Dry sliding wear behavior of epoxy composite reinforced with short palmyra fibers

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Abstract. The present work explores the possibility of using palmyra fiber as a replacement for synthetic fiber in conventional polymer composites for application against wear. An attempt has been made in this work to improve the sliding wear resistance of neat epoxy by reinforcing it with short palmyra fibers (SPF). Epoxy composites with different proportions (0, 4, 8 and 12 wt. %) of SPF are fabricated by conventional hand lay-up technique. Dry sliding wear tests are performed on the composite samples using a pin-on-disc test rig as per ASTM G 99-05 standards under various operating parameters. Design of experiment approach based on Taguchi’s L\textsubscript{16} Orthogonal Arrays is used for the analysis of the wear. This parametric analysis reveals that the SPF content is the most significant factor affecting the wear process followed by the sliding velocity. The sliding wear behavior of these composites under an extensive range of test conditions is predicted by a model based on the artificial neural network (ANN). A well trained ANN has been used to predict the sliding wear response of epoxy based composites over a wide range.

1. Introduction
The use of various natural fibers as substitutes for synthetic functional fibers is increasing day-by-day owing to their several advantages like bio-degradability, renewability, low-cost and low-toxicity. These composites find several applications starting from household appliances to wear resistant components. A number of studies on friction and wear characteristics of natural fiber composites have been reported in recent past. Chand et. al. [1] studied the influence of fiber orientation on the wear characteristics of sisal fiber reinforced composites with epoxy as the matrix material. It was found that the wear rate decreased considerably by addition of sisal fiber to the epoxy composites. Yousif et. al. [2] studied and compared the mechanical and tribological properties of oil palm fiber reinforced polyester composites (OPRP) and chopped strand mat glass fiber reinforced composites (CGRP). Similarly, Tong et. al. [3] studied the sliding wear behavior of bamboo fiber against grey iron (HT200). Chin et. al. [4] studied the potential of kenaf fiber as reinforcement for application against wear. Tayeb [5] studied sugarcane fiber reinforced polyester composites for tribological characterizations. Nirmal et. al. [6] studied the effect of betelnut fiber on the adhesive wear of polyester composites. A superior wear performance was observed in anti-parallel oriented betelnut fiber followed by parallel orientation and normal orientation of the fiber. Siva et. al. [7] studied the mechanical and tribological characteristics of woven coconut fibers and found the wear resistance to be maximum when a combination of silane treated glass fiber and coconut fiber was used. Chand et. al. [8] studied the effect of silane coupling agent and applied load on the frictional and sliding wear
behavior of sisal fiber reinforced polyester composites. Most of the published works on palmyra fibers have reported on the strength properties of the composites and not on the effects of fibers on friction and wear behavior. Moreover, although a lot of work has been done on the wear characteristics of composites with other natural fibers, no work has been reported so far on epoxy based composites reinforced with short palmyra fiber. In view of this, the present work includes the investigation of dry sliding wear behavior using a pin-on-disc set up for epoxy filled with short palmyra fibers with an objective to find ways to use these locally available inexpensive fibers as a substitute for highly expensive synthetic fibers for wear resistance applications. Taguchi technique and Artificial Neural Network (ANN) have been used in an integrated manner in this work for parametric analysis of the wear process and to predict the sliding wear response of epoxy-palmyra fiber composites within and beyond the experimental limits.

2. Experimental details

2.1. Sliding Wear Test

In the present work Epoxy LY556 which belongs to the epoxide family has been used as the matrix material. Epoxy LY556 is a low-temperature curing resin and it is mixed with hardener HY951 in the ratio of 10:1. The short palmyra fiber (SPF) used in the present work is extracted from the palmyra tree leaf stalk and this fiber is thoroughly mixed with the epoxy resin (LY556) in four different weight proportions (0, 4, 8 and 12 wt%) to prepare composite samples. The samples are subjected to sliding wear test using a pin-on-disc type friction and wear monitoring test rig as per ASTM G 99-05. The counter body is a disc made of hardened ground steel (EN-32, hardness 72 HRC, surface roughness 0.6 μm Ra). The specimen is held stationary while the disc rotates. Normal load is applied through a lever mechanism. A series of tests are conducted with four sliding velocities of 63, 125,190 and 250 cm.s⁻¹ each under four different normal loads of 5, 10, 15 and 20 N. The material loss from the composite surface is measured using a precision electronic balance with accuracy ±0.1 mg and the specific wear rate (mm³/N-m) is expressed on a volume loss basis as:

\[
W_s = \frac{\Delta m}{\rho \times t \times V_s \times F_n}
\]

where \(\Delta m\) is the mass loss of the composite in the test duration (g), \(\rho\) is the density of the composite (g/mm³), \(t\) is the test duration (s), \(V_s\) is the sliding velocity (cm.s⁻¹), and \(F_n\) is the average normal load (N).

2.2. Taguchi Experimental Design

Taguchi experimental design is a very powerful tool to make parametric appraisal of any multi variable engineering process. In the present study for sliding wear test of epoxy-SPF composites, four major factors have been considered such as sliding velocity, applied load, sliding distance and fiber content each at four levels according to Taguchi’s L₁₆ orthogonal array as shown in Table 1. Use of Taguchi L₁₆ reduced the number of experiments from \(4^4 = 256\) conventional runs to just 16 runs thereby saving a lot of experimental time and cost. These experimental observations are again converted into signal-to-noise (S/N) ratios. The S/N ratio for minimum wear rate can be expressed as “smaller is better” which is calculated as logarithmic transformation of loss function as shown below:

\[
\frac{S}{N} = -10 \log \left( \frac{1}{n} \sum y^2 \right)
\]

where \(n\) is the number of observations and \(y\) is the observed data.
Table 1. Control Factors and their Selected Levels for Dry Sliding Wear

| Control factors         | Levels | 1  | 2  | 3  | 4  | Units |
|-------------------------|--------|----|----|----|----|-------|
| Sliding velocity (A)    |        | 63 | 125| 190| 250| Cm/sec|
| Normal load (B)         |        | 5  | 10 | 15 | 20 | N     |
| Sliding distance (C)    |        | 250| 500| 750| 1000|m      |
| Fiber content (D)       |        | 0  | 4  | 8  | 12 | Wt %  |

Table 2. Specific Wear Rates Obtained for Different Test Conditions with S/N Ratios

| Test Run | Sliding Velocity (A) (cm/sec) | Normal Load (B) (N) | Sliding Distance (C) (m) | SPF Content (D) (wt %) | Sp. Wear Rate $(10^{-4} \text{mm}^3/N\cdot m)$ | S/N Ratio (dB) |
|----------|--------------------------------|---------------------|--------------------------|------------------------|-----------------------------------------------|----------------|
| 1        | 63                             | 5                   | 250                      | 0                      | 6.3600                                        | -16.0691       |
| 2        | 63                             | 10                  | 500                      | 4                      | 5.4690                                        | -14.7582       |
| 3        | 63                             | 15                  | 750                      | 8                      | 3.6250                                        | -11.1862       |
| 4        | 63                             | 20                  | 1000                     | 12                     | 0.9165                                        | 0.7574         |
| 5        | 125                            | 5                   | 500                      | 8                      | 3.8560                                        | -11.7227       |
| 6        | 125                            | 10                  | 250                      | 12                     | 2.3320                                        | -7.3546        |
| 7        | 125                            | 15                  | 1000                     | 0                      | 7.8180                                        | -17.8619       |
| 8        | 125                            | 20                  | 750                      | 4                      | 5.8230                                        | -15.3029       |
| 9        | 190                            | 5                   | 750                      | 12                     | 1.4440                                        | -3.1913        |
| 10       | 190                            | 10                  | 1000                     | 8                      | 2.8280                                        | -9.0296        |
| 11       | 190                            | 15                  | 250                      | 4                      | 6.4300                                        | -16.1642       |
| 12       | 190                            | 20                  | 500                      | 0                      | 8.8180                                        | -18.9074       |
| 13       | 250                            | 5                   | 1000                     | 4                      | 7.4690                                        | -17.4652       |
| 14       | 250                            | 10                  | 750                      | 0                      | 9.4840                                        | -19.5398       |
| 15       | 250                            | 15                  | 500                      | 12                     | 2.6660                                        | -8.5172        |
| 16       | 250                            | 20                  | 250                      | 8                      | 3.6560                                        | -11.2601       |

2.3. Prediction Using Artificial Neural Network

ANN is widely used in the field of classification and control of dynamic system, medical science, image and speech recognition, etc [9]. In the present study ANN serves as a very helpful tool for predicting the specific wear rate as it is very difficult to get a mathematical formulation for the wear behavior. This proposed approach not only yields a sufficient understanding of the effects of process parameters but also produces an optimal parameter setting to ensure that the composites exhibit the best wear performance characteristics. The details of this methodology are described by Kadi [10].
1. Results and discussion

1.1. Sliding Wear Test Results
The specific wear rates and their corresponding S/N ratios obtained by Taguchi L_{16} orthogonal array for all the 16 experiments are presented in Table 2. From the Table 2 it is found that the overall mean of the S/N ratio is -12.4429 dB for epoxy based composites reinforced with short palmyra fibers. A commercial software Minitab 14 was used for the application of design of experiment. From the S/N ratio output, it is observed that among all the four factors considered for the analysis, the specific wear rate is mostly affected by the SPF content in the epoxy composite followed by the sliding velocity, sliding distance and normal load. The analysis showed that at sliding velocity (A) of 63 cm/s, normal load (B) of 20 N, sliding distance (C) of 1000 m and SPF content (D) of 12 wt%, the specific wear rate is minimum as evident from the response table for S/N ratios (Table 3).

1.2. Artificial Neural Network for Prediction
ANN is a very useful tool to predict the input and output pattern of nonlinear problems such as sliding wear. In the present analysis sliding velocity, normal load, sliding distance and SPF content are taken as the four input parameters. The input variables are normalized so that it lies in the range 0-1. The output layer has one neuron which represents the specific wear rate. Different structures of ANN were tested by varying the number of neurons in the hidden layer, gradient value and friction coefficient value (\(\mu\) value). Finally one structure with minimum error was selected for training. The selected structure was trained rigorously by selecting maximum number of cycles. The predicted values are compared with the experimental values and the results are shown in Table 4 with the associated error percentages.

The Figure 1-2 below shows the effect of two most dominant factors i.e. SPF content and sliding velocity on the specific wear rate of the specimens and a simulated specific wear rate has been predicted using ANN.

| Level | A     | B     | C     | D     |
|-------|-------|-------|-------|-------|
| 1     | -10.314 | -12.112 | -12.712 | -18.095 |
| 2     | -13.061 | -12.671 | -13.476 | -15.924 |
| 3     | -11.823 | -13.432 | -12.305 | -10.800 |
| 4     | -14.196 | -11.178 | -10.900 | -4.576  |
| Delta | 3.882  | 2.254  | 2.577  | 13.518  |
| Rank  | 2      | 4      | 3      | 1      |
Table 4. Comparison of Experimental Results with ANN Predicted Values

| Test Run | Experimental | ANN Predicted | Error % |
|----------|--------------|---------------|---------|
| 1        | 6.360        | 6.359136      | 0.013   |
| 2        | 5.469        | 5.468302      | 0.012   |
| 3        | 3.625        | 3.601238      | 0.655   |
| 4        | 0.917        | 0.979166      | 6.837   |
| 5        | 3.856        | 4.343180      | 12.634  |
| 6        | 2.332        | 2.328292      | 0.159   |
| 7        | 7.818        | 7.773308      | 0.571   |
| 8        | 5.823        | 5.818631      | 0.075   |
| 9        | 1.444        | 1.443930      | 0.004   |
| 10       | 2.828        | 2.805736      | 0.787   |
| 11       | 6.430        | 6.425846      | 0.064   |
| 12       | 8.818        | 8.119834      | 7.917   |
| 13       | 7.469        | 7.382000      | 1.520   |
| 14       | 9.484        | 9.433750      | 0.529   |
| 15       | 2.666        | 2.654097      | 0.446   |
| 16       | 3.656        | 3.660072      | 0.111   |

Figure 1. ANN prediction of variation in specific wear rate with SPF content for SPF-epoxy composite
Figure 2. ANN prediction of variation in specific wear rate with sliding velocity for SPF-Epoxy composites.

2. Conclusions
The present experimental effort shows that successful fabrication of short palmyra fiber reinforced epoxy composites is possible and such composites can be employed in dry sliding wear situations. It is seen that by increasing the fiber loading, the wear resistance of neat epoxy can be significantly improved. A parametric appraisal of the wear process revealed that the fiber content and the sliding velocity are the most significant factors that affect the wear performance of the composites in an interacting environment. This work also illustrates the gainful use of artificial neural networks for predicting the specific wear rate of the composites with increase in fiber content and sliding velocity beyond the experimental domain.

3. References
[1] Chand N and Dwivedi UK  2007 Polymer Composites 28 437-441.
[2] Yousif B F and Tayeb N S M  2009 International Journal of Precision Technology 1 213-222.
[3] Tong J, Arnell R D and Ren L Q  1998 Wear 221 37–46.
[4] Chin C W and Yousif B F  2009 Wear 267 1550–1557.
[5] Tayeb N S M 2008 Wear 265 223–235.
[6] Nirmal U, Yousif B F, Rilling D and Brevern P V  2010 Wear 268 1354–1370.
[7] Siva I, Jappes J T W and Suresha B 2012 Polymer Composites 33 723-732.
[8] Chand N and Dwivedi U K  2008 *Polymer Composites* **29** 280-284.

[9] Padhi P K and Satapathy A 2013 *Tribology Transactions* **56** 789-796.

[10] Kadi H E 2006 *Composite Structures* **73** 1–23.