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# WEAR RESISTANCE PROPERTIES OF EPOXY ALUMINIUM MICROPARTICLE COMPOSITE

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**Abstract:** *Present priority of light materials for enhancing automobile safety and fuel efficiency creates a premise for developing new materials with optimum combination of lightness and better or comparative properties to replace existing heavy alloys for transportation applications. Previous authors' study reveals development of epoxy aluminium composite with investigation of mechanical properties and its targeted application as an automobile bumper but the wear resistance of the composite has not been reported. This study investigates wear resistance properties of epoxy containing 10% by weight of aluminium microparticles. The composite was produced from epoxy resin (MAX 1618 A) cured with hardener (MAX 1618 B) at 2:1 volume mix ratio through in-situ polymerisation. Firstly, wear rates (volume loss per unit time) were measured as a function of the applied load. Then, the wear rates (mass loss per sliding distance) were examined as a function of the applied load, velocity and % weight of aluminium particles. Worn-out surfaces of examined samples were tracked morphologically. Result obtained indicated that the applied load, sliding speed and percentage by weight are all significant factors influencing the wear resistance of the epoxy composites with the model, P value of $0.049 \leq 0.05$. The sliding velocity of β value = 0.011 contributed to increase in the wear rate than the applied load having lower β value (0.001). Addition of aluminium particles (β value = -0.003) to the epoxy lowered the wear rate. This implies that an increase in the wt% of aluminium particle added to the epoxy enhances the wear resistance of the composites. SEM study affirms the wear mechanism by crack nucleation which is characterised with continual propagation, deflection and pining. A greater damage observed on the surface of epoxy polymer justifies its higher wear rates in comparison with those of the composite.*

***Keywords:*** *Epoxy, aluminum, load, sliding distance, wear rate.*

## 1. INTRODUCTION

Epoxy polymeric composites have been found useful for many applications because of their better combination of mechanical properties when compared with their counterparts such as heavy alloy and metal matrix composites. Besides optimum combination of mechanical properties, ease of formability in shape detailing which is a function of a reduction in the number of individuals parts and overall automobile weights has also favoured the epoxy polymeric composites [1-4].

Globally, efforts have been made to reduce the weight of automobiles parts such as bumper using light structural polymer matrix composites. This is to enhance the pedestrians' safety on accidental collision with vehicles and to reduce the fuel consumption. In designing a bumper beam; safety, performance, weight, size, cost, environmental issues and appearance are taken into considerations. Low impact test at 4.0 km/h using longitudinal pendulum, high speed test at 8 km/h and pedestrian impact test using a leg form impactor through finite element modellings are the three safety criteria used by European car manufacturers [5, 6]. Based on these, bumper materials should be light, tough and strong. A bumper system contains three parts, namely: fascia, bumper beam and bumper damp. The fascia is for aesthetics and aerodynamic force reduction; bumper beam is the major beam structure that absorbs kinetic energy due to collision and the bumper damp helps in preventing the vibration of the car structures. The bumper beam needs to be strong, ductile and tough. Strength increases the car safety abilities and helps in load distribution to various components but lowers the damping ability. Flexural strength helps in preventing beam from plastic region while the ductility/toughness aids the damping abilities. Besides prerequisites mechanical properties, wear resistance forms part of requirement of automobile bumper because the bumper is not used in isolation, it is attached to the frontal and rear parts of automobiles at point of installation. Based on unavoidable contact of the bumper with the anchoring material, wear knowledge of bumper materials is inevitable in the bumper design and fabrication. Previous work of this author and his team in a published article [7] reveals mechanical properties of epoxy aluminium composites and its possible selection for automobile bumper application. However, this study is focused on wear resistance properties of epoxy containing 10% aluminium microparticles.

## 2. MATERIALS AND METHODS

Epoxy/aluminium composites used in this work was produced from epoxy resin (MAX 1618 A), hardener (MAX 1618 B) and absolute ethanol. Both the resin and hardener were purchased from Polymer Composite Institute, Canada via a local chemical vendor at Ojota Lagos, Nigeria. A weighed quantity of aluminium (10% of epoxy resin) was added to ethanol in a measuring cylinder and agitated for 5 minutes to dissolve particle clusters before adding to epoxy resin in a reaction flask. The mixture was stirred mechanically for 20 minutes and heated at 100˚C and stirred on a Stuart heating mantle to evaporate ethanol. Then, the mixture was degassed in a vacuuming process at 150 mmHg for 30 minutes after which a weighed quantity of hardener (50% of epoxy resin) was added to the degassed mixture and gently stirred until the gelation of the mixture began and the composite blend was poured into a metallic mould whose cavity formed a representative sample for the wear test. The wear resistance property of 50 x 10 x 6 mm$^3$ epoxy samples were investigated using a central circular disc wear testing machine with P 60 SiC coarse emery paper. Initial mass ($m_o$) of each sample was determined using the Pioneer weighing scale. The 10 x 6 mm$^2$ sample surface firmly fixed to the wear rig was placed on the emery paper at 50 mm from the center of the disc. While the sample was kept at 50 mm from the centre of the disc under applied load of 9 N, the disc with emery paper was made to rotate against the sample surface at a speed of 125 mms$^{-1}$ for 20 s. New mass ($m_1$) of the sample was taken after it was demounted from the rig. The process was repeated first, by gradually increasing the period of rotation of the disc from 30 seconds to 3 minutes at 30 second intervals while the load was kept constant. Second, the applied load was increased to 25 N at 4 N intervals. Mass of the sample in each case was measured and recorded. At the end of each run, the wear debris was removed from the surface of the emery paper with hard brush. The mass loss due to friction, volume and wear rate were estimated using Equations 1-3.

$$Mass\,loss = initial\,mass\,m_0 - final\,mass\,m_1 \quad (1)$$

$$Volume\,loss = \frac{mass\,loss}{density\,of\,the\,sample} \quad (2)$$

$$Wear\,rate = \frac{total\,volume\,loss}{total\,wear\,duration} \quad (3)$$

# 3. RESULTS AND DISCUSSION

## 3.1 Wear resistance of epoxy aluminium composites

Wear rate of epoxy/Almp composites were evaluated using volume loss-per unit time and mass loss-per unit sliding distance approaches. Figure 1 shows the wear rate (volume loss-per time) of epoxy and epoxy/10Almp composites at different applied loads, ranging from 9 to 25 N. It is understood from Figure 1 that the wear rate increased with an increment in applied loads. Similar observation was earlier being made in [4, 8]. The increment could be attributed to increased cutting efficiency as the applied load increased. With an increase in loads, materials under study were pressed more firmly on emery paper placed on the disc. The firm grip of the samples on the disc by the wear pin increased the friction between the sample and the emery paper, leading to higher cutting efficiency of the emery paper during the wear investigation. Results of SEM examination of the worn-out surfaces of the tested samples display severity of the surface wear in form of different trench networks due to wear induced crack initiation, propagation and growths. Continual long trenches seen in Plate 1 are explained by ease of propagation of wear induced cracks within the epoxy matrix. Since unfilled epoxy is very soft and less stiff because of absence of second phase particles, it has low strength to inhibit the crack propagation. Presence of firmly bonded second phase particles within epoxy/10Almp composites impinged and blocked the cracks and prevented their easy advancement within the composites. This causes differences in trench geometries in Plate 2 which are described as crack deflection or twisting.

In the volume-per unit time wear rate approach, the applied loads are the influential factor that affects the wear rate since experiment was performed at constant velocity (0.65 ms$^{-1}$) and sliding distance (200 m), effect of loads (predictor/independent variable) on wear rate (response) was studied at 95 % confidence level using linear regression model involving full factorial experimental design. Equations 4-7 present the design of matrices for predictor variable, regression coefficients and responses in line with [9], found in [10].

$$x = [9:4:25] \quad (4)$$

$$x_p = [9:.04:25] \quad (5)$$

$$coeff = polyfit(x, y, 1) \quad (6)$$

$$y_p = polyval(coeff, x_p) \quad (7)$$

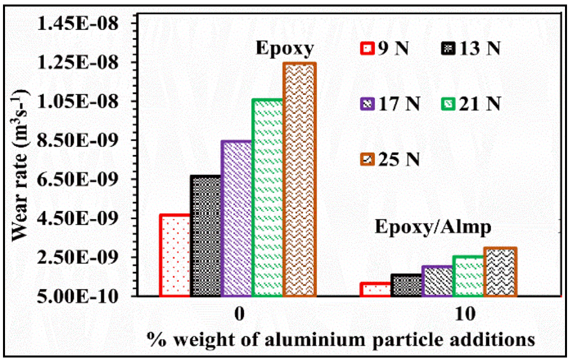


**Figure 1.** Wear rate of epoxy/Almp and epoxy/Alnp composites

Figure 2 shows the plot of the modelled and experimental data. Relationship between wear rate (response) of epoxy/Almp composites and the applied loads (predictor variable) is explained by the model. A function describing the mono-variate regression model is presented in Equation 8. The regression coefficient of determination for this model is 0.9992 (see Table 1). The deduction from this is that 99.92 % of experimental wear rate are explained by the model. However, mean of residuals (-7.60exp-13) reveals goodness of the data fit due to absence of the systematic error from response determination. The model exhibits a good predictability. Residuals between predicted and actual values of epoxy/Almp composites wear rate are shown in Table 2.

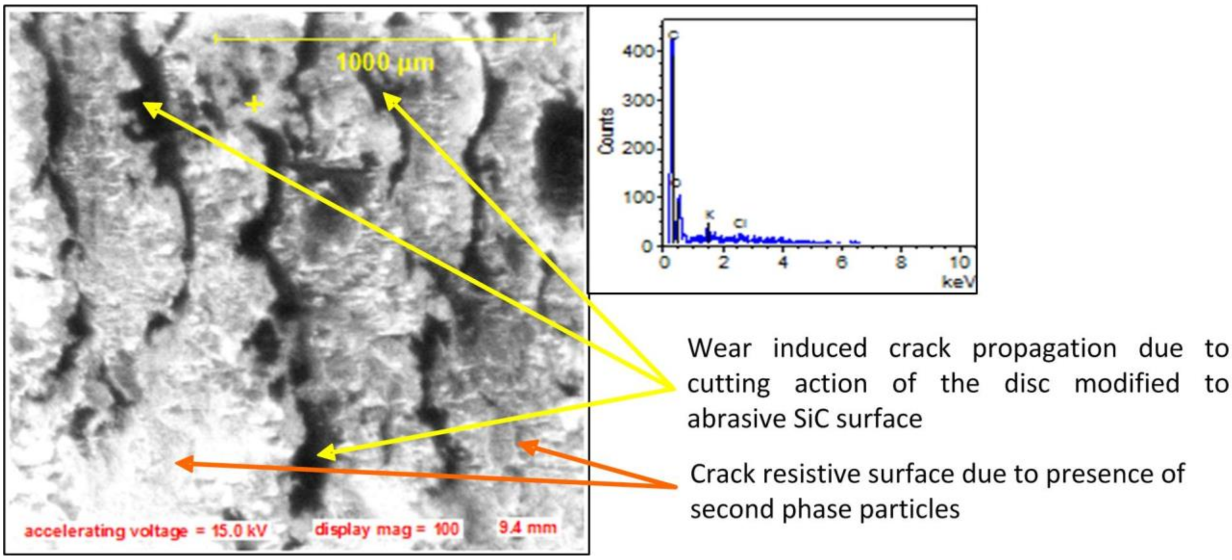


**Plate 1.** SEM/EDX of worn-out surface of the epoxy matrix

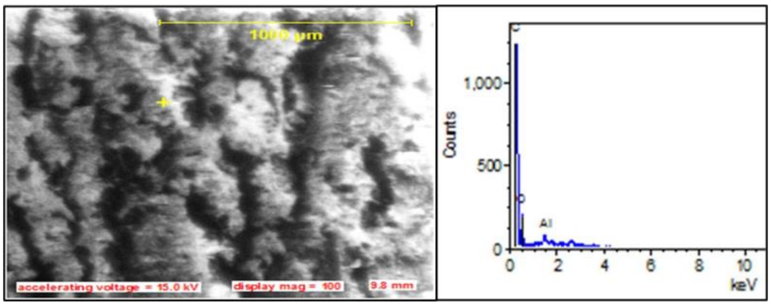


**Plate 2.** SEM/EDX of worn-out surface of epoxy/10Almp composites

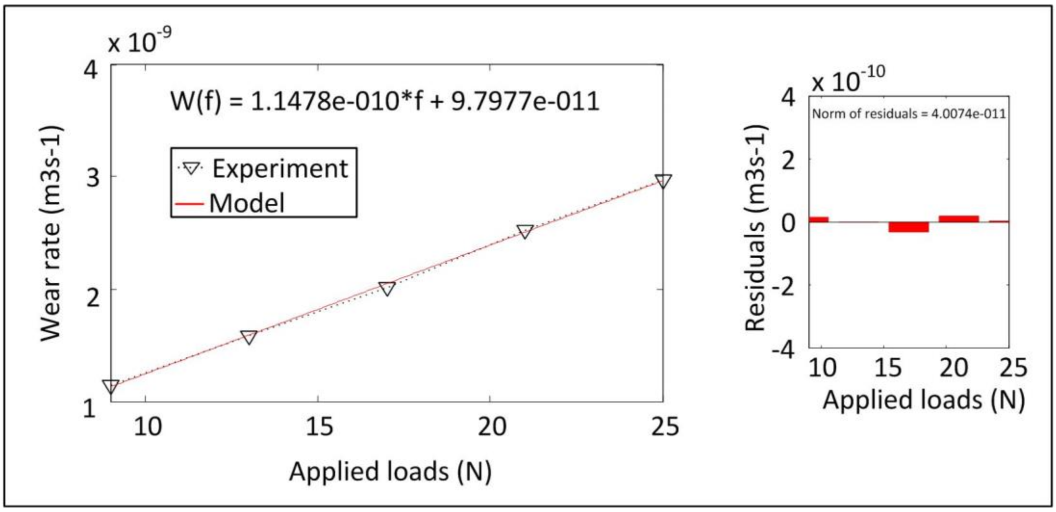


**Figure 2.** Regression model prediction of wear rate for epoxy/Almp composites

$$W(f)_{Epoxy/Almp\,composites} = 1.1478x10^{-10}\,f + 9.7877x10^{-11} \quad (8)$$

**Table 1.** ANOVA of epoxy/Almp composites wear rate

| Sum of squares | | Mean | Model summary |
|---|---|---|---|
| Regression | Residuals | Residuals | R square |
| 2.13607E-16 | 1.60588E-21 | -7.60E-13 | 0.999238708 |

**Table 2.** Confirmation of experiment and validation of epoxy/Almp composites wear rate

| Order | Independent variable | Response (($m^3s^{-1}$) | | |
|---|---|---|---|---|
| | Applied load, f (N) | Actual values | Predicted values | Residual |
| 1 | 9 | 1.14E-09 | 1.131E-09 | -9.00E-12 |
| 2 | 13 | 1.59E-09 | 1.59012E-09 | 1.20E-13 |
| 3 | 17 | 2.02E-09 | 2.04924E-09 | 2.92E-11 |
| 4 | 21 | 2.53E-09 | 2.50836E-09 | -2.16E-11 |
| 5 | 25 | 2.97E-09 | 2.96748E-09 | -2.52E-12 |

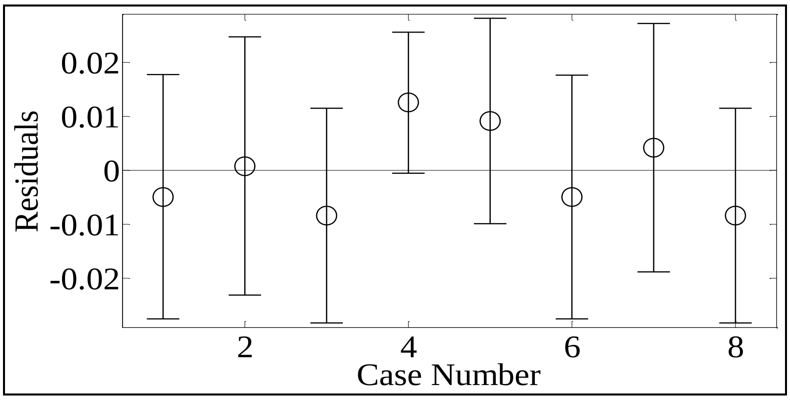


**Figure 3.** Co-plot of residuals and residual intervals for epoxy/Almp composites wear rate (W)

**Table 3.** Design layout and response data for wear behaviour of epoxy/Almp composites

| Order | Applied loads, f (N) | Speed of rotation v ($ms^{-1}$) | $A_m$ | Wear rate (W) (f, v, $A_m$) ($gm^{-1}$) |
|---|---|---|---|---|
| 1 | 9 | 0.65 | 0 | 0.020667 |
| 2 | 25 | 0.65 | 0 | 0.04352 |
| 3 | 9 | 1.3 | 0 | 0.02445 |
| 4 | 25 | 1.3 | 0 | 0.06253 |
| 5 | 9 | 0.65 | 10 | 0.007951 |
| 6 | 25 | 0.65 | 10 | 0.010975 |
| 7 | 9 | 1.3 | 10 | 0.010252 |
| 8 | 25 | 1.3 | 10 | 0.014792 |
| Am – weight of aluminium micro particles | | | | |

