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Estimation of Tribological Performance of Al-MMC Reinforced with a Novel In-Situ Ternary Mixture using Grey Relational Analysis

Siva Sankara Raju[1]*, Ajit Ku. Senapathi[1] and Gunji Srinivas Rao[2]

[1]Faculty of Mechanical Engineering, Gandhi Group of Institutions (GIET), Gunupur – 765022, Odisha, India; sivaraju80@gmail.com

[2]Faculty of Mechanical Engineering, RVR and JC, Guntur – 522019, Andhra Pradesh, India

Abstract

Objectives: To prepare 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. 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. Moreover, multi- outputs are convinced into a single outcome by grey relational analysis (GRA) to avoid uncertainty in decision making. **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. From the ANOVA of TFA notify that load is the most affecting factor followed sliding time and combined effect of sliding velocity and load on grey relational grade (GRG). The obtained optimal condition is $T_1V_2L_2$ (i.e. sliding time (1000see), velocity (2m/s) and Load (30N)). The optimum value of weight loss and coefficient of friction (COF) are 0.019 grams and 0.168 respectively. Finally, 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: Al-MMCs, ANOVA, Fly Ash, GRA, RSM

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 high specific modulus , stiffness, specific strength, and better resistance to wear[1,2]. 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, aerospace, marine and mineral processing industries. Choice of a suitable combination of matrix with reinforcement materials has become an interesting area for manufacturing science in MMCs[3,4]. Aluminium - silicon alloys present a great 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[5]. 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[6]. The specified above problem has been overcome by addition of reinforcement such as Silicon Carbide (SiC), Alumina (Al2O3), boron carbide (B4C), Titanium carbide (TiC), Titanium di boride (TiB2), Magnesium oxide (MgO),

**Author for correspondence*

Titanium dioxide (TiO2) and Boron Nitride (BN) in Al-Si alloy. The properties of composites has been enhance with addition of hard phase ceramic particulates (reinforcement) into matrix[7–9]. The melting and casting route for the preparation of these materials is comparatively easier and enhance properties of composites[10,11]. Stir casting is a useful technique adapted for producing AMCs[4,12]. Because of poor wettability of ceramic particulates such as SiC, Al_2O_3 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[12–14].

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[12,13]. The composite are made-up widely with fly ash and used in aero space and automotive application[4,13,15]. 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[16]. The hybrid AMCs (HMCs)reinforced with SiC (Up to 5% of weight) and Gr (up to 5%) particulates with overall up to 10%. The author said HMCs has been improved of hardness and dry sliding wear behavior up to 3.75% Gr[17]. The developed a composite contains SiC-Al_2O_3-C from fly ash. Generally, The Indian fly ash contains the chemical elements like SiO_2, Al_2O_3, Fe_2O_3, and CaO etc. In the Presences plasma reactor, the compound SiO2 has been converted to SiC with addition of carbon[12].

To minimise the wear volume loss and coefficient of friction for an aluminium composite of SiC exhibits with various process variables of contact surface, % of reinforcement, sliding distance and sliding velocity by using Taguchi orthogonal array [L25]. Multi outcomes are converted into a single outcome via grey relational analysis for avoiding uncertain conditions. From this report, sliding velocity as a vital role in wear mechanism, followed by %of reinforcement, sliding distance and contact surface[18]. The minimization of COF and specific wear rate for ABS/TiO_2 composite by using Taguchi (L27) combined with grey relational analysis (GRA). The influencing parameters were filler content, load and sliding speed. The optimal condition has been obtained at 10% vol. of filler, Load (35N) and sliding speed (120 rpm). The results exhibited improving grey relational grade as 11% from primary to optimal condition. This study reveals, mainly influence factor as load and follow by % of filler and sliding speed[19].

This study demand to determination of optimal condition on wear behaviour in the Al-Si alloy based MMC reinforced with thermally treated fly ash. The experiments are planned based on RSM and accomplished by pin-on-disc wear testing set up. Tribological performance of TFA is compared with untreated fly ash and base alloy under identical conditions. The effect of wear behaviour on AMC, the process parameters employed i.e. load (N), sliding time (See), and speed (m/s); furthermore, wear loss and coefficient of friction are responses. Multi responses are converted into a single response using grey theory. The optimal condition of GRG is obtained by ANOVA. Confirmation tests are also done to validate the experimental results. Afterward, the worn-out surfaces are studied using SEM in order to understand the wear mechanisms involved.

2. Experimental Details

2.1 Materials

In this study, Al-Si alloy Table 1. is used as the matrix. The reinforcement as fly ash, which is acquired from thermal power plant, is screened below 240 mesh size. Well, judged amount of activated carbon is added to the fly ash for converting SiO_2 to SiC before treating it in a plasma reactor under below atmospheric condition[12]. Afterword, Untreated, and treated fly ashes are analyzed by SEM, EDS and are also characterized by XRD.

2.2 Preparation of Al-MMC

Initially, Al-Si ingot surfaces are properly cleaned and cut along weighed in essential quantities, to be charged

Table 1. Elements presence in 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	Al
0.09	0.03	0.06	0.02	0.01	0.01	Bal.

into a bottom poured furnace which maintains at 550 ^{0}C. The reinforcement of fly ashes (treated and untreated) has been preheated to 650 ^{0}C±5 ^{0}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 ^{0}C than molten metal poured into a cast iron mould has a dimension of 250*20*45 mm^3. 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.

The tribological performance of base alloy and composites are tested by DUCOM TR-201 LE tester. Before testing each specimen has been polished by SiC papers of grit as 240, 320 and 600. The dimensions of tested specimen have ø8 mm and 38 mm long. The specimen has been sliding against a steel counter face of track radius 65 mm. To find weight loss, considering the variation of initial and final weight. The COF is the ratio of frictional forces to the normal load[20]. 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

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 within the range of variation of the variables[21,22]. In this work, the authors have been developed correlations with three input factors (i.e. sliding time, sliding speed and load) for two outcomes such as weight loss (g) and COF. To assessment the responses, experimental correlations have been developed by statistical design software package DX-9. ANOVA has been used to assessment the statistical parameter. The variable parameters are sliding time (T), sliding speed (S) and load (L), and their level is shown Table 3.

The design of the matrix along with the experimental results of responses is represented as Table 4. To ascertain the error, experimental runs (15-20) are exploiting as the center point. The Experimental design obtains a quadratic model, which consists of 2^3 runs, plus point a star configuration ($\alpha = \pm 2$) with their replicates at the center. Moreover, in this study, multi-outputs are transformed into a single output using GRA. This theory is deals to avoid uncertainty in decision making. Grey lies between known (bright) and hidden (dark) are used with reducing undecided output.

2.5 Grey Relational Analysis (GRA)

From the GRA, the tentative response values of the load,% of CSAp , Sliding distance, and sliding velocity have been initially normalized and once the grey relational coefficient (GRC) has been calculated from the normalized data for a state that association between the predicted and actual experimental once. Afterwards, compute the GRG has been employed by the mean of GRC represents for each objective of responses[18,23].

From the Grey relational analysis (GRA), the tentative response (outcome) values of the wear, wear rate and COF have been initially normalized, due to avoiding the variation in units, targets, and scales of the response.

Table 2. Mechanical properties

		Strength		
	Density	**Hardness**	**Tensile**	**Impact**
Al-Si	2.465	63.25	144	0.5
Al-UFA	2.387	68.25	162.7	2.5
Al-TFA	2.359	75.4	212.9	2.7

Table 3. Process factors and their levels

Factors	Unit	Level of factor		
		−1	**0**	**1**
Time (T)	Sec	1000	2000	3000
Speed (V)	m/s	1	2	3
Load (L)	N	10	30	50

Table 4. Design of Experiments

Si.No	T	V	L	Weight loss (g)	COF
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

The results vary in among 0 and 1,based on smaller-the -better on the criterion of eq.(1) and once the GRC has been calculated, state the alliance between the actual and predicted experimental once according to eq. (2). Afterwards, calculate the GRG has been employed by eq. (4) the mean of GRC represents for each objective of responses. In generally, estimation of the multiple quality process responses transformed to single response is based on GRG.

$$X_i(k) = \frac{\max y_i(k) - y_i(k)}{(\max y_i(k) - \min y_i(k))} \quad (1)$$

Whereas Xi (k) is normalized grey relation value for the k^{th} response, max y_i (k) and min y_i (k) are the greatest and least values of y_i (k) for a k^{th} response. Experimental runs (i=1to 27) and a number of factors (k=1 to 3).

$$\xi_i(k) = \frac{(\Delta_{min} - \zeta\Delta_{max})}{(\Delta_{oi}(k) + \zeta\Delta_{max})} \quad (2)$$

$$\Delta_{oi}(k) = \left\| x_o(k) - x_i(k) \right\| \quad (3)$$

$$\gamma_i = \frac{1}{n}\sum_{k=1_i}^{n} \xi_i(k) \quad (4)$$

Where, the Δ_{oi} (k) deviation sequence is the reference sequence, the difference between maximum and minimum of $x_o(k)$ and $x_i(k)$ absolute significance. The GRG facilitated based on the overall performance index. This reveals, if GRG has been a higher value, indicates better performance.

3. Results and Discussion

3.1 Mechanical properties of Al-MMC

The fly ash subjected to chemical analysis as XRD of treated fly ash are shown in Figure 1. In the treated fly ash Al_2O_3, SiC are major and SiO2, C and Fe_2O_3 are minor constitutes. The chemical compounds Al_2O_3, and SiO2 are well known, which improves mechanical properties. From the reduction of iron oxide by the wet magnetic separate and treated by the carbothermal process, SiO_2 is converted into SiC. SiC is a harder compound than SiO_2 and Carbon which resulting greater properties than untreated fly ash[12,24]. Table 2 shows the mechanical properties of composites such as Al-Si, Al-UFA and Al-TFA. This revealed that, Al-TFA is exhibit superior strength than others (base alloy and untreated composite), due to treated reinforced harder particles and strain hardening effect in composite. Generally, Reinforcement particles are harder in phase, So that those can capable of load bearing, and constraints disruption of particle reduces interspacing to movement of matrix.

The density of composites (Al-UFA and Al-TFA) is lesser than the base alloy due to ceno spherical particles are introduced into matrix. The ceno spherical particles

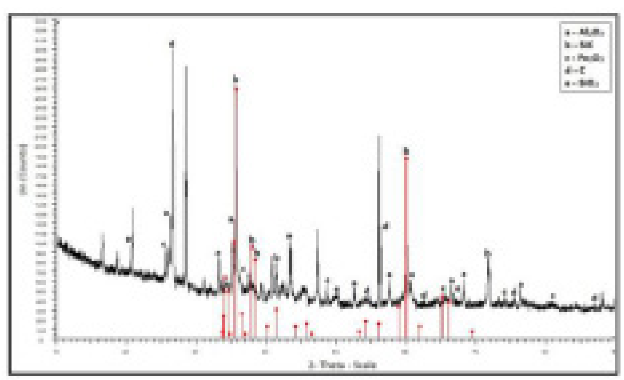

Figure 1. XRD of Treated fly ash.

are lesser density than the precipitators and alloy density. By the thermal treatment of fly ash, particulates are converted in the form of irregular and seen to be fibers or needles, shown in Figure 2. Similarly, the 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 microstructures are used to quantify the morphological and material characteristic. The morphological study of Al-Si, Al-UFA and Al-TFA are shown in Figure 3. 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 3 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 enabled improvement in the properties because of change in morphology of the microstructure i.e. spherical shape to rod-shaped as well due to the fineness of the reinforcing particles.

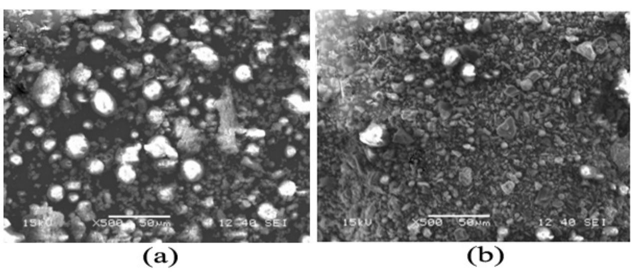

Figure 2. SEM of **(a)** Untreated **(b)** Treated fly ash particulates.

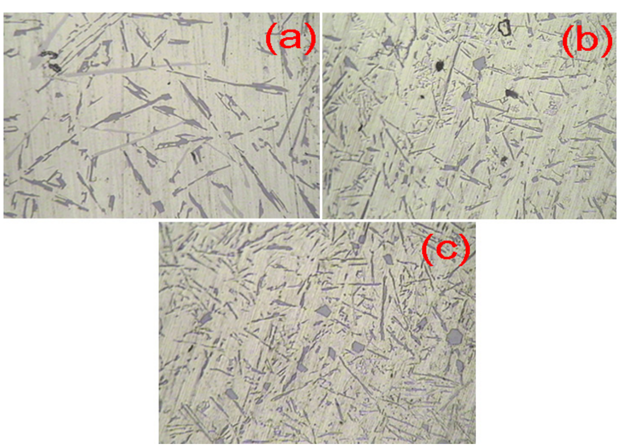

Figure 3. Micro Structures **(a)** Pure **(b)** Al-UFA **(c)** Al-TFA.

3.2 Tribological Behaviour of Composites

Figure 4 shows the effect of load against weight loss at constant sliding time (2000 see) and sliding velocity (30 N) on the three materials i.e. pure, untreated and treated composites. It has been observed that all the materials, weight loss are increased with increasing of load due delaminating layers and ploughing caused by hard debris. Al-TFA exhibits least weight loss than the others due to chemical composition, the carbon is converted into graphite and form a lubricated layer on the contact surface[25,26]. Figure 5 the COF is varying with load with constant parameters (i.e. sliding time of 2000 see and sliding velocity of 2m/s). It observed that at initial load coefficient of friction are high and later decreases again increasing with increase of load. Initially, the movement between pin and disc is difficult which increases the coefficient of friction. Moreover, due to hard phase reinforcement particles is contact and transfer debris into counter face, which possible to increase the coefficient of friction with an increase of load.

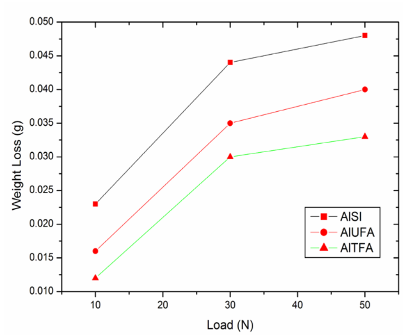

Figure 4. Load against weight loss.

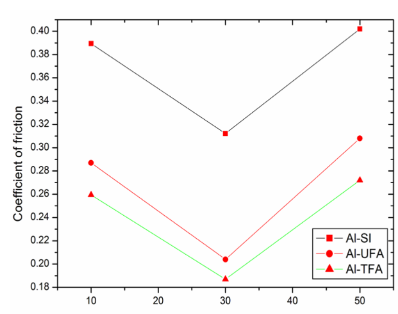

Figure 5. Load against COF.

From Figure 6 the sliding velocity adjacent to weight loss and coefficient of friction at a constant load of 30N and sliding time of 2000 see. Figure 6 states that while sliding velocity increases with increase of weight loss for all the composites. However, Al-TFA composite exhibits lower weight loss due to formation of mechanically mixed layer between pin and disc, and the conversion of SiO_2 into SiC with Carbon is in the form of graphite, which protects the matrix from deformation and delamination. Moreover, Figure 6 reveals that, coefficient of friction decrease with increase of load up to 30N than increases. Al-TFA composite is shown smallest amount of coefficient of friction than pure and untreated fly ash composite. This attributed to the treated fly ash particulates are come out from the matrix and formed an oxide layer and carbon particles forming a lubricated layer in the interface of pin and disc. These layers can protect the matrix for a short period while increasing of sliding velocity at a specific time the coefficient of friction decreases than increases.

In this work, the optimization of wear behavioral parameters on responses for Al-TFA composite only performed due to Al-TFA composite exhibits greater mechanical strength and better wears behavioral properties than the pure (Al-Si) and untreated fly ash (Al-UFA) composite.

3.3 ANOVA of Grey Relational Analysis

As per the procedure of GRA, find-out the outcomes (responses) of weight loss, and COF are initially normalised through applicable formula. Consequently, calculate the GRC and GRG for all tribological behavioural outcomes is an index in Table 5. The ANOVA of GRG is indicates the influence of parameter effect of individual and combination with a contribution by the process parameters as well as error. From Table 6. Load (45.28%) is dominant influence parameter followed by sliding time (20.01%) and combined effect of sliding velocity and load

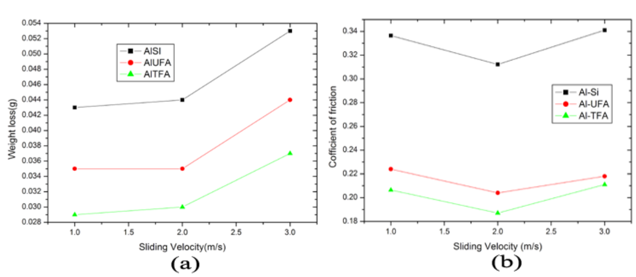

Figure 6. Sliding velocity Vs weight loss and COF.

Table 5. Grey relational coefficients with grade

Si. No	wt.loss	coff.	GRG	Si. No	wt.loss	coff.	GRG
1	1.000	0.525	0.762	11	0.446	0.745	0.596
2	0.707	0.392	0.549	12	0.358	0.723	0.540
3	0.879	0.856	0.867	13	0.935	0.551	0.743
4	0.592	0.590	0.591	14	0.397	0.519	0.458
5	0.547	0.663	0.605	15	0.433	0.856	0.644
6	0.420	0.569	0.494	16	0.433	0.856	0.644
7	0.377	0.338	0.357	17	0.433	0.856	0.644
8	0.333	0.333	0.333	18	0.433	0.856	0.644
9	0.744	1.000	0.872	19	0.433	0.856	0.644
10	0.475	0.579	0.527	20	0.433	0.856	0.644

Table 6. ANOVA of GRG

Source	SS	DF	MS	F Value	Prob > F
Model	0.2939	9	0.033	39.60	< 0.0001
T	0.0605	1	0.060	73.31	< 0.0001
V	0.0116	1	0.012	14.01	0.0038
L	0.1368	1	0.137	165.89	< 0.0001
TV	0.0006	1	0.001	0.70	0.4236
TL	0.0120	1	0.012	14.56	0.0034
VL	0.0325	1	0.033	39.42	< 0.0001
T^2	0.0047	1	0.005	5.72	0.0379
V^2	0.0174	1	0.017	21.10	0.0010
L^2	0.0052	1	0.005	6.37	0.0302
Residual	0.0082	10	0.001		
LOF	0.0082	5	0.002		
Error	0.0000	5	0.000		
Cor Total	0.3022	19			

SS- 'sum of square'; DF- 'degree of freedom';
MS-'Mean square';LOF- 'Lack of fit'

(10.76%) as well as sliding velocity (3.82%). The overall contribution factors are performed 97.27%.

The ultimate experimental correlations of regression have shown in the form coded factors for GRG of Al-TFA in Eq. 5. The positive and negative signs are indicating the interdependent and antagonistic effect respectively for the outcome of parameters.

$$\begin{aligned}\gamma_1 &= 0.0754 - 3.18e^{-4} * T + 0.0363 * V + 3.21e^{-3} * L \\ &+ 8.47e^{-6} * TV + 1.94e^{-6} * TL - 3.19e^{-3} * VL \\ &+ 4.14e^{-8} * T^2 - 7.96e^{-2} * V^2 - 1.09e^{-4} * L^2 \end{aligned} \tag{5}$$

The definite and the anticipated values of GRG is delineated in Figure 7. Definite (actual) standards are

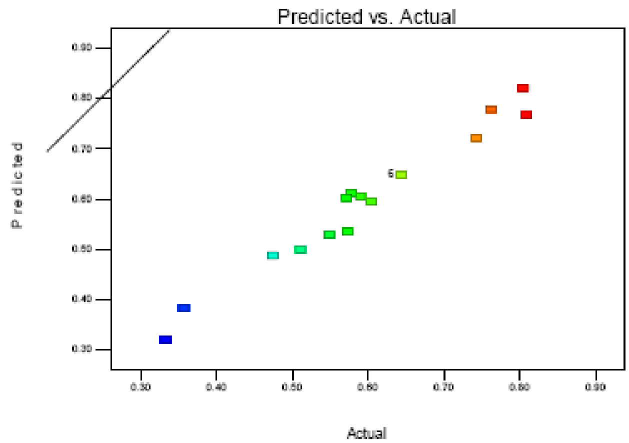

Figure 7. Comparison of calculated and experimental for GRG.

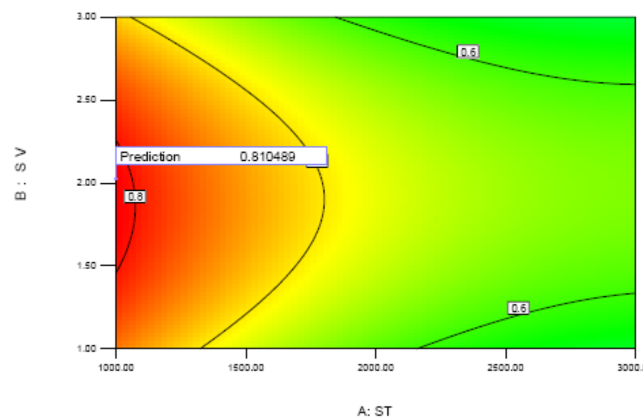

Figure 8. Optimized region for GRG.

Table 7. Optimal test for estimated and actual relational grades with error

Performance characteristics	T2V2L2	T1V2L2	Gain	Improve (%)	Error
GRG experimental	0.644	0.81	0.166	20.49	0.047
GRG Predicted	0.648	0.767	0.119	15.52	
Weight loss	0.03	0.019	–0.011	–57.89	
Coefficient of friction	0.187	0.168	–0.019	–11.31	

obtained by experiments for a particular run, which the measured response data. Similarly, the anticipated standards are classified by the model equation, those produced via exact functions. From Figure 7 the acquired value of R2 and R2adj is 0.973 & 0.948 for GRG of Al-TFA respectively. The predicted R^2 is in reasonable agreement with the R^2_{adj}. The ratio of signal to noise has been measured for Adequate precision. The ratio has been greater than 4, which is significant. The ratio concerning GRG of Al-TFA is 24.63. This study indicates an adequate specifying which the maximum GRG value (Exp. no 9) in Table 5. Table 6 has been listed with correlation coefficients with significant and insignificant terms. The correlation coefficients are in wider range, which influence of process parameters. ANOVA has been used to investigate the individual, interaction and square effects of the parameters on both the responses. The ANOVA for GRG is represented as Tables 6. The F-values of GRG is found to be 39.59, which implies that the correlations obtained are significant. There is only 0.01% chance that a "Model F-Value" this large could occur due to noise. A value of "Prob > F" less than 0.05 indicates model terms are significant. Thus, for GRG the model terms T, V, L, TL, VL, T^2, V^2 and L^2 are significant.

