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ORIGINAL CONTRIBUTION

Evaluation of Surface Response of Ficus Benghalensis Fiber—Epoxy Composites Under Dry Sliding Wear Conditions

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Abstract In the current investigation chopped Ficus benghalensis (commonly known as banyan), fiber reinforced polymer matrix composite (PMCs) was prepared by hand layup technique. This work includes the surface response of these PMCs to the dry sliding wear at room temperature. Chemically extracted fibers are reinforced into the epoxy matrix in different weight proportions (2, 4 and 6 wt %) with continuous stirring action. A pin-on-disk sliding wear tester is used to estimate the sliding wear response of the newly fabricated PMCs. Sliding wear assessments are prepared as per the experimental design based on Taguchi's L9 orthogonal array in order to spot predominantly dominant factors affecting the wear rate. This investigation shows that the fiber content is the most major factor followed by the sliding velocity, sliding distance and applied load on the sliding wear rate of examined PMCs. It was observed that the wear rate increases with an increase in impact velocity, whereas it reduces with an increase in fiber content.

Keywords Ficus benghalensis fiber · PMCs · Sliding wear · Taguchi's design

Introduction

As structural materials in automotive, aerospace and chemical industries, polymer composites are increasingly providing lower weight substitute to conventional metallic materials over the past decades owing to their superior properties (mechanical strength, stiffness, hardness, low density, etc.) [1–3]. The quality that composes polymer composites so capable in industry relevance is the prospect to tailor their properties with unique fillers in order to enhance their strength and therefore the load-carrying capacity [4–8]. Nowadays, the entire world is aware and concern about protecting the environment and thus leads them to focus more and more on natural fibers. Natural fibers are freely available in the environment and often used in many engineering purposes such as transportation which entail automobiles, aerospace, railway coaches and in some cases construction such as ceiling and partition board. Moreover, natural fiber possesses numerous advantages over synthetic fiber like methods of production, properties, availability, eco-friendly, etc. The advantages of natural fibers are lightweight, low density, low cost, easy availability, specific strength property, easy separation method, non-corrosive, high toughness, biodegradable, etc. The properties of natural fibers can differ depending on the source, age, sorting out techniques. Keeping these things in view, there is so much research and development carried out in the field of natural fiber such as jute, coir, bamboo, sisal and Amari [7–11]. From many progressive kinds of research, it is concluded that composites are not only good at their structural properties but also for electrical, thermal and tribological properties. The advantages of these materials suggest their use in the safeguarding and restore activities of parts and equipment in different tribological components, such as gears, cams, bearings and seals, where

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the self-lubrication of polymers and polymer composites is of exceptional benefit [12]. In the year 2012, Kumar et al. [13] proposed an article on the tensile behavior of ficus benghalensis fiber reinforced with polyester resin and concluded that these composites have high impact strength with moderate tensile and flexural properties. Padmanabhan and Umashankar [14] performed some experimental investigation on various mechanical properties of hybrid polymer composites reinforced with ficus benghalensis fiber and gypsum powder. Prasath et al. [15] performed a few FEA analyses on the mechanical properties of banayan fiber reinforced polymer composites with random and unidirectional orientation. Recently in 2020, Thandavamoorthy and palanival [16] reported detailed testing and evaluation of hybrid composite reinforced with short neem and bidirectional banyan fiber.

To enhance the quality of a process or a product, statistical methods are often used in various fields. Such methods facilitate the researcher to study and define the effect of each control factor associated with an experiment where various parameters are involved. Dry sliding wear is such a process in which a number of process parameters collectively determine the performance output, i.e., the specific wear rate. In this context, Taguchi's experimental design happens to be a powerful analysis tool for modeling and analyzing the relative influence of process parameters on the performance output. The Taguchi method determines the best combination of factors through an orthogonal array. The orthogonal array is denoted as Lp(qr), where '*p*' is the number of factor combinations in the experiment, '*q*' is the number of levels for each factor and '*r*' represents the number of factors in the experiment. Instead of full experiments as in the case of the traditional approach, the number of experiments is drastically reduced based on the design of orthogonal arrays in Taguchi's experimental design. The Taguchi method is an excellent tool for optimizing an intermediate number of variables (3 to 50) where only a few variables contribute significantly and interaction effects are relatively low [17]. A proper orthogonal array is selected (L9) with respect to the number of factors and the number of levels for each factor in the experiment.

In view of the above-literature survey, it was observed that some good work has been reported on the fabrication and evaluation of basic mechanical properties of ficus benghalensis fiber reinforced polymer composites. However, as per the best knowledge of authors, a study on tribological properties in specifically sliding wear response in dry conditions of these composites are rarely reported. Therefore, this current investigation is focused on evaluating the effect of natural fiber (Ficus benghalensis) reinforcement on dry sliding wear performance of polymer composite.

Experimental Detail

Fiber Extraction

Alkaline treatment (one of the chemical treatments of natural fibers) is used to extract the natural banyan root (Ficus benghalensis) fibers from shortly chopped aerial roots which are sun-dried for 2 to 3 days for partial removal of wax and oil present in the outer surface of the roots. In this process, the short aerial roots are immersed in aqueous NaOH (2 N solution) for 10 to 12 h. It basically acts as a bleaching agent for cleaning the surface of the aerial roots. This treatment removes a certain amount of hemicellulosic compound, lignin, wax, oils covering the external surface of the fiber cell wall which exposes the short length fibers. The addition of NaOH to the natural fiber promotes the ionization of the hydroxyl group to the alkoxide [18].

$$\mathrm{Fiber-OH} + \mathrm{NaOH} \rightarrow \mathrm{Fiber{-}O{-}Na} + \mathrm{H2O}$$

Because of alkaline treatment the surface roughness of the fiber increases which results in better mechanical interlocking, fiber strength and stiffness.

Composite Fabrication

In this present study, different sample of composites is tailored by adding different wt % of filler material (chemically extracted banyan root fