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Effects of Applied Loads and Aluminium Nanoparticle Additions on Wear Resistance Properties of Particle Reinforced Epoxy Nanocomposites

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A B S T R A C T

The recent technology advancement has emerged aluminium nanoparticles for polymer reinforcements. Mechanical properties of epoxy containing aluminium nanoparticle was reported but its wear resistance is left unstudied. This study has been focused on effect of aluminium nanoparticle reinforced epoxy under different applied loads and velocities. It is obtained that the wear resistance increases with the applied loads but decreases with the percentages by weight of aluminium nanoparticle additions to epoxy. The wear rates recorded with aluminium nanoparticle reinforced epoxy are 81.2% and 82% smaller than those of the unreinforced epoxy and greater than 75.5 and 76.1% reductions noticed with the aluminium microparticle reinforced epoxy under applied loads of 9 and 25 N already reported in literature. Greater percentage reductions in the wear rates affirms aluminium nanoparticle as better reinforcement with improved wear resistance than its aluminium microparticle counterparts. Fishers' value, 7.389 and prob, 0.042<0.05 affirms that the linear response surface model is significant in evaluating the wear resistance of the aluminium nanoparticle reinforced epoxy with 84.7% predictability while the remnants accounts for the residuals.

1. INTRODUCTION

In the fabrication of composites, an impertinent factor is the homogenous distribution of fillers within the polymer matrix. This is to produce isotropic composites which their properties are independent of loading directions. Several fibre and nanotube reinforced composites have been produced with their established applications in aircraft, automobiles, marine and trains [1-4]. On the other hands, their anisotropic nature has also been reported although some efforts like fibre weaving, knitting and laminations have been adopted to improve isotropy of the fibre reinforced composites. All the additional techniques for achieving isotropic fibre reinforced composites are tedious and highly laborious. This has made productions of the fibre reinforced composites difficult. Isotropy of materials is very important to material service life since materials in service are under different forms of loading in any directions [5-7]. Moreover, anisotropy in materials can cause sudden failures when the prevailing conditions of the material service environment favour the increased load application along a transverse direction where strength of the fibre reinforced composite is low.

Researchers currently focus their studies on the particle reinforced polymer matrix composites to address difficulties in the manufacturing of the isotropic fibre reinforced composites. Different materials within the micrometre sizes have been used as reinforcements in polymers as reported in many studies [8-10]. An emerging optimised powder metallurgy has established productions of nanoparticles through repeated plastic deformation that takes place during ball milling of both organic [11-13] and inorganic materials [14-18] for producing dispersion strengthening materials (nanocomposites). Nanoparticles are materials which their sizes (diameters or length) are within nanometre size ranges. Based on their higher surface areas of exposure than their microparticle counterparts, they distribute more evenly within the matrix and are held by the matrix molecules with stronger forces of adhesion. This guarantees better properties for the nanocomposites than the conventional particulate composites. This has been buttressed by reports in literature. For instance, laboratory experimentation and statistical analysis reported in [19] shows greater tensile properties of epoxy reinforced with aluminium nanoparticles than the epoxy containing aluminium microparticles. Similarly, enhancements in the tensile elastic modulus of epoxy were reported with decreases in sizes of nano quicklime and silica [20]. Mechanically, the present trends have established aluminium nanoparticles as better reinforcement in epoxy than the aluminium microparticle counterparts, but the wear resistance of the aluminium nanoparticle reinforced epoxy benchmarked with the wear resistance of aluminium microparticle reinforced epoxy has not been established. Therefore, this study focuses on experimentation and statistical analysis of the wear resistance of the epoxy comparing both effects of aluminium micro and nanoparticle additions.

2. MATERIALS AND METHODS

2.1 Materials

Materials used in this study are the control poxy and epoxy nanocomposite of diglycidyl ether of bisphenol cured with amine hardener and reinforced with 10% by weight of aluminium nanoparticles. Synthesis, characterisation and size determination of aluminium nanoparticles were reported in [17] and 10wt% aluminium nanoparticle reinforced epoxy was produced using composite stir technique according to [19].

2.2 Method

Locally fabricated abrasion type wear tester was used for the wear examinations. Cylindrical wear pins of 12 mm diameter and 20 mm high were prepared from the nanocomposite samples. Each pin was partially and firmly slotted into the hole facility forming a part of the sample holder with the surface of the wear pin touched the surface of the horizontal drum/cylinder modified to the P 600 SiC emery paper. Initial mass of the wear pin was taken using Ohaus weighing balance of ±0.001g accuracy and its volume was determined using immersion method. After starting the wear machine, surface of the wear pin under applied load of 9 N rubbed against the emery paper on the rotating drum and caused chipping of the particles off the pin surface. The sample holder moves linearly on the track at a speed of 0.65 ms^{-1} and slides 200 m at the end of the track when the worn-out pin was removed from the holder and its mass was taken again. The wear rate was computed using a change in mass per unit sliding distance and volume per unit second. Experiments were repeated at the same velocity with an increase in the applied loads up to 25 N at an interval of 4 N and at 1.3 ms^{-1} under the applied loads, 9, 13, 17, 21 and 25 N. Moreover, effect of wear rate in terms of volume per unit time was investigated using linear regression model developed through MATLAB application software, according to [21] and wear rate in terms of mass per sliding distance was analysed as a function of weight fraction (wf) of the aluminium micro and nanoparticles, speed (v) and applied load (f) to study relationship among the wear parameters using historical approach two-function interaction (2FI) response surface model.

3. RESULTS AND DISCUSSION

Wear rate (volume loss-per time) of the pristine epoxy, epoxy containing 10 wt% aluminium microparticle (E/Almp) and 10wt% aluminium nanoparticle reinforced epoxy at different applied loads, ranging from 9 to 25 N increases with an increment in the applied loads (Figure 1). The increment could be attributed to greater impacts of the applied load on the wear pin which pressed the pin much deeper into the SiC emery paper and increased the surfaces of the pin engaged the abrasive surface of the emery paper. With the increase in the applied loads, the examined pin was pressed more firmly in the surface of the emery paper on the disc and increased proportion of the pin surface that chopped off as the wear debris by the abrasive surface. Comparing the wear rates of epoxy, epoxy/Almp and epoxy/Alnp composites, it is observed that epoxy/Alnp composites have lowest wear rate at each level of applied loads. A good wear resistance requires rigid second phase particles firmly bonded to the matrix. Epoxy/10Alnp composite that has the minimum wear rate exhibits a best wear resistance among epoxy and epoxy/10Almp composites. The better performance of epoxy/10Alnp composites in term of wear resistance could be linked with rigid second phase particles, dispersed evenly within, and firmly bonded to the epoxy matrix as reported in [19].

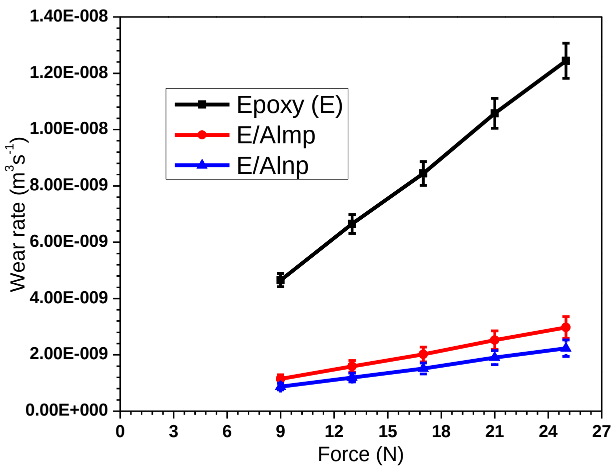


Fig. 1. Comparation of wear rates of the pristine epoxy and epoxy containing 10wt% of aluminium micro and nanoparticles.

Moreover, in the volume-per unit time wear rate approach, the applied loads are the independent factor on which the wear rate depends. The model was conducted at constant velocity of 0.65 ms^{-1}, particle size of 0.08247 µm and sliding distance of 200 m, effect of loads (predictor/independent variable) on wear rate (response) was analysed at 95 % confidence level using linear regression model.

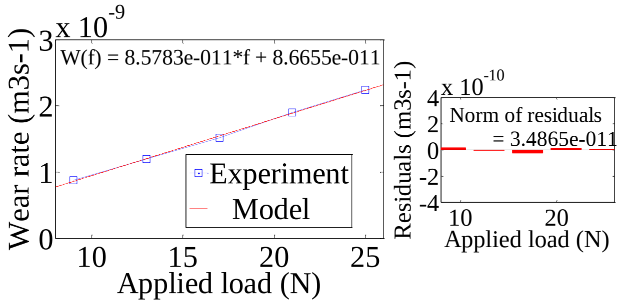


Fig. 2. Prediction of epoxy/Alnp composites wear rate using mono-variate regression model.

Table 1. ANOVA for volume per time wear rate of epoxy/Alnp composites.

Sum of squares		Mean	Model summary
Regression	Residuals	Residuals	R^2
2.4674E-16	1.21727E-21	-1.83E-12	0.998967234

Moreover, Figure 2 and Tables 1-2 display the results of the linear regression model developed for wear rate of epoxy/Alnp composites. Deduction from Tables 1-2 and Figure 2 is the good prediction of the wear rate by the model.

Table 2. Actual and predicted values for volume per time wear rate of epoxy/Alnp composites.

Predictor variable	Wear rate of epoxy/Alnp nanocomposite (m^3s^{-1})		
Applied load, F(N)	Actual values	Predicted values	Residuals
9	8.74E-10	8.58702E-10	-1.53E-11
13	1.20E-09	1.20183E-09	1.83E-12
17	1.52E-09	1.54497E-09	2.50E-11
21	1.90E-09	1.8881E-09	-1.19E-11
25	2.24E-09	2.23123E-09	-8.77E-12

Therefore, this model is statistically relevant to the experiment confirmation and validation of epoxy/Alnp wear rate. Smaller regression coefficients in Equations 1 of the epoxy/Alnp with those of the epoxy/Almp in literature [21] show the lower regression coefficients in respect of the epoxy/Alnp which implies that the model predicts lower wear rate at each level of applied loads for epoxy/Alnp. This agrees with experimental results in Figure 1.

$$W(f)_{Epoxy/Alnp} = 8.6 \times 10^{-11} f + 8.7 \times 10^{-11} \quad (1)$$

$$W(A_n, f, v)_{Alnp} = \beta_1 + \beta_2 f + \beta_3 v + \beta_4 A_n \quad (2)$$

Table 3. Pearson correlation of variables for epoxy/Alnp wear rates.

	Variables	$W(A_n,f,v)$	f	V	A_n
W – wear rate; f – applied load, v – speed; An – weight of aluminium nanoparticles	$W(A_n,f,v)$	1.000	0.444	0.167	-0.789
	f	0.444	1.000	0.000	0.000
	v	0.167	0.000	1.000	0.000
	A_n	-0.789	0.000	0.000	1.000

Table 4. ANOVA of epoxy/Alnp wear rate.

Standard order	Model	Sum of Squares	Degree of freedom	Mean Square	Fishers' value	Significance	R^2
1	Regression	0.003	3	0.001	7.389	0.042	
2	Residual	0.000	4	0.000			
3	Total	0.003	7				
4	Summary						0.847

Table 5. Regression coefficients for predicting response (epoxy/Alnp wear rate).

Standard order	Predictors	β	Standardised error	Standardised β	95 confidence intervals for β		Tolerance	VIF
					Lower Bound	Upper Bound		
1	(Constant)	0.010	0.015		-0.032	0.051		
2	F	0.001	0.000	0.444	0.000	0.002	1.000	1.000
3	V	0.010	0.012	0.167	-0.022	0.042	1.000	1.000
4	A_n	-0.003	0.001	-0.789	-0.005	-0.001	1.000	1.000
Key: f - applied load; A_n - weight of aluminium nanoparticles; v – speed of disc rotation; VIF - Variance inflation factor								

Table 6. Pearson correlation of variables for epoxy/Alnp wear rates.

	Variables	$W(A_n,f,v)$	f	V	A_n
W – wear rate; f – applied load, v – speed; An – weight of aluminium nanoparticles	$W(A_n,f,v)$	1.000	0.444	0.167	-0.789
	f	0.444	1.000	0.000	0.000
	v	0.167	0.000	1.000	0.000
	A_n	-0.789	0.000	0.000	1.000

Table 7. ANOVA of epoxy/Alnp wear rate.

Standard order	Model	Sum of Squares	Degree of freedom	Mean Square	Fishers' value	Significance	R^2
1	Regression	0.003	3	0.001	7.389	0.042	
2	Residual	0.000	4	0.000			
3	Total	0.003	7				
4	Summary						0.847

Table 8. Regression coefficients for predicting response (epoxy/Alnp wear rate).

Standard order	Predictors	β	Standardised error	Standardised β	95 confidence intervals for β		Tolerance	VIF
					Lower Bound	Upper Bound		
1	(Constant)	0.010	0.015		-0.032	0.051		
2	F	0.001	0.000	0.444	0.000	0.002	1.000	1.000
3	V	0.010	0.012	0.167	-0.022	0.042	1.000	1.000
4	A_n	-0.003	0.001	-0.789	-0.005	-0.001	1.000	1.000
Key: f - applied load; A_n - weight of aluminium nanoparticles; v – speed of disc rotation; VIF - Variance inflation factor								

Table 9. Result of model trials to select the best function to fit the wear rates of the aluminium particle reinforced epoxy.

Functions	Sum of Squares	DF	Mean Square	Fishers' Value	Prob > F	Summary
Mean	0.017606	1	0.017606			
Linear	0.009338	4	0.002334	34.15863	< 0.0001	
2FI	0.001751	6	0.000292	64.79496	< 0.0001	Suggested
Quadratic	0	0				Aliased
Cubic	9.46E-05	4	2.36E-05	480700.9	< 0.0001	Aliased
Residual	8.36E-10	17	4.92E-11			
Total	0.028789	32	0.0009			

Table 10. ANOVA for the model parameters of the wear rates of aluminium particle reinforced epoxy.

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	R^2	Adjusted R^2	Predicted R^2	Adequate Precision
Model	0.011088	10	0.001108811	246.242494	< 0.0001	Signifi-cant			
F	0.002357	1	0.002357005	523.438888	< 0.0001				
V	0.000376	1	0.000375753	83.4464027	< 0.0001				
Ps	2.8E-05	1	2.80435E-05	6.22783786	0.0210				
wf	0.006577	1	0.006576709	1460.54204	< 0.0001				
F*V	0.000141	1	0.000140826	31.2744443	< 0.0001				
F*Ps	1.31E-08	1	1.31067E-08	0.00291071	0.9575				
F*wf	0.001415	1	0.001415462	314.342977	< 0.0001				
V*Ps	1.12E-06	1	1.12107E-06	0.24896495	0.6230				
V*wf	0.000165	1	0.000165138	36.6734561	< 0.0001				
Ps*wf	2.8E-05	1	2.80398E-05	6.22701545	0.0210				
Residual	9.46E-05	21	4.50292E-06						
Statistics						0.9915	0.9875	0.9804	45.672

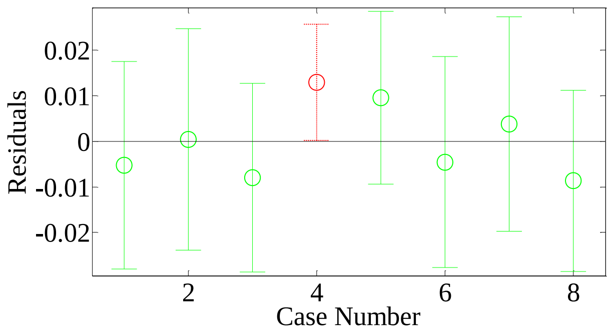


Fig. 3. Plot of residuals and its interval for epoxy/Alnp wear rate

Furthermore, mass loss-per sliding distance wear rate of epoxy/10Alnp is expressed as a function of three independent/predictor variables, percentage weight of Alnp (An) additions, speed (v) and applied load (f) at two different levels using historical approach linear response surface. The model was built at 95 % confidence level, with alpha (α) = 0.05. Outputs of the historical approach linear response surface model built for predicting wear rate of epoxy/Alnp composites are presented in Tables 3-7 and Figure 3. Table 3 shows a good correlation between the dependent and independent variables. Zero correlation coefficient between independent variables implies no relationship between any two of them. Regression Fisher's value, 7.389 and its prob>F value, 0.042 <0.05 (alpha) affirm that every term of the model is statistically significant in a making a reasonable explanation on the relationship between the predictor variables and the response. Mean of residual, 0.000 confirms absence of systematic errors from response generation. R^2, 0.847 shows that the model explains 84.7 % of the response, affirming a good predictability of the relationship between the dependent variables and the response. The standardised coefficient of f, v and A_n are 0.444, 0.167 and -0.789, respectively; meaning that A_n contributed most towards the prediction of the response and its negative sign proves that addition of Alnp to the epoxy matrix plays a significant role in reducing the wear rate (response) and enhancing the wear resistance of the epoxy/Alnp composites. Substitution of β (see Table 5) into Equation 2 gives rise to the model function for predicting the response as shown in Table 7. The mean of Cook's distance for this model is 0.250<1, and standardised residuals range from -0.812 to 1.204 are confirmation that response matrix is free from the outlier. Diagnosis of model using Durbin-Watson method (see Figure 3) indicates the presence of an outlier in the response matrix. In addition, Mahalabonis' distance, 2.625<16.27 confirms that within the model assumptions, even with one observed outlier there is no critical case that requires further attention in using the model for generating the wear rate of the epoxy/Alnp composite. Mean of residual which is equal to zero justifies the freedom of the model from systematic error and the model is statistically appropriate in fitting the experimental wear rate of epoxy/Alnp composite.

For widening the scope of prediction of the wear rate of aluminium particle reinforced epoxy within the micro and nanometre size ranges, size of the particle (Ps) was added to the predictor variables and variables were subjected to trials using various functions of the historical approach response surface model to ascertain a best model for the fitting the wear rate. Those functions include mean, linear, 2FI, quadratic and cubic functions and summarised results of the trials is presented in Table 9. Mean function was discarded because of an inability to ascertain its significance to the model because Fisher's and Prob values can not be determined. Both quadratic and cubic functions were rejected as well because they are aliased. Once the model is aliased, it cannot generate equations to compute values of the dependent variables with known values of the predictor variables. Greater Fishers' value of 2FI model (64.79496) than 34.15863 of the linear model forms a basis for selection of 2FI model to explain the relationship of the wear rate with the predictor variables since it is more significant.

Table 11. Diagnostic case statistics of the 2FI model for aluminium particle reinforced epoxy.

Standard Order	Actual Value	Predicted Value	Residual	Leverage	Student Residual	Cook's Distance	Outlier t	Run Order
1	0.005657	0.004166	0.001491	0.34375	0.867433	0.03583	0.862113	31
2	0.06253	0.060655	0.001875	0.34375	1.09098	0.056678	1.096206	12
3	0.04352	0.045437	-0.00192	0.34375	-1.11489	0.05919	-1.12173	10
4	0.007951	0.009837	-0.00189	0.34375	-1.09685	0.057289	-1.10246	21
5	0.043521	0.045437	-0.00192	0.34375	-1.11431	0.059128	-1.1211	26
6	0.010252	0.008325	0.001926	0.34375	1.120527	0.05979	1.127756	23
7	0.014792	0.016344	-0.00155	0.34375	-0.90283	0.038815	-0.89869	8
8	0.010975	0.009464	0.001511	0.34375	0.879186	0.036808	0.874238	6
9	0.004894	0.006426	-0.00153	0.34375	-0.89105	0.037808	-0.8865	13
10	0.020667	0.019125	0.001542	0.34375	0.896914	0.038307	0.892561	25
11	0.00804	0.006134	0.001906	0.34375	1.108744	0.058539	1.115156	14
12	0.007951	0.009837	-0.00189	0.34375	-1.09697	0.057302	-1.10258	5
13	0.024452	0.026367	-0.00192	0.34375	-1.11409	0.059105	-1.12087	19
14	0.062531	0.060989	0.001542	0.34375	0.89727	0.038338	0.89293	20
15	0.024452	0.025952	-0.0015	0.34375	-0.87271	0.036267	-0.86755	27
16	0.06253	0.060655	0.001875	0.34375	1.09098	0.056678	1.096206	28
17	0.06253	0.060989	0.001541	0.34375	0.896689	0.038288	0.892328	4
18	0.010252	0.008325	0.001926	0.34375	1.120527	0.05979	1.127756	7
19	0.004894	0.006426	-0.00153	0.34375	-0.89105	0.037808	-0.8865	29
20	0.020667	0.018792	0.001876	0.34375	1.091049	0.056685	1.096279	1
21	0.0104	0.012265	-0.00187	0.34375	-1.08512	0.056071	-1.08997	16
22	0.02445	0.026367	-0.00192	0.34375	-1.11525	0.059228	-1.12211	3
23	0.010975	0.009464	0.001511	0.34375	0.879244	0.036813	0.874298	22
24	0.00804	0.006134	0.001906	0.34375	1.108744	0.058539	1.115156	30
25	0.005657	0.004166	0.001491	0.34375	0.867433	0.03583	0.862113	15
26	0.014792	0.016344	-0.00155	0.34375	-0.90283	0.038815	-0.89869	24
27	0.043521	0.045022	-0.0015	0.34375	-0.87307	0.036298	-0.86793	18
28	0.0104	0.012265	-0.00187	0.34375	-1.08512	0.056071	-1.08997	32
29	0.020667	0.019125	0.001542	0.34375	0.896901	0.038306	0.892548	9
30	0.020667	0.018792	0.001876	0.34375	1.091055	0.056686	1.096286	17
31	0.04352	0.045022	-0.0015	0.34375	-0.87365	0.036346	-0.86853	2
32	0.02445	0.025952	-0.0015	0.34375	-0.87387	0.036364	-0.86875	11

$$W = 0.00222x10^{-3} + 1.12x10^{-3}F + 3.2394x10^{-3}V - 1.85433x10^{-5}Ps + 1.13463x10^{-3}wf + 8.06852x10^{-4}F * V - 9.04823x10^{-8}F * Ps - 1.6627x10^{-4}F * wf + 2.05987x10^{-3}V * wf + 6.6964x10^{-6}Ps * wf \quad (3)$$

Moreover, 2FI model is a significant model for determining values of the wear rates of the aluminium particle reinforced epoxy. This is established upon its prob value, <0.00001 (Table 10) which is much less than α (0.05 [95% confidence]). Its Fishers value, 246.242494 is so high that there is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. Therefore, the model affirms that neary all the predictor variables are significant which is butressed by their prob values of many of them that are less than 0.05. The regression coefficient of determination (R2), 0.9915 (99.15%) indicates that the 2FI model can account for approximated 99 out of every 100 data, the remaining one datum explains the residual (Table 11). This is the excellent predictability compared with similar models in literatures [22].

The Pred R-Square of 0.9804 is in reasonable agreement with the Adj R-Squared of 0.9875. As it has been mentioned earlier that nearly all model terms are significant parameters being had prob value much less than 0.05, F*Ps that has prob value of 0.9575 >0.05 and V*Ps which prob value of 0.6230>0.05 are insignificant. Their insignificance could arise from the fact that there is no way both F and Ps and V and Ps could interact since Ps is a material's property and F and V are process paramters. F, V, wt and F*V are the most significant variables that influence the wear rate of the aluminium particle reinforced epoxy. Moreover, a unique contribution to an estimation of the wear rate differs from one most significant variable to another (Equation 3). Upon the coefficient of every term in Equation 3, V has greatest unique contribution followed by wf while the least unique contribution belongs to F*Ps. Positive coeffcents of F, V and wf indicate that their increments enhance the wear rate implying that as the applied load and the velocity at which the pin slides increase, mass per unit length of the composite surface that wears increases and the greater the weight fraction of the aluminium particles in epoxy, the lower is the resistance which the aluminium particle reinforced epoxy offers to the surface wear. Although, Although, the prediction by the 2FI model with respect to the wf contradicts the observations from the laboratory experimental result and the linear response surface model that establish the decrease in the wear rate with an increment with An, it could be possible that the 2FI proposes the aluminium saturation level above which the epoxy matrix is incapacitative to bind all aluminium particle together which can lead to discontinuity within the composites. The discontinuity in the aluminium particle reinforced epoxy composite may impair its wear resistance and other properties. Many articles [23-25] have linked impairement of materials' properties with the materials' defect. On the other hands, the negative coefficient of the product term (F*wt) nullifies the effect of the wear rate increase proposed by the wf only. The nullification of the wear rate increase by the positive coefficient of wf by the negative coefficient of the F*wf is confirmed by the 3D surface plots that describe the wear rate as a function of two parameters (Figure 4).

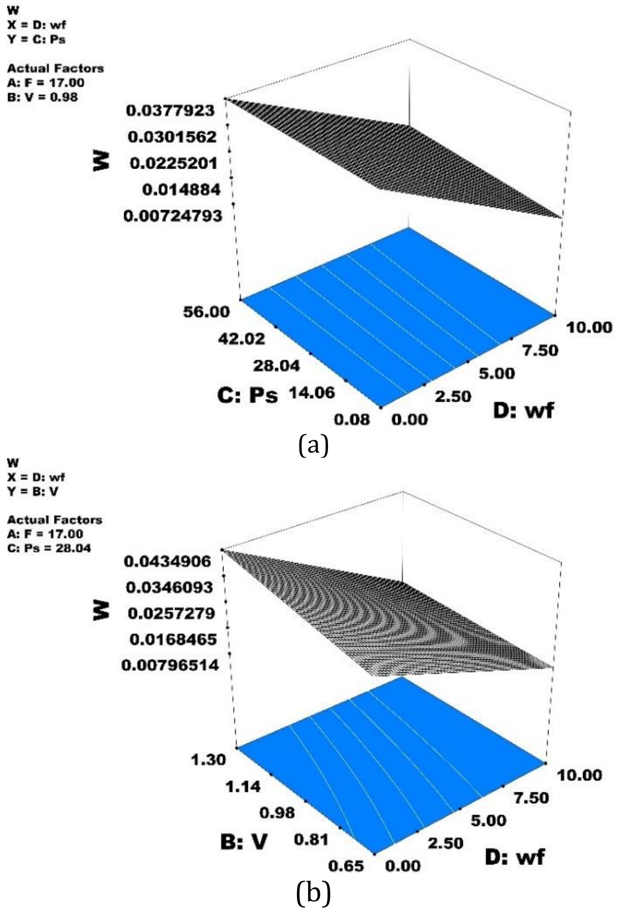
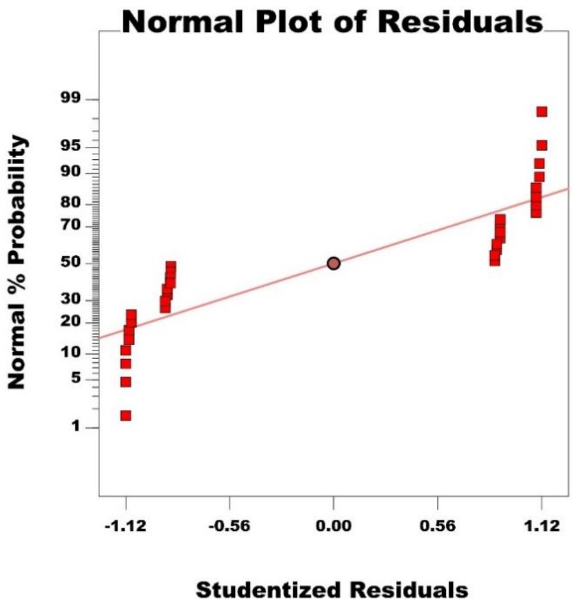
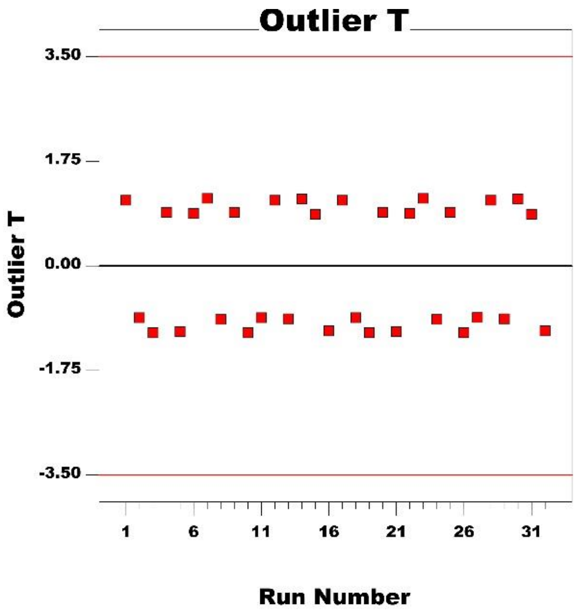


Fig. 4. 3D surface plot of the wear rate as a function two parameters (a) particle size and weight fraction of aluminium particle (b) sliding speed and weight fraction of aluminium particles.



(a)



(b)

Fig. 5. Model diagnostic plots of the two functional interaction model for the aluminium particle reinforced epoxy.

Table 12. Optimised parameters of the wear rate obtained from the two-functional interaction model.

Optimisation number	F	V	Ps	wf	W	Desirability
1	9.28	1.20	0.50	9.93	0.00482377	1
2	9.58	1.28	0.29	9.92	0.004689	1
3	9.00	0.96	0.08	10.00	0.00536556	0.991825
4	11.05	1.17	0.43	10.00	0.00546497	0.9901
5	21.71	0.65	0.08	10.00	0.0062022	0.977309
6	16.61	0.65	0.08	10.00	0.00628787	0.975823
7	9.07	1.30	36.02	10.00	0.00688148	0.965524
8	9.00	1.13	38.99	10.00	0.00750302	0.95474
9	16.73	1.30	0.08	10.00	0.00807801	0.944764
10	21.93	1.28	0.08	10.00	0.0105471	0.901926

Explanation in Figure 4a is that there is an increase in the wear rate with decrease in the aluminium particle size (Ps) but a decrease in the wear rate with an increase in the particle weight fraction. Figure 4b also establishes the decrease in the wear rate with an increase in the Ps. The model diagnosis in Figure 5a affirms that residuals are normally distributed around the mean. That is none of the residual is greater or lower than the limit and the absence of the outlier confirms no systematic error in the predicted data. All these speak goodness of the 2FI model for determining the wear rate of the epoxy composites.

Moreover, optimisation of the wear parameters with a sole goal of the minimum wear rate gives 10 possible results (Table 12) that demonstrate conditions upon which each of the wear rate can be generated. For instance, the basic interpretation of the optimisation 1 is that when the 9.93%-0.5 μm sized aluminium particle reinforced epoxy composite is subjected to an applied load of 9.28 N at a sliding speed/velocity of 1.2 ms^{-1}, it will experience a wear rate of 0.00482377 gm^{-1}. This is the best result because of its desirability of 1 and the minimum possible wear rate. This is followed by optimisation 2. The respective materials of the 1st and 2nd optimisation can only be used under applied load of 10N. For an application where the prevailing loading constraint is up to 21 N, optimisation 5 and 10 can be selected.

4. CONCLUSIONS

Based on investigations conducted and results obtained in this study, the following conclusions were made:

1. Volume loss per time and mass loss per sliding distance were used for computing the wear rate.
2. Linear regression analysis, linear and two-functional interaction response surface models were employed to establish relationship among the applied loads, sliding velocities/speeds, particle size and percentage by weight (weight fraction) of aluminium particles.
3. The two-functional interaction response surface model is significant for predicting the wear rate with the predictability of 99.15%
4. Optimisation of the wear parameters by the two-functional interaction response model establishes that the epoxy reinforced with 10 percentage by weight of 0.08 μm (80 nm) sized aluminium particle will experience 0.0105471 gm^{-1} under applied load of 21.93 N and 1.28 ms^{-1}
5. Upon the optimised condition, a brake pad can be produced from the aluminium reinforced epoxy and period of usage under maximum load can be obtained.

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