Polymer-Plastics Technology and Engineering

ISSN: 0360-2559 (Print) 1525-6111 (Online) Journal homepage: https://www.tandfonline.com/loi/lpte20

Abrasive Wear Behavior of Granite-Filled Glass-Epoxy Composites by SiC Particles Using Statistical Analysis

S. Basavarajappa , S. Manjunath Yadav , Santosh Kumar , K. V. Arun & Narendranath S.

To cite this article: S. Basavarajappa , S. Manjunath Yadav , Santosh Kumar , K. V. Arun & Narendranath S. (2011) Abrasive Wear Behavior of Granite-Filled Glass-Epoxy Composites by SiC Particles Using Statistical Analysis, Polymer-Plastics Technology and Engineering, 50:5, 516-524, DOI: 10.1080/03602559.2010.543734

To link to this article: https://doi.org/10.1080/03602559.2010.543734

Polymer-Plastics Technology and Engineering, 50: 516–524, 2011

ISSN: 0360-2559 print/1525-6111 online
DOI: 10.1080/03602559.2010.543734

Abrasive Wear Behavior of Granite-Filled Glass-Epoxy Composites by SiC Particles Using Statistical Analysis

S. Basavarajappa[1], **S. Manjunath Yadav**[1], **Santosh Kumar**[1], **K. V. Arun**[2], **and Narendranath S.**[3]
[1]*Department of Studies in Mechanical Engineering, Univ. B.D.T. College of Engineering, Davangere, Karnataka, India*
[2]*Department of Studies in Industrial and Production Engineering, Univ. B.D.T. College of Engineering, Davangere, Karnataka, India*
[3]*Department of Mechanical Engineering, National Institute of Technology, Srinivasanagar, Surathkal, Karnataka, India*

This experimental investigation deals with the evaluation of abrasive wear behavior of Glass Epoxy (G-E) composites on pin-on-disc test rig. A plan of experiments, based on the Taguchi Design of Experiments, was performed to acquire data in controlled way. An orthogonal array and the analysis of variance were employed to investigate the percentage of contribution of various process parameters like sliding speed, applied load, sliding distance and their interactions affecting the abrasive wear volume loss of composites. The correlations between the various factors affecting the abrasive wear behavior of composites were obtained by using multiple linear regression equations. The obtained results indicate that applied load and sliding distance were the wear factors that have the highest physical as well as statistical influence on the abrasive wear behavior of both filled and unfilled G-E composites. A good agreement between the predicted and actual wear resistance was observed within ± 12%.

Keywords Granite filler; Polymer-matrix composite; Taguchi Method; Two-body abrasion

INTRODUCTION

Polymer matrix composites are increasingly finding industrial application because of their unique combination of mechanical, electrical and thermal properties[1]. Typically, they have high specific strength and modulus, excellent fracture toughness, fatigue properties, and good corrosion, thermal and electrical resistance properties. One possible way to widen the scope and usage of these materials is to resort to the introduction of fillers into the polymeric system having fibrous reinforcement[2–5].

This would enable the user to have optimum wear rate and coefficient of friction. However, the use of these filler based composites in actual service requires a careful cataloguing of the processing conditions employed and the attendant structure that follows. Wear is one of the most commonly encountered industrial problems, leading to frequent replacement of components, particularly abrasion. Abrasive wear has a contribution of at least 60% of the total cost due to wear. Abrasive wear is caused by hard particles that are forced and moving along a solid surface[6].

In past, many works have been carried out for abrasive wear mechanism for polymers in general and polymer composite in particular[7–10]. In a review of some of the literature concerning abrasive wear of polymers, Liu et al.[10] investigated the abrasive wear behavior of ultrahigh molecular weight polyethylene (UHMWPE) polymer. They concluded that the applied load is the main parameter and the wear resistance improvement of filler reinforced UHMWPE was attributed to the combination of hard particles, which prevent the formation of deep, wide and continuous furrow. Rajesh et al.[11] studied the behavior of polyamide 66. They concluded that the water absorption and thermal properties affected the morphology of polyamides, which in turn affected the tribological properties of polyamides.

Harsha and Tewari[12] investigated the abrasive wear behavior of (polyaryletherketone PAEK) and its composites against SiC_p abrasive paper. They concluded that the sliding distance, applied load, abrasive grit size have a significant influence on abrasive wear performance. Shipway and Ngao[13] investigated the abrasive behavior of polymeric materials in micro-scale level. They concluded that the wear behavior and rates of polymers depended critically on the polymer type.

Bijwe et al.[14] have studied the abrasive wear behavior of fabric-reinforcedpolyetherimide composites. They conducted the abrasive wear studies on seven composites of polyetherimide (PEI) reinforced with three types of fabrics viz. glass (with three different weaves), carbon and aramid (Kevlar 29). Their result indicate that aramid fabric (AF)

Address correspondence to S. Manjunath Yadav, Department of Studies in Mechanical Engineering, Univ. B.D.T. College of Engineering, Davangere-577004, Karnataka, India. E-mail: manjunathyadavs@gmail.com

revealed significant potential to improve abrasive the wear performance of PEI. Suresha and Shiva Kumar[15] studied the mechanical and two-body abrasive wear behavior of glass/carbon fabric reinforced vinyl ester composites. They concluded that wear volume loss increases with increase in abrading distance/abrasive particle size. However, the specific wear rate decreases with increase in abrading distance and decrease in abrasive particle size.

The desired testing parameters are either determined based on experience or by use of a handbook. It, however, does not provide optimal testing parameters for a particular situation. Therefore, several mathematical models based on statistical regression techniques have been constructed to select the proper testing conditions[16–18]. Taguchi's design can be simplified by expending the application of the traditional experimental designs to the use of orthogonal array and linear graphs. It is an efficient and systematic approach to optimize designs for performance, quality and cost. The abrasive wear of composites also depends on several factors such as size, shape, content of particle, loading conditions and environment[19–21].

In past two decades, ceramic filled polymer composites have emerged as a subject of extensive research. In this context, Mondal et al. has shown that natural mineral granite can be successfully used as filler material. Their results have shown that inclusion of granite as filler improves the wear resistance[22,23].

The aim of the study was, therefore, to investigate the Two-body abrasive wear behavior of G-E composites based on the Taguchi design of experiments. Furthermore, the analyses of variance were employed to study the wear behavior of G-E composites.

MATERIALS AND METHODS

Material

The matrix material used was a medium viscosity epoxy resin (LAPOX L-12) and a room temperature curing polyamine hardener (K-6). This matrix was chosen since it provides good resistance to alkalis and has good adhesive properties. The reinforcement material employed was 7-mil E-glass fabric. The granite particles of 75 to 150 mesh size is used as filler material. The properties of glass fabric, epoxy resin and filler are as shown in Table 1.

TABLE 1
Properties of matrix, reinforcement and filler

Properties	E-Glass Fabric	Epoxy* (Lapox L-12)	Granite
Density in g/cc	2.48	1.25	2.77
Tensile strength in MPa	3448	50–60	7.00–25.0
Compressive strength in MPa	30000	110–120	96.5–310
Modulus of elasticity in GPa	72.4	4.4–4.6	20.0–60.0
Coefficient of linear thermal expansion in μ/°C	5	64–68	3.70–11.0

*In 25°C temperature 14–24 hrs of time is required to cure.

Specimen Fabrication

The two-body abrasive wear specimen consists of brittle polymer epoxy resin, bidirectional piles of plain weave woven glass fabric and fillers. A hand lay-up technique was used for preparation of the specimen. The procedure consists of placing the glass fibers with epoxy compatible finish on a substrate material, which had a release coat applied on it.

At room temperature weighed quantities of a curing agent hardener (K6) and Granite particles are mixed in the liquid epoxy and smeared over the glass fabric to polymerize the polymer and form a solid network cross-linked polymer. On this, another layer of the glass fabric was laid and the process continued. The whole lay-up was covered with a mat finished fabric over which a steel plate was placed with the necessary release coat applied on it. The lay-up assembly was pressed in a press. The excess resin was allowed to squeeze out.

The laminate was cured at ambient conditions for a period of about 24 hrs. The cured laminates were cut using a diamond tipped cutter to yield an abrasive wear test specimen of size 10 mm × 10 mm × 3 mm. Two types of composites were produced, one with 60% of glass fiber volume fraction and other with 20% volume fraction of granite paricles are added to 40% of glass fiber, but the volume faction of Epoxy resin 40% was kept constant for both composites. All the mix ingredients were weighed using an analytical balance and mixed using a commercial blender.

Experimental Setup

The two-body abrasive wear tests are conducted as per ASTM G-99 standards using pin-on-disc testing machine. The surface of the sample 10 mm × 10 mm was glued to a pin of 8 mm diameter and 27 mm height. These glued specimens were abraded against a silicon carbide (SiC_p) abrasive paper of 600 grade fixed on the disc. The tests were conducted for specified test duration, applied load, and sliding speed. First the test specimens were rubbed against a 1200 grade SiC_p emery paper to make the surface perfectly flat. The surfaces of specimens were cleaned with a soft paper in acetone before the test. The initial weight of the pin assembly was recorded accurately using a digital electronic balance with a least count of 0.0001 grams.

After fixing both the emery paper on disc and the specimen pin in their respective positions, the normal load to the

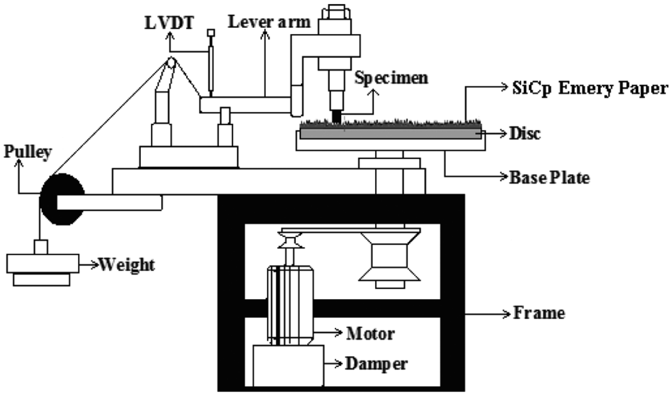

FIG. 1. Representation of a pin on disc apparatus used in the Two-body Abrasion wear studies.

pin was applied through a pivoted loading lever with a string and pan assembly. The required loads were applied by placing known deadweights on the pan. In order to encounter fresh abrasive papers, the specimen was also moved against the parallel surface of the rotational steel disc. The representation of pin on disc apparatus used in the two-body abrasive wear study is as shown in Figure 1.

At the end of the test, the tested specimen was again weighed in the same balance. The difference between the initial and final weights was a measure of abrasive wear loss, then the volume loss was calculated. All these tests were conducted at room temperature. A minimum of two trials were conducted to ensure repeatability of test data.

Taguchi Design of Experiments

The experiments were conducted using the standard orthogonal array. The selection of the orthogonal array is based on the condition that the degrees of freedom for the orthogonal array should be greater than or equal to sum of those wear parameter.

The degree of freedom is defined as the number of comparisons between design parameters that need to be made to determine which level is better. In the present investigation, an L27 orthogonal array was chosen, which has 27 rows and 13 columns as shown in Table 2. The first

TABLE 2
Standard orthogonal L_{27} (3^{13}) array of Taguchi for wear

L_{27} (3^{13}) Test	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2	2	2	2	2	2
3	1	1	1	1	3	3	3	3	3	3	3	3	3
4	1	2	2	2	1	1	1	2	2	2	3	3	3
5	1	2	2	2	2	2	2	3	3	3	1	1	1
6	1	2	2	2	3	3	3	1	1	1	2	2	2
7	1	3	3	3	1	1	1	3	3	3	2	2	2
8	1	3	3	3	2	2	2	1	1	1	3	3	3
9	1	3	3	3	3	3	3	2	2	2	1	1	1
10	2	1	2	3	1	2	3	1	2	3	1	2	3
11	2	1	2	3	2	3	1	2	3	1	2	3	1
12	2	1	2	3	3	1	2	3	1	2	3	1	2
13	2	2	3	1	1	2	3	2	3	1	3	1	2
14	2	2	3	1	2	3	1	3	1	2	1	2	3
15	2	2	3	1	3	1	2	1	2	3	2	3	1
16	2	3	1	2	1	2	3	3	2	1	2	3	1
17	2	3	1	2	2	3	1	1	2	3	3	1	2
18	2	3	1	2	3	1	2	2	3	1	1	2	3
19	3	1	3	2	1	3	2	1	3	2	1	3	2
20	3	1	3	2	2	1	3	2	1	3	2	1	3
21	3	1	3	2	3	2	1	3	2	1	3	2	1
22	3	2	1	3	1	3	2	2	1	3	3	2	1
23	3	2	1	3	2	1	3	3	2	1	1	3	2
24	3	2	1	3	3	2	1	1	3	2	2	1	3
25	3	3	2	1	1	3	2	3	2	1	2	1	3
26	3	3	2	1	2	1	3	1	3	2	3	2	1
27	3	3	2	1	3	2	1	2	1	3	1	3	2

TABLE 3
Process parameters with their values at three levels

Levels	Applied load in N	Sliding speed in ms^{-1}	Sliding distance in m
1	10	1	10
2	20	2	20
3	30	3	30

column was assigned to Applied load (P), second column was assigned to Sliding speed (S), and fifth column was assigned to Sliding distance (D) and the remaining columns were assigned to their interactions. The response to be studied was the two-body abrasive wear volume loss with the objective of achieving minimum wear. The experiments were conducted as per the orthogonal array with level of parameters given in each row. The levels of the process variables used for testing are as presented in Table 3.

DATA ANALYSIS, RESULTS AND DISCUSSION

The experiments were conducted with an aim of relating the influence of applied load (L), sliding speed (S) and sliding distance (D) on two-body abrasive wear of both filled and unfilled composites under study. On conducting the experiments as per the orthogonal array, the two-body abrasive wear results for various combinations of parameters were obtained and shown in Table 4.

It is inferred from the Table that 20% granite-filled G-E composites possesses better wear resistance compared to an unfilled one. It can be observed further that increase of applied load, sliding speed, sliding distance increases the wear volume loss for both materials.

Anova and Effect of Factors

The ANOVA allows analyzing the influence of each variable on the total variance of the results. Table 5 shows the results of ANOVA of Two-body abrasive wear of G-E

TABLE 4
Orthogonal array of Taguchi for Two-body abrasive wear

Trial NO	Load in N	Speed in ms^{-1}	Distance in m	Wear volume loss of G-E composites in mm^3	Wear volume loss of 20% Granite filled G-E Composites in mm^3
1	10	1	10	10.1626	2.7641
2	10	1	20	12.1951	2.9121
3	10	1	30	14.9898	5.5775
4	10	2	10	10.9248	4.1461
5	10	2	20	19.5122	6.5647
6	10	2	30	33.0285	6.4659
7	10	3	10	12.9573	4.3929
8	10	3	20	20.0203	6.6204
9	10	3	30	40.7012	10.3159
10	20	1	10	21.4939	7.6012
11	20	1	20	30.4878	8.5884
12	20	1	30	50.8130	10.4146
13	20	2	10	22.1037	9.1807
14	20	2	20	47.7846	13.3761
15	20	2	30	68.4411	19.4669
16	20	3	10	22.2561	8.1441
17	20	3	20	40.4878	15.4492
18	20	3	30	78.6585	18.4600
19	30	1	10	26.0671	15.3011
20	30	1	20	41.6565	18.7562
21	30	1	30	53.7907	25.0543
22	30	2	10	26.1524	14.6101
23	30	2	20	42.5305	15.8934
24	30	2	30	66.4533	35.0533
25	30	3	10	28.5203	16.2883
26	30	3	20	43.7500	30.5035
27	30	3	30	70.5650	40.0099

TABLE 5
AN OVA for GE composites

Sources of variance	SS	Dof	Variances	Test F	F	P %
D	4963.43	2	2481.71	216.9971	5.27[a]	49.00
L	3488.46	2	1744.22	152.5121	5.27[a]	34.37
S	569.36	2	284.68	24.8920	5.27[a]	5.41
SXD	309.22	4	77.3050	6.7594	3.91[a]	2.61
LXD	303.58	4	75.8950	6.6361	3.91[a]	2.55
LXS	37.23	4	9.31	0.8140	—	—
Error/Other	411.73	35	11.4366			6.06
Total	10083.01	53	4684.5566			100

ss = sum of variance, Dof = Degree of freedom, P = Percentage of contribution.
[a] = 99% confidence.
[b] = 95% confidence.

composite test samples. This analysis was performed with a level of significance of 1%, i.e., for a level of confidence of 99%[24,25]. The last column of the Table shows the contribution % (P) of each variable in the total variation indicating the influence degree on the wear of contact pair.

If the "Test F" value is greater than the F (1%) column value, then the assigned variable is statistically significant. One can observe from the ANOVA Table 5 that the sliding distance ($p = 49.00\%$), applied load ($p = 34.37\%$) and sliding speed ($p = 5.41\%$) has great influence on the Two-body abrasive wear. However the interactions between sliding speed/sliding distance (2.61%) and applied load/sliding distance (2.55%) also as an influence on the abrasive wear and other interaction Load/sliding speed does not have a significant effect (both physical and statistical) on the abrasive wear so they are neglected. The error associated in the ANOVA table is about 6.06%.

The ANOVA for granite-filled G-E composites is as shown in Table 6. It can be observed that the applied load ($p = 60.70\%$) is the major factor followed by sliding distance ($p = 17.74\%$), sliding speed ($p = 6.163\%$) and the interactions between applied load/sliding distance (3.61%), sliding speed/sliding distance (1.99%), applied load/sliding speed (1.19%) exerts a significant influence on the two-body abrasive wear. The error associated in the ANOVA table is 8.61%.

The main effect plots for abrasive wear volume loss of G-E composites and 20% granite-filled G-E composites are represented as shown in Figure 2(a) and (b), respectively.

It is clear from these figures that increase of applied load, sliding speed, and sliding distance increases the wear volume loss. It is inferred from Figure 2(a) that sliding distance has the greatest effect on the optimal testing conditions, followed by applied load. The influence of sliding speed shows a slight effect and it contributes to a lesser extent compared to other parameters.

It is depicted from the Figure 2(b) that applied load has the greatest effect on the optimal testing condition followed. The sliding distance has significant influence on

TABLE 6
ANOVA for Granite (20%) filled GE composites

Sources of variance	SS	Dof	Variances	Test F	F	P %
L	1482.33	2	741.1	192.1640	5.27[a]	60.70
D	438.73	2	219.37	56.8817	5.27[a]	17.74
S	157.43	2	78.71	20.4019	5.27[a]	6.16
LXD	103.22	4	25.80	6.6898	3.91[a]	3.61
SXD	63.93	4	15.98	4.1435	3.91[a]	1.99
LXS	44.56	4	11.14	2.8885	2.64[b]	1.19
Error/Other	138.84	35	3.8566			8.61
Total	2429.04	53	1148.89			100

ss = sum of variance, Dof = Degree of freedom, P = Percentage of contribution.
[a] = 99% confidence.
[b] = 95% confidence.

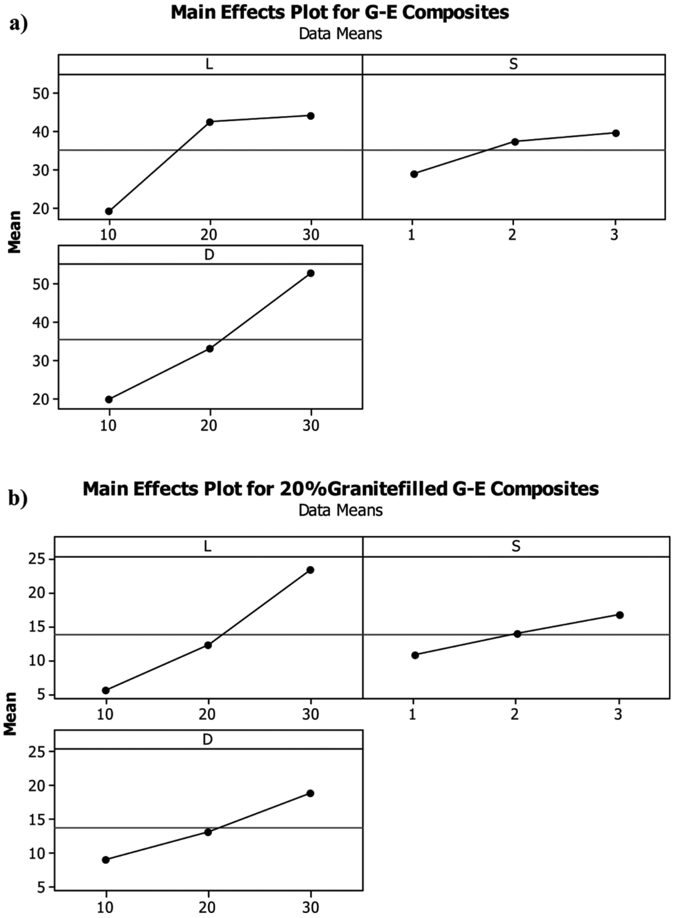

FIG. 2. Main effect plots for abrasive wear volume loss, a) G-E composites, b) 20% Granite filled G-E composites.

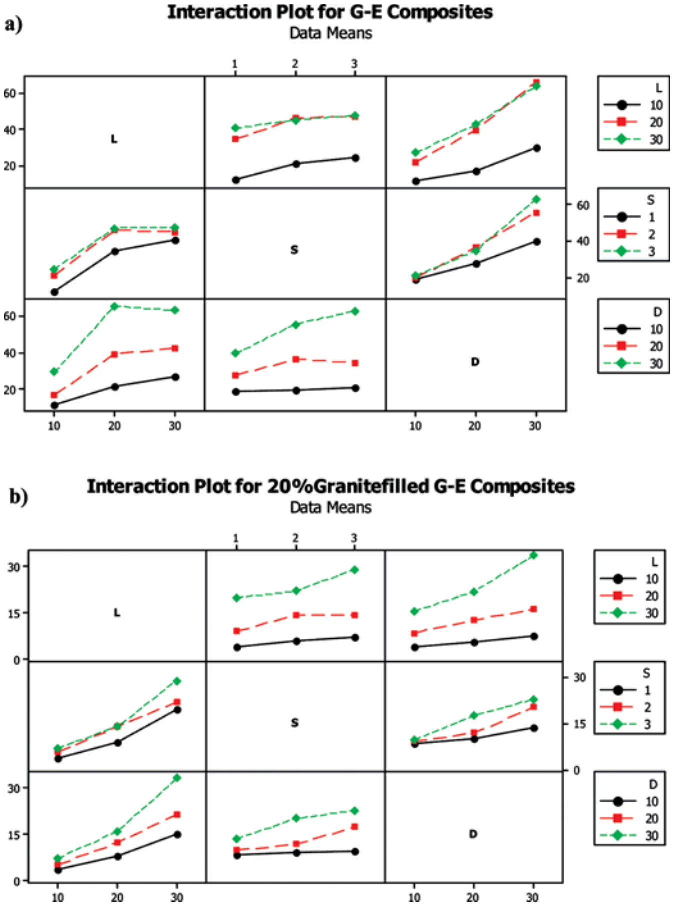

FIG. 3. Interaction plots for abrasive wear volume loss, a) G-E composites, b) 20% Granite filled G-E composites.

wear behavior is also found to be significant, whereas sliding speed has lesser effect.

Figures 3(a) and 3(b) refer to interaction plots for abrasive wear volume loss of G-E composites and 20% granite-filled G-E composites, respectively. It is noticed from Figure 3(a) that load/distance interaction has more effect on the abrasive wear volume loss followed by speed/distance. However the load/speed interaction has less significance. It is clear from the Figure 3(b) that load/distance interaction has more influence on optimal testing condition followed by load/speed. The speed/distance interaction is found less significant.

Discussion

It is inferred from Tables 4–6 and Figures 2 and 3 that the increases of applied load, sliding distance and sliding speed increases the wear volume loss for both filled and unfilled composite system subjected to Two-body abrasion. As the applied load increases, the wear volume loss also increases because, abrasive particles in the present investigation behave as a single body. This is due to the fact that they are embedded on an emery paper, which in turn is rigidly fixed on a metallic disc held against the specimens.

This results in transfer of total stress applied on the particles to the specimen surface. As a consequence, high-stress conditions are created in this mode of wear operation, wherein individual abrasive particles (embedded into the emery paper) penetrates into the specimen surface to a same depth irrespective of the nature of micro-constituents present in the material. However, the depth of penetration is a function of factors like stress level[23,26], rake angles of the abrasive tip and hardness of the specimen surface subjected to wear. The depth of penetration increases with increasing abrasive size, rake angles and applied stress levels, while decreases with increasing the hardness of the test materials[27,28].

Also the fractured small particles of SiC_p between the pin and the counterface form a third body. As the load increases further, more SiC_p particles in irregular fashion leads to the formation of new edges. These new edges plough the pin. As the sliding distance increases, more number of cycles is required to complete the test and the more number of asperities are come in contact with specimen surface. As the sliding speed increases the composite adhered to the emery paper which in turn cause the reduction in the increment of the wear volume loss.

It is clear from the tables and figures that 20% granite-filled glass-epoxy composites possess higher resistance to abrasive wear compared to unfilled ones. This is because the formation of air bubbles and voids are practically unavoidable in unfilled glass-epoxy composites. These voids reduce the strength and also initiate the cracks in the composite. The addition of granite filler in the composite not only reduces the voids but also increases the strength and wear resistance[23]. Wear occurs primarily at asperity tips either as abrasion or micro fracture. This generates subsurface intergranular cracking and leads to subsequent grain pullouts. This in turn results in increasing the wear volume loss of the composites.

Various researchers[23,29–33] have been predicted that the use of ceramic materials (granite, SiC_p, Al_2O_3) as fillers increases the abrasive wear resistance. There is appreciable reduction in the wear volume loss of the GE composites with the addition of the granite as secondary filler and lower value of the load accounts for reduces volume loss, since it has a highest contribution for the wear as mentioned in Table 5.

Regression Analysis

A linear regression technique was used to study the Two-body abrasive wear volume loss of the composites. The generalized linear regression equation for the experiment can be written as

$$Y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_1x_2 + a_5x_3x_1 + a_6x_2x_3 + +a_7x_1x_2x_3 \tag{1}$$

The factorial design of experiments and the values of the response variables corresponding to each set of trials are represented in equation 1 for the specimen, where Y is the wear volume loss. The variables x_1, x_2, x_2 are the L, S and D, respectively[34]. The a_1, a_2 and a_3 are the coefficients of the independent variables x_1, x_2 and x_3 respectively. The a_4, a_5, a_6, and a_7 are the interaction coefficients between x_1x_2, x_1x_3, x_2x_3 and $x_1x_2x_3$ respectively, with on the selected levels of each variables. After calculating each of the coefficients of equation 1, the final linear regression equation for the wear volume loss of GE and granite-filled G-E composites are obtained.

The regression equation for GE composites is

$$Y1 = 10.3 + 0.15\ L - 7.2\ S - 0.78\ D + 0.090\ LXS + 0.0677\ LXD + 0.751\ SXD - 0.0107\ LXSXD, R^2 = 87.7\% \tag{2}$$

The regression equation for granite-filled (20%) GE composites is

$$Y2 = -2.43 + 0.433\ L + 1.35\ S - 0.090\ D - 0.125\ LXS + 0.0086\ LXD - 0.067\ SXD + 0.0136\ LXSXD, R^2 = 94.2\% \tag{3}$$

In these equations, Y1 and Y2 are the two-body abrasive wear volume loss for G-E and granite-filled G-E composites, respectively.

The coefficient of determination (R^2) for G-E composites and 20% granite-filled G-E composites are 87.8% and 94.2%, respectively. From the individual linear regression results, it appears the wear behavior of granite-filled composites can be described more accurately than the unfilled one. The values of a_0 for unfilled and filled G-E Composites are 10.3 and –2.43 respectively. The value of a_0 is the intercept of the plane and is a mean response value for all experiments conducted[34]. The value of a_0 depends not only on the major parameters like applied load, sliding velocity, sliding distance which are considered in this study, but also with experimental irregularities like machine vibrations, environmental conditions, surface conditions and the surface finish of the composite pin.

Confirmation Test

Confirmation tests were conducted to validate the statistical analysis by conducting the two-body abrasive wear tests selecting experimental conditions that are different from those used for analysis.

Table 7 shows the experimental conditions selected for the confirmation tests. Table 8 shows the results obtained from the tests, and a comparison is made between the computed values from the regression model developed in the present work (Eqs. (2), (3)) and the values obtained experimentally.

From analyzing the data in the tables, the error associated with the relationship between the experimental values and the calculated values from the regression model for G-E composites is between 8.63 and 11.45%, while for 20% granite-filled G-E composites, it is between 9.07 and 11.98%. Hence, the model demonstrates a feasible and effective way to evaluate two-body abrasive wear behavior of these composites.

TABLE 7
Parameters used in the confirmation test

Test	Applied load in N	Sliding velocity in ms^{-1}	Sliding distance in m
1	15	1.5	15
2	25	2.5	25

TABLE 8
Confirmation test results and their comparison with regression model

	G-E composite			20% Granite filled G-E composites		
Test	Experimental	Model (Eq 2)	Error, %	Experimental	Model (Eq 3)	Error, %
1	18.8156	20.5937	8.6341	6.1125	6.9450	11.9870
2	60.9735	54.7062	11.4562	26.3360	24.1450	9.0743

CONCLUSIONS

Based on the experimental analysis presented, the following conclusions are drawn from the two-body abrasive wear behavior of G-E and 20% granite-filled G-E composites.

- Applied load and Sliding distance were the wear factors that have the highest physical as well as statistical influence on the abrasive wear of both filled and unfilled G-E composites. However, relative contribution of sliding distance in wear of unfilled composites is significantly higher than that of the applied load.
- The incorporation of the Granite in the G-E composites as a secondary reinforcement increases the abrasive wear resistance of the material. This is because the Granite particles opposes the penetration of the abrasive particle and also provide resistance against abrasive particles.
- The error associated to the ANOVA Table (maximum 8.61% and minimum of 6.06%) for the factors and the coefficients of regression obtained with the multiple regression (maximum 0.942% and minimum 0.878%) shows that the satisfactory correlation was obtained.
- The confirmation tests showed that the error associated to G-E composite (maximum value 11.4562% and minimum 8.6341%) and granite-filled G-E composites (maximum value 11.9870% and minimum 9.0743%), which are excellent.

REFERENCES

1. Kishore, P.; Sampathkumaran, S.; Seetharamu, A.; Murali Kumar, R.K. Dry sliding wear behavior of glass–epoxy composite. J. Reinf. Plast. Compos. **1999**, *18*, 55–62.
2. Ramakrishna, H.V.; Padma Priya, S.; Rai, S.K. Tensile and flexural properties of unsaturated polyester/granite powder and unsaturated polyester/fly ash composites. J. Reinf. Plast. Comp. **2005**, *24*, 1279–1287.
3. Kishore, B.P.; Kulkarni, S.M. Compression strength of saline water-exposed epoxy system containing fly ash particles. J. Reinf. Plast. Comp. **2005**, *24*, 1567–1576.
4. Ramakrishna, H.V.; Padma Priya, S.; Rai, S.K.; Varadarajulu, A. Studies on tensile and flexural properties of epoxy toughened with PMMA/granite powder and epoxy toughened with PMMA/fly ash composites. J. Reinf. Plast. Comp. **2005**, *24*, 1269–1277.
5. Kishore, S.S. Impact studies in elastomer, fly ash, and hybrid filled epoxy composites: Comparison of data and fracture features of the samples cured via a single room temperature and multiple high temperatures. J. Reinf. Plast. Comp. **2005**, *24*, 1013–1024.
6. Standard Terminology Relating to Wear and Erosion. Annual book of standards. 03.02, ASTM, 1987, pp. 243–250.
7. Bijwe, J., Tewari, U.S.; Vasudevan, P. Friction and wear studies of short glass fibre reinforced polyetherimide composites. Wear **1989**, 132, 247–264.
8. Bolvari, A.E.; Gleen, S.B. Abrasive wear of polymer composites. Eng. Plast. **1996**, *9*, 205–215.
9. Trizona, R.I.; Hutchings, I.M. Three-body abrasive wear testing of soft materials. Wear **1999**, *233–235*, 209–221.
10. Liu, C.; Ren, L.; Arnell, R.D.; Tong, J. Abrasive wear behavior of particle reinforced ultrahigh molecular weight polyethylene composites. Wear **1999**, *225–229*, 199–204.
11. Rajesh, J.J.; Bijwe, J.; Tewari, U.S. Abrasive wear performance of various polyamides. Wear **2002**, *252*, 769–776.
12. Harsha, A.P.; Tewari, U.S. Two-body and three-body abrasive wear behavior of polyaryletherketone composites. Polym. Test. **2003**, *22*, 403–418.
13. Shipway, P.H.; Ngao, N.K. Microscale abrasive wear of polymeric materials. Wear **2003**, *255*, 742–750.
14. Bijwe, J.; Indumathi, J.; Ghosh, A.K. On the abrasive wear behavior of fabric-reinforced polyetherimide composites. Wear **2002**, *253*, 768–777.
15. Suresha, B.; Shiva Kumar, K.N. Investigations on mechanical and two-body abrasive wear behavior of glass/carbon fabric reinforced vinylester composites. Mater. Des. **2009**, *30*, 2056–2060.
16. Paulo Davim, J. An experimental study of the tribological behavior of the brass/steel pair. J. Mater. Process. Technol. **2000**, *100*, 273–277.
17. Esteban Fernandez, J.; Ma del Rocio Fernandez, M.; Vijande Diaz, R.; Tucho Navarro, R. Abrasive wear analysis using factorial experiment design. Wear **2003**, *255*, 38–43.
18. Basavarajappa, S.; Chandramohan, G. Wear studies on metal matrix composites: A Taguchi approach. J. Mater. Sci. Technol. **2005**, *21*, 845–850.
19. Deuis, R.L.; Subramanian, C.; Yellup, J.M. Three-body abrasive wear of composite coatings in dry and wet environments. Wear **1998**, *214*, 112–130.
20. Mondal, D.P.; Das, S.; Jha, A.K.; Yegneswaran, A.H. Abrasive wear of Al alloy–Al_2O_3 particle composite: A study on the combined effect of load and size of abrasive. Wear **1998**, *223*, 131–138.
21. Paulo Davim, J. Effect of carbon fibre reinforcement in the frictional behavior of Peek in a water lubricated environment. J. Mater. Process. Technol. **2001**, *251*, 1100–1104.
22. Singh, M.; Jha, A.K.; Das, S.; Yegneswaran, A.H. Preparation and properties of cast aluminium alloy-granite particle composites. J. Mater. Sci. **2000**, *35*, 4421–4426.
23. Singh, M.; Prasad, B.K.; Mondal, D.P.; Jha, A.K. Dry sliding wear behavior of an aluminium alloy–granite particle composite. Tribol. Inter. **2001**, *34*, 557–567.
24. Ross, J. *Taguchi Technique for Quality Engineering*, McGraw-Hill: New York, 1993.

25. Roy, K.R. *A Primer on Taguchi Method*, Van Nostrand Reinhold: New York, 1990.
26. Prasad, B.K.; Das, S.; Jha, A.K.; Modi, O.P.; Dasgupta, R.; Yegneswaran, A.H. Factors controlling the abrasive wear response of a zinc-based alloys silicon carbide particle composite. Compos. Pt. A. **1997**, *28*, 301–308.
27. Prasad, B.K. Abrasive wear characteristics of a zinc based alloy and zinc alloy SiC composite. Wear **2002**, *252*, 250–263.
28. Cenna, A.A.; Doyle, J.; Page, N.W.; Beehag, A.; Dastoor, P. Wear mechanisms in polymer matrix composites abraded by bulk solids. Wear **2000**, *240*, 207–214.
29. Kassim, S.; Al-Rubaie, H.N.Y.; Biasoli de Mello, J.D. Two-body abrasive wear of Al–SiC composites. Wear **1999**, *233–235*, 444–454.
30. Wang, A.; Rack, H.J. Abrasive wear of silicon carbide particulate and whisker-reinforced 7091 aluminium matrix composites. Wear **1991**, *146*, 337–348.
31. Lee, H.L.; Lu, W.H.; Chan, S. Abrasive wear of powder metallurgy Al alloy 6061-SiC particle composites. Wear **1992**, *159*, 223–231.
32. Garcıa-Cordovilla, C.; Narciso, J.; Louis, E. Abrasive wear resistance of aluminium alloy ceramic particulate composites. Wear **1996**, *192*, 170–177.
33. Chand, N.; Naik, A.; Neogi, S. Three-body abrasive wear of short glass fibre polyester composite. Wear **2000**, *242*, 38–46.
34. Montgomery, D.C. *Design and Analysis of Experiments*, 4th edition, Wiley: Singapore, 2001.