WEAR PERFORMANCE EVALUATION OF PINE WOOD DUST FILLED EPOXY COMPOSITES

Ganguluri Kranthi, Rajlakshmi Nayak, S. Biswas and **Alok Satapathy**

National Institute of Technology, Rourkela - 769008, India

ABSTRACT

This paper reports the development and wear performance evaluation of a new class of epoxy based composites filled with pine wood dust. The dust particles of average size 100 μm are reinforced in epoxy resin to prepare particulate filled composites of three different compositions (with 0, 5 and 10 wt% of pine wood dust). Dry sliding wear trials are conducted following a well planned experimental schedule based on design of experiments (DOE) using a standard pin-on-disc test set-up. Significant control factors predominantly influencing the wear rate are identified. Effect of pine wood dust content on the wear rate of polyester composites under different test conditions is studied. An Artificial Neural Networks (ANN) approach taking into account training and test procedure to predict the dependence of wear behavior on various control factors is implemented. This technique helps in saving time and resources for large number of experimental trials and predicts the wear response of pine wood dust filled epoxy composites within and beyond the experimental domain

Keywords: Pine wood dust, Epoxy, Polymer composites, Sliding wear; Artificial Neural Networks;

INTRODUCTION

In the past few decades, research and engineering interest has been shifting from monolithic materials to fiber-reinforced polymeric materials. These composite materials (notably aramid, carbon and glass fiber reinforced plastics) now dominate the aerospace, leisure, automotive, construction and sporting industries. Glass fibers are the most widely used to reinforce plastics due to their low cost (compared to aramid and carbon) and fairly good mechanical properties. However, these fibers have serious drawbacks such as non-renewability, non-recyclability, non-bio-degradability etc. These shortcomings have been highly exploited by proponents of natural fiber composites. Though mechanical properties of natural fibers are much inferior to those of glass fibers, their specific properties, especially stiffness, are comparable to the stated values of glass fibers. Besides hard particulate fillers consisting of ceramic or metal particles and fiber fillers made of glass are being used in natural fiber composites these days to dramatically improve the mechanical properties such as wear resistance, even up to three orders of magnitude [1]. Various kinds of polymers and polymer matrix composites reinforced with metal particles have a wide range of industrial applications such as heaters, electrodes [2], composites with thermal durability at high temperature [3] etc. These engineering composites are desired due to their low density, high corrosion resistance, ease of fabrication and low cost [4-6]. Similarly, ceramic filled polymer composites have been the subject of extensive research in last two decades. The inclusion of inorganic fillers into polymers for commercial applications is primarily aimed at the cost reduction and stiffness improvement [7,8]. Along with fiber-reinforced composites, the composites made with particulate fillers have been found to perform well in many real operational conditions. When silica particles are added into a polymer matrix to form a composite, they play an important role in improving electrical, mechanical and thermal properties of the composites [9,10]. Currently, particle size is being reduced rapidly and many studies have focused on how single-particle size affects mechanical properties [11-17]. The shape, size, volume fraction, and specific surface area of such added particles have been found to affect mechanical properties of the composites greatly. In this regard, Yamamoto et al. [18] reported that the structure and shape of silica particle have significant effects on the mechanical properties such as fatigue resistance, tensile and fracture properties. Nakamura et al. [19-21] discussed the effects of size and shape of silica particle on the strength and fracture toughness based on particle-matrix adhesion and also found an increase of the flexural and tensile strength as specific surface area of particles increased. Despite the interest and environmental appeal of natural fibers, their use has been limited to non-tribological applications due to their lower strength and stiffness compared with synthetic fiber reinforced polymer composite.Very little information concerning the tribological performance of natural fiber reinforced composite material has been reported.

EXPERIMENTAL DETAILS

Matrix and Filler Materials

Epoxy LY 556 resin, chemically belonging to the ‘epoxide’ family is used as the matrix material. Its common name is Bisphenol A Diglycidyl Ether. The low temperature curing epoxy resin (Araldite LY 556) and corresponding hardener (HY951) are mixed in a ratio of 10:1 by weight as recommended. Epoxy is chosen primarily because it happens to be the most commonly used polymer and because of its insulating nature (low value of thermal conductivity, about 0.363 W/m-K). Pine wood dust (PWD) is generated during the cutting of chir pine tree wood. The scientific name of Chir Pine is *Pinus roxburghii.* Main organic constituents of pine wood are: cellulose, glucomannan, xylan, lignin and some extractives. Its dust particles are chosen as the filler material in this work mostly for its very low thermal conductivity (0.068 W/m-K) and low density (0.52 gm/cc).

Composite Fabrication

The low temperature curing epoxy resin (LY 556) and corresponding hardener (HY951) are mixed in a ratio of 10:1 by weight as recommended. Pine wood dust (PWD) particles (collected from HP) with average size 100 μm are reinforced in epoxy resin (density 1.1 gm/cc) to prepare the composites. The dough (epoxy filled with PWD) is then slowly decanted into the glass tubes, coated beforehand with wax and uniform thin film of silicone-releasing agent. The composites are cast by conventional hand-lay-up technique in glass tubes so as to get cylindrical specimens (dia 9 mm, length 120 mm). Composites of four different compositions, as listed in Table 1 are made.

Sliding Wear Test

To evaluate the performance of these composites under dry sliding condition, wear tests are carried out in a pin-on-disc type friction and wear monitoring test rig (supplied by DUCOM) as per ASTM G 99. The counter body is a disc made of hardened ground steel (EN-32, hardness 72 HRC, surface roughness 0.6 m Ra). The specimen is held stationary and the disc is rotated while a normal force is applied through a lever mechanism. A series of tests are conducted with three sliding velocities of 42, 84 and 126 cm/s under three different normal loadings of 5, 10 and 15 N. The material loss from the composite surface is measured using a precision electronic balance with accuracy ±0.1mg and the specific wear rate (mm^3/ N-m) is then expressed on 'volume loss' basis as:

$$Ws = \Delta m / (\rho \; t \; Vs \; Fn) \qquad \ldots\ldots\ldots\ldots (1)$$

Where Δm is the mass loss in the test duration (g), ρ is the density of the composite (g/mm^3), t is the test duration (s), Vs is the sliding velocity (m/s), and Fn is the average normal load (N). The specific wear rate is defined as the volume loss of the specimen per unit sliding distance per unit applied normal load.

Experimental Design

Design of experiment is a powerful analysis tool for modeling and analyzing the influence of control factors on performance output. The most important stage in the design of experiment lies in the selection of the control factors. Therefore, a number of factors are included so that non-significant variables can be identified at the earliest opportunity. The wear tests on the composites are carried out under different operating conditions considering four parameters, viz., sliding velocity, normal load, filler content and sliding distance each at three levels as listed in Table 1 in accordance with L_9 (3^{13}) orthogonal array as per design-of-experiments. The impact of these four parameters are studied using L_9 (3^4) orthogonal design. The tests are conducted as per experimental design given in Table 2 at room temperature. In conventional full factorial experiment design, it would require $3^4 = 81$ runs to study four parameters each at three levels whereas, Taguchi's factorial experiment approach reduces it to only 9 runs offering a great advantage in terms of experimental time and cost. The experimental observations are further transformed into signal-to-noise (S/N) ratios. The S/N ratio for minimum erosion rate can be expressed as "lower is better" characteristic, which is calculated as logarithmic transformation of loss function as shown below.

Smaller is the better characteristic: $\frac{S}{N} = -10 \log \frac{1}{n}\left(\sum y^2\right)$ (2)

where 'n' the number of observations, and y the observed data. The plan of the experiments is as follows: the first column is assigned to sliding velocity (A), the second column to normal load (B), third column to filler content (C) and the fourth column to sliding distance (D).

Table 1 Levels of the variables used in the experiment

Control factor	Level			
	1	2	3	Units
A: Sliding velocity	42	84	126	cm/sec
B: Normal load	5	10	15	N
C: Filler content	0	5	10	wt%
D: Sliding distance	252	504	756	m

RESULTS AND DISCUSSION

The specific wear rates obtained for all the 9 test runs along with the corresponding S/N ratio are presented in Table 2. From this table, the overall mean for the S/N ratio of the wear rate is found to be 54.984 dB. This is done using the software MINITAB 14 specifically used for design of experiment applications.

Table 2 Experimental design (L_9 orthogonal array) with output and S/N ratio

Test run	Sliding velocity (cm/s)	Normal load (N)	Filler content (wt%)	Sliding distance (m)	Specific wear rate (mm^3/N-m)	S/N Ratio
1	42	5	0	252	0.00216	53.3109
2	42	10	5	504	0.00172	55.2894
3	42	15	10	756	0.00025	72.0412
4	84	5	5	756	0.00202	53.8930
5	84	10	10	252	0.00178	54.9916
6	84	15	0	504	0.00309	50.2008
7	126	5	10	504	0.00197	54.1107
8	126	10	0	756	0.00352	49.0691
9	126	15	5	252	0.00207	53.6806

Table 3 Signal to noise ratio response table for erosion rate

Level	A	B	C	D
1	60.21	53.77	50.86	53.99
2	53.03	53.12	54.29	53.20
3	52.29	58.64	60.38	58.33
Delta	7.93	5.52	9.52	5.13
Rank	**2**	**3**	**1**	**4**

