

Figure 5. Comparison of calculated and experimental for weight loss (WL) and coefficient of friction (COF).

| Si.No | T  | V  | L  | Weight loss (g) (TFA) | Coefficient of Friction (TFA) |
|-------|----|----|----|----------------------|-----------------------------|
| 1     | 1000 | 1  | 10 | 0.011                | 0.2694                      |
| 2     | 3000 | 1  | 10 | 0.017                | 0.342                       |
| 3     | 1000 | 3  | 10 | 0.013                | 0.187                       |
| 4     | 3000 | 3  | 10 | 0.021                | 0.246                       |
| 5     | 1000 | 1  | 50 | 0.023                | 0.225                       |
| 6     | 3000 | 1  | 50 | 0.031                | 0.253                       |
| 7     | 1000 | 3  | 50 | 0.035                | 0.387                       |
| 8     | 3000 | 3  | 50 | 0.04                 | 0.392                       |
| 9     | 1000 | 2  | 30 | 0.019                | 0.168                       |
| 10    | 3000 | 2  | 30 | 0.027                | 0.251                       |
| 11    | 2000 | 1  | 30 | 0.029                | 0.206                       |
| 12    | 2000 | 3  | 30 | 0.037                | 0.211                       |
| 13    | 2000 | 2  | 10 | 0.012                | 0.261                       |
| 14    | 2000 | 2  | 50 | 0.033                | 0.272                       |
| 15    | 2000 | 2  | 30 | 0.03                 | 0.187                       |
| 16    | 2000 | 2  | 30 | 0.03                 | 0.187                       |
| 17    | 2000 | 2  | 30 | 0.03                 | 0.187                       |
| 18    | 2000 | 2  | 30 | 0.03                 | 0.187                       |
| 19    | 2000 | 2  | 30 | 0.03                 | 0.187                       |
| 20    | 2000 | 2  | 30 | 0.03                 | 0.187                       |
Table 4. ANOVA of WL

| Source | SS      | DF | MS     | F Value | Prob > F |
|--------|---------|----|--------|---------|----------|
| Model  | 0.001305| 9  | 0.000145| 59.88   | < 0.0001 |
| T      | 0.000123| 1  | 0.000123| 50.61   | < 0.0001 |
| V      | 0.000123| 1  | 0.000123| 50.61   | < 0.0001 |
| L      | 0.000774| 1  | 0.000774| 319.91  | < 0.0001 |
| TV     | 1.25E-07| 1  | 1.25E-07| 0.052   | 0.8248   |
| TL     | 1.25E-07| 1  | 1.25E-07| 0.052   | 0.8248   |
| VL     | 2.81E-05| 1  | 2.81E-05| 11.62   | 0.0067   |
| T^2    | 7E-05   | 1  | 7E-05   | 28.92   | 0.0003   |
| V^2    | 6.75E-05| 1  | 6.75E-05| 27.89   | 0.0004   |
| L^2    | 8.46E-05| 1  | 8.46E-05| 34.94   | 0.0001   |
| Residual | 2.42E-05| 10 | 2.42E-06|         |          |
| Fit    | 2.42E-05| 5  | 4.84E-06|         |          |
| Error  | 0       | 5  | 0      |         |          |
| Total  | 0.001329| 19 |        |         |          |

Table 5. ANOVA of COF

| Source | SS      | DF | MS     | F Value | Prob > F |
|--------|---------|----|--------|---------|----------|
| Model  | 8.29E-2 | 9  | 0.0092 | 51.33   | < 0.0001 |
| T      | 6.06E-3 | 1  | 0.0061 | 33.75   | 0.0002   |
| V      | 1.62E-3 | 1  | 0.0016 | 9.02    | 0.0133   |
| L      | 5.07E-3 | 1  | 0.0051 | 28.26   | 0.0003   |
| TV     | 1.67E-4 | 1  | 0.0002 | 0.93    | 0.3568   |
| TL     | 1.22E-3 | 1  | 0.0012 | 6.77    | 0.0264   |
| VL     | 2.87E-2 | 1  | 0.0287 | 160.08  | < 0.0001 |
| T^2    | 5.39E-4 | 1  | 0.0005 | 3.01    | 0.1136   |
| V^2    | 5.28E-4 | 1  | 0.0005 | 2.94    | 0.1171   |
| L^2    | 1.38E-2 | 1  | 0.0138 | 76.93   | < 0.0001 |
| Residual | 1.79E-3| 10 | 0.0002|         |          |
| Fit    | 1.79E-3 | 5  | 0.0004|         |          |
| Error  | 0       | 5  | 0      |         |          |
| Total  | 8.47E-2 | 19 |        |         |          |

3.3 Effect of Process Parameters on the Responses

Figure 6 illustrates the combined effect of sliding velocity and sliding time on WL of TFA-AMC at a constant load of 30N. The combined effect of velocity and time is the antagonistic effect on WL. It is experiential that WL is increased up to sliding time 2200 sees than decreases due to the adhesion the movement between pin and disc has difficult at initial period. This caused to rise of temperature in the base material causes thermally soften, which increases in WL. While increases of time the composite become thermally stable and harder due to secondary reinforced material.[10,31]

Similarly, WL is decreased up to sliding velocity 2m/s than increases due to the thermally treated fly ash reinforcement which protect the matrix from the load, which form a thin layer film. This film causes to decrease the weight loss. Moreover, the film protects up to certain, while more speed the particles are move out from the matrix causing an increase of WL.[28] Figure 6 represents the combined effect of sliding time and load on WL at a constant sliding velocity of 2 m/s. The combined effect of sliding time and load is the antagonistic effect on WL. WL is increasing with load due to friction offered by the counter face. Sliding time and load are inversely proportional characteristic to WL. Weight loss decreases with increase of secondary particles which improves in hardness of AMC. Figure 6 represents the combined effect of sliding velocity and load on weight loss at a constant sliding time of 2000see. The combined effect of sliding velocity and load is a synergistic effect on weight loss, observed from Eq.1.