3.4 Optimization of Responses using RSM

The study is to acquisition the optimum process parameters to minimize both responses i.e. weight loss and COF from the mathematical model equations developed. The optimum region for GRG on the sliding time and sliding velocity is shown in Figure 8. The optimum conditions for GRG (1000.03see, 2.02 m/s, 23.73 N) for the Al-TFA-MMC is shown in Figure 8 to achieve the maximum as 0.810, which revealed that the optimal values of weight loss and COF are 0.019 g and 0.168 respectively.

The best wear behavioral optimal conditional is specifying which the maximum GRG value in Table 5. The run 9 indicates maximum value of GRG. Table 7 states that grey relational analysis is exhibited better wear behavioral properties with unique optimal level (T1V2L2). The initial design experimental parameter (T2V2L2) is the centre run in the experimental Table 4. The confirmation test signifies weight loss is decreased from 0.03 to 0.019g, and COF is reduced from 0.187 to 0.168 respectively. The initial parameter of the GRG as 0.644 through optimal conditional values of the GRG is 0.81. The error is calculated from the improvement and obtained 0.047, which reveals the approach have been less than 0.05 and which is significant.

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 coun-

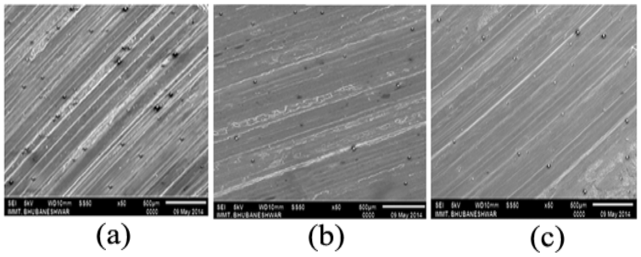

Figure 9. SEM worn out surfaces.

Table 8. Regression test condition for GRG

Si.No	T	V	L	Predicted GRG	Experimental GRG	Error
1	1500	1	30	0.655	0.663	1.14
2	1500	1.5	30	0.696	0.685	−1.57
3	1000	2	30	0.767	0.783	2.14
4	1200	3	10	0.784	0.817	4.26

ter 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 fly ash is thermally treated than particles are become more harden and thermally stable, which enhances the properties of composite. Treated fly ash improves wear behavior and resist tribo surface from delamination and plastic deformation.

4. Testing of Regression Equation

The developed model regression equation has been tested for responses, which has been tested with optimal condition. The tested conditional parameters along with responses were listed in Table 8. the examination of all variables and parameters calculating the percentage of error. The predicted (calculated) values are obtained from regression equation. The actual and calculated values have been obtained almost same and error is lies within ±5%. Hence, the acquire values from equations are capable of predicting wear behavioral response (weight loss and COF) to a satisfactory point.

5. Conclusions

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

1. Determined the chemical composition by XRD of Untreated and treated fly ash particles. 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.
2. 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.
3. The wear behavioral process parameters (sliding time, sliding velocity and load) are optimized to responses (weight loss and COF).
4. Multi outcomes are convinced into a single outcome using grey relational analysis to avoid uncertainty in decision making.
5. A regression equation is developed to optimize the response of GRG is 0.810 for Al-TFA composite.
6. The ANOVA of GRG notify that the most affecting factor is load then time and combined of sliding velocity and load. Moreover, the value of R^2 and R^2_{adj} is 0.973 and 0.948. The model value of Adequate Precision is 24.62.
7. The GRA the weight loss and COF are reduced to 0.03 to 0.019 and 0.187 to 0.168 respectively. The error is less than 5%, which indicate significantly.

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