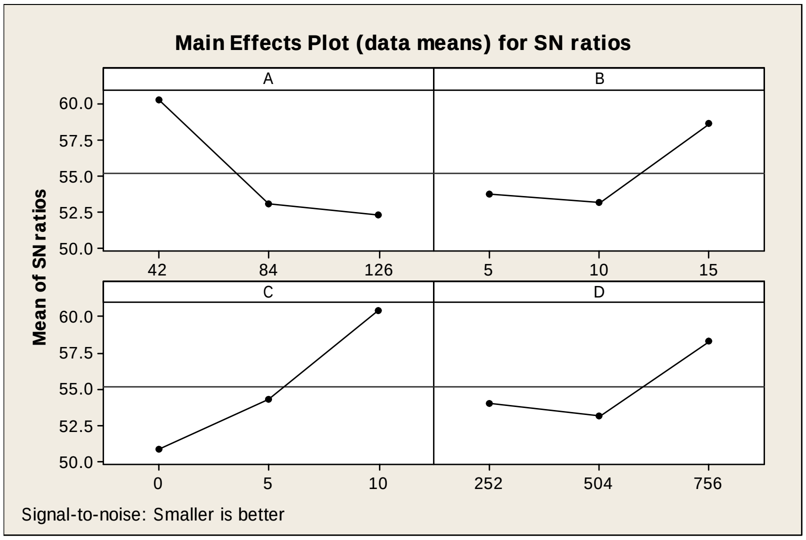

Figure 1 Effect of control factors on sliding wear rate

The S/N ratio response analysis, presented in Table 3 shows that among all the factors, filler content is the most significant factor followed by sliding velocity and normal load while the sliding distance has the least or almost no significance on wear rate of the particulate filled composites under this investigation.

The effects of individual control factor are shown graphically in Figure 1. The analysis of the results leads to the conclusion that factor combination of A_1, B_3, C_3 gives the minimum specific wear rate.

CONCLUSIONS

Successful fabrication of pine wood dust reinforced epoxy composites is possible by simple hand-lay-up techniques. Dry sliding wear characteristics of these composites can be experimented following a design-of-experiment approach. This study reveals that pine wood dust possesses good filler characteristics as it improves the sliding wear resistance of the polymeric resin. It further shows that factors like filler content, sliding velocity and normal load, in this sequence, are identified as the significant factors affecting the specific wear rate.

1. J. Bitter, *A study of erosion phenomena*, part 1, Wear 6 (1963) **5–21**.

REFERENCES

1. Gregory, S.W, Freudenberg, K.D, Bhimaraj, P. and Schadler, L. S, *A study on the friction and wear behavior of PTFE filled with alumina nanoparticles* .Wear, 254 (2003): **573–580**.
2. Jung-il, K., Kang, P.H. and Nho, Y.C., *Positive temperature coefficient behavior of polymer composites having a high melting temperature,* J Appl Poly Sci., 92 (2004):**394–401**.
3. Nikkeshi, S, Kudo, M and Masuko, T, *Dynamic viscoelastic properties and thermal properties of powder-epoxy resin composites,* J Appl Poly Sci., **69** (1998) **2593-8**.
4. Zhu, K and Schmauder, S, (2003). Prediction of the failure properties of short fiber reinforced composites with metal and polymer matrix, *Comput Mater Sci.*, **28**:743–8.
5. Rusu, M, Sofian, N and Rusu, D, (2001). Mechanical and thermal properties of zinc powder filled high density polyethylene composites, . **20**: 409–17.
6. Tavman, I. H, (1997). Thermal and mechanical properties of copper powder filled poly (ethylene) composites, *Powder Technol*, **91**: 63–7.
7. Rothon, R.N., (1997). Mineral fillers in thermoplastics: filler manufacture, *J Adhesion*, **64**:87–109.
8. Rothon, R.N., (1999). Mineral fillers in thermoplastics: filler manufacture and characterization. *Adv. Polym. Sci.*,**139**: 67–107.
9. Nielsen, L.E. and Landel, R.F., (1994). Mechanical properties of polymers and composites. *2nd ed. New York:* Marcel Deckker,377–459.
10. Peters S.T, (1998). *Handbook of composites.* 2nd ed. London: Chapman and Hall,242–243.
11. Young, R.J. and Beaumont, P.W.R., (1977). Failure of brittle polymers by slow crack growth Part 3 Effect of composition upon the fracture of silica particle-filled epoxy resin composites. *J Mater Sci*., **12(4)**: 684–92.
12. Kinoch, A.J., Maxwell, D.L. and Young, R.J., (1985).The fracture of hybrid particulate composites. *J Mater Sci*., **20**:4169–84.
13. Young, R., Maxwell, D.L. and Kinloch, A.J., (1986). The deformation of hybrid particulate composites. *J Mater Sci*., **21**:380–388.
14. Koh, S.W., Kim, J.K. and Mai, Y.W., (1993). Fracture toughness and failure mechanisms in silica-filled epoxy resin composites: effects of temperature and loading rate. *Polymer*, **34(16)**:3446–3455.
15. Cantwell, W.J. and Moloney, A.C., (1994). Fractography and failure mechanisms of polymers and composites. *Amsterdam*: Elesvier,233.
16. Imanaka, M., Takeuchi, Y., Nakamura, Y., Nishimura, A. and Lida, T., (2001).Fracture toughness of spherical silica-filled epoxy adhesives. *Int J Adhesin Adhes*., **21**:389–396.
17. Wang, H., Bai, Y., Lui, S., Wu, J. and Wong, C.P., (2002). Combined effects of silica filler and its interface in epoxy resin. *Acta Mater*., **50**:4369–4377.
18. Yamamoto, I., Higashihara, T. and Kobayashi, T., (2003). Effect of silica-particle characteristics on impact/usual fatigue properties and evaluation of mechanical characteristics of silica-particle epoxy resins. *JSME Int J*, **46(2)**:145–153.