Figure 6. (a) combined effect of sliding time and sliding velocity (b) sliding time and load (c) sliding velocity and load on weight loss.
The combined effect of sliding velocity and sliding time is the antagonistic effect on COF shown in Figure 7. The combined effect is considered at a constant load of 30N. Sliding velocity and sliding distance increase with increases of COF due to weak intrinsic bonding with reinforcement and matrix. Figure 7 represents the collective effect of sliding time and load on COF at a constant sliding velocity of 2 m/s. The united effect of sliding time and load is antagonistic effect on COF. Similarly, From Figure 7 represents the jointed effect of sliding velocity and load on COF at a constant sliding time of 2000see. This combined effect is a synergistic effect, which reviewed in Eq.2. While, sliding velocity is an increase with increasing COF due to initially high adhesive friction between composite pin and steel disc. Afterwards, decreasing with constant sliding velocity and up to the load of 30N, while load increase with sliding velocity which increase of COF due to severe plastic deformation.

Figure 7. (a) combined effect of sliding time and sliding velocity (b) sliding time and load (c) sliding velocity and load on coefficient of friction.

4. Optimization of Responses using RSM

This session details, optimization of process parameters to obtained minimization of responses (i.e. WL and COF) by model equation. The optimum region for responses on the sliding time (T) and sliding velocity (V) is shown in Figure 8 respectively. The optimum conditions for WL (1011.71see, 2.02 m/s, 10.70 N) and COF (1000see, 2.02m/s,17.62 N) for the Al-TFA- MMC is shown in Figure 8 to achieve the minimum WL and COF of 0.0071 g and 0.185 respectively.

Figure 8. Optimized condition for (a) weight loss (WL) (b) Coefficient of friction (COF).

The SEM of worn out surfaces for Al-Si, Al-UFA, and Al-TFA composite are shown in Figure 9. All the samples of SEM are tested at a load of 30N, sliding velocity of 2m/s and sliding time of 2000see.From Figure 9. it exposed that, the wear mechanism occurs between pin and counter face. The cast (Al-SI) sample is observed on the worn – out surface the presence of longitudinal grooves, shearing of matrix and irregular pits as well as micro cracks. Figure 9 represents worn-out surfaces for Al-UFA and Al-TFA respectively. The volume fraction (fly ash) has increased in composite; which enhances hardness and able to thermally constant due to the reduction in the plastic deformation. This reason, the composites could withstand the effect of wear behaviors.
5. Testing of Regression Equation

Confirmation test for the developed model regression equations for responses, which has been tested with the optimal condition. The tested conditional parameters along with responses are listed in Table 6. The examination of all variables and parameters calculating the percentage of error. The error is less than or equal to ±5%, which is significant. The obtained regression equations for WL and COF are satisfactory point of precision.

Table 6. Confirmation test with conditions

| Si.No | ST  | SV  | L   |   | Coefficient of friction | Weight loss |
|-------|-----|-----|-----|---|-------------------------|-------------|
|       |     |     |     |   | Pred.       | Exper. | Error | Pred. | Exper. | Error |
| 1     | 1500| 1   | 30  |   | 0.180       | 0.189  | -4.89 | 0.0276| 0.0265| 3.98  |
| 2     | 1500| 1.5 | 30  |   | 0.177       | 0.181  | -2.09 | 0.0257| 0.0271| -5.59 |
| 3     | 1000| 2   | 50  |   | 0.285       | 0.298  | -4.48 | 0.0241| 0.0230| 4.37  |
| 4     | 1000| 2   | 30  |   | 0.180       | 0.174  | 3.08  | 0.0207| 0.0200| 3.25  |
| 5     | 1200| 3   | 10  |   | 0.188       | 0.179  | 4.89  | 0.0154| 0.0160| -3.74 |

6. Conclusion

This study, the composite is fabricated by stir casting process; matrix is Al-Si and reinforcement as untreated fly ash (UFA) and treated fly ash (TFA) with 12% of volume.

1. Determined the chemical composition by XRD of Untreated and treated fly ash particles.

2. The mechanical properties of composite (Al-Si, Al-UFA, and Al-TFA) are revealed that treated fly ash composite is exhibited better than the others.

3. Al-TFA composite has better Tensile strength, hardness, impact strength than the Al-UFA composite and base alloy. Similarly, the density of Al-TFA composite is lesser than others.

4. The wear behavioural process parameters (sliding time, sliding velocity and load) are optimized to responses (i.e. WL and COF) by FCC design.

5. A regression equation is developed to optimize the WL and COF for Al-TFA composite.

6. The ANOVA of WL is exposed that load is the highest influencing parameter followed by sliding velocity and sliding time. Moreover, the value of $R^2$ and $R^2_{adj}$ is 0.982 and 0.965. The model value of Adequate Precision is 28.73.

7. The ANOVA of COF is revealed that the combined effect of sliding velocity and load is the highest influencing parameter followed by sliding time and load. Afterward, the value of $R^2$ and $R^2_{adj}$ is 0.979 and 0.960. The model value of Adeq. Precision is 22.401.

8. The optimized value of WL and COF is 0.0071 g and 0.185 respectively.

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