**Table 4.** Pearson correlation of dependent and independent variables for epoxy/Almp composites wear rate

| W- wear rate; f – applied load; $A_m$ - weight of aluminium micro particles; v – speed of rotation of the disc | Variables | W($A_m$,v,f) | F | $A_m$ | V |
|---|---|---|---|---|---|
| | W($A_m$,v,f) | 1.000 | 0.477 | -0.747 | 0.201 |
| | f | 0.477 | 1.000 | 0.000 | 0.000 |
| | $A_m$ | -0.747 | 0.000 | 1.000 | 0.000 |
| | v | 0.201 | 0.000 | 0.000 | 1.000 |

**Table 5.** ANOVA of the wear rate of epoxy/Almp composites

| Standard order | Model | Sum of squares | Df | Mean Square | F | Significance | $R^2$ |
|---|---|---|---|---|---|---|---|
| 1 | Regression | 0.002 | 3 | 0.001 | 6.313 | 0.049 | |
| 2 | Residual | 0.001 | 4 | 0.000 | | | |
| 3 | Total | 0.003 | 7 | | | | |
| 4 | Summary | | | | | | 0.826 |
| Df – degree of freedom; F – Fisher's value; $R^2$ – regression coefficient of determination | | | | | | | |

**Table 6.** Regression coefficients (β) characterising the model function for epoxy/Almp composites wear rate

| Standard order | Predictors | B | Standardised Error | Standardised β | 95 % confidence interval for β | | Tolerance | VIF |
|---|---|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound | | |
| 1 | (Constant) | 0.009 | 0.015 | | -0.032 | 0.050 | | |
| 2 | f | 0.001 | 0.000 | 0.477 | 0.000 | 0.002 | 1.000 | 1.000 |
| 3 | $A_m$ | -0.003 | 0.001 | -0.747 | -0.005 | -0.001 | 1.000 | 1.000 |
| 4 | V | 0.011 | 0.012 | 0.201 | -0.021 | 0.043 | 1.000 | 1.000 |
| Key: f - applied load; $A_m$ - weight of aluminium micro particles; v – speed of disc rotation; VIF - Variance inflation factor | | | | | | | | |

**Table 7.** Model evaluation parameters for epoxy/Almp composites wear rate

| | Minimum | Maximum | Mean | Standard deviation |
|---|---|---|---|---|
| Mahalalabonis Distance | 2.625 | 2.625 | 2.625 | 0.000 |
| Cook's Distance | 0.003 | 0.702 | 0.250 | 0.226 |
| Standardised residual | -1.120 | 1.676 | 0.000 | 1.069 |

$$W\left(A_m, f, v\right)_{Almp} = \beta_1 + \beta_2 A_m + \beta_3 f + \beta_4 v \tag{9}$$

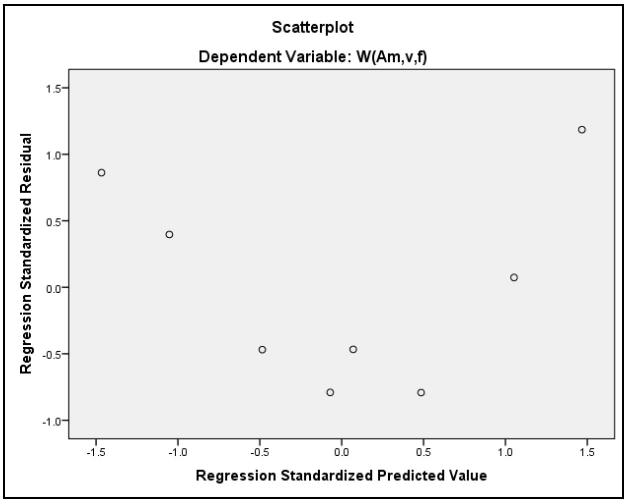


**Figure 4.** Standardised residuals for epoxy/Almp composites wear rate

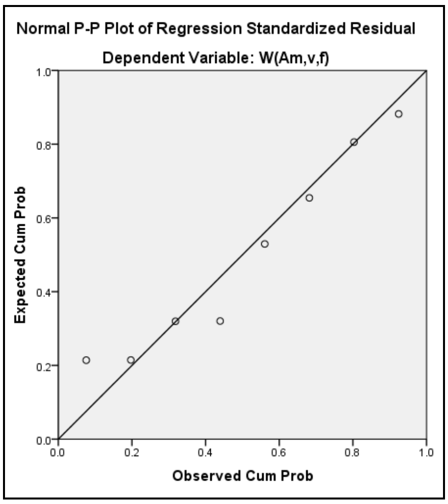


**Figure 5.** Expected and observed cumulative probabilities for epoxy/Almp composites wear rate

**Table 8.** Result of confirmation of experiment and validation epoxy/Almp composites wear rate

| Standard order | Wear rate ($gm^{-1}$) | | |
|---|---|---|---|
| | Experiment | Model | Residuals |
| 1 | 0.020667 | 0.0256 | -0.0049 |
| 2 | 0.04352 | 0.0427 | 0.0008 |
| 3 | 0.02445 | 0.0328 | -0.0084 |
| 4 | 0.06253 | 0.05 | 0.0126 |
| 5 | 0.007951 | -0.0012 | 0.0091 |
| 6 | 0.010975 | 0.0159 | -0.005 |
| 7 | 0.010252 | 0.006 | 0.0042 |
| 8 | 0.014792 | 0.0232 | -0.0084 |

Mass loss-per sliding distance wear rate of epoxy/10Almp was modelled as a function of three independent/predictor variables, percentage weight of Almp (Am) additions, speed (v) and applied load (f) at two different levels. The model was built using full factorials design of experiments ($2^3$ = 8) at 95 % confidence level, with alpha = 0.05. The design layout for the model is presented in Table 3. Relationship between dependent variable, wear rate (W) and independent variables; f, v and $A_m$ in Table 4 shows that f and $A_m$ are statistically significant in prediction of W.

Correlation coefficient of v (0.201) less than 0.3 as reported by Pallant [11] indicates a weak relationship between W and v. Evaluating the interaction between v, $A_m$ and f, their correlation coefficient is 0.000 indicating no relationship between them. This is excellent; it implies that linear multi-interaction among independent variables in prediction of response (W) is obeyed. The last three columns of Table 5 indicate model Fisher value of 6.313, meaning that there is a very low chance that noise could occur in this model; prob>F value of 0.054 approximated to 0.05 indicating that every term of this model is statistically significant in the prediction of responses and $R^2$ is equal to 0.826. This implies that 82.6 % of the data can be explained by the model.

Tolerance and variance inflation factor (VIF) values of 1 each, for all independent variables which is higher than 0.1 and less than 10 is a confirmation of obedience to multicollinearity of the independent variables f, v and $A_m$. Neglecting the negative sign in the front of the standardised β in Table 6, $A_m$ (0.747) has largest contribution to the prediction of the response (W), followed by f (0.477). These observations imply that the model gives a reasonable explanation on the relationship between the predictor variables and the response. This agrees with a report in [2]. The co-plot of residuals and their intervals in Figure 3 demonstrates that all residuals at each case or level ranges from negative through zero to positive values, affirming that no outlier is found in the response matrix, that is, no response value is much higher or lower than expected values.

This agrees with standardised residual plot in Figure 4 which according to Tabachanick and Fiddell (2001) found in [11], the standardised residuals should fall between -3.3 and 3.3. Also, the mean Cook's distance (0.250) which is less than one affirms absence of an outlier in the model. The scatter plot in Figure 5 which shows the data distribution along the diagonal line through the origin is a confirmation of little difference between the predicted and actual values. The mean Mahalabonis' distance (2.625) in Table 7 which is lower than 16.27 assigned to any linear regression involving three independent variables [11] shows that the prediction of the response (W) by this model is free from any critical case that may require additional attention. Substitution of β in Table 6 into Equation 9 gives the regression function for obtaining the response, the predicted values of the epoxy/Almp composites wear rate (W) as shown in Table 8.

## 3.0 CONCLUSIONS

Based on the result of investigation, the following conclusion can be made:

[1] There were 177.8 and 160.6 % increases in the wear rates of epoxy polymer and epoxy aluminium composites, respectively when the applied load increased from 9 to 25N.

[2] Smaller percentage wear rate of the epoxy composite is attributed to addition of aluminium particles to epoxy.

[3] Regression coefficients of determination for both analyses are 99.92 and 82.6 % which show good coverage of input data.

[4] Absence of outlier and critical case in the regression analyses establishes that both the models are appropriate for prediction of the wear rates of epoxy/aluminium composites.

[5] The continual trench-geometry observed on the worn-out surface of the epoxy polymer indicates a greater damage to the surface in comparison with that of the epoxy polymer.

[6] There is an agreement between the wear rates and worn-out surface geometry of the examined materials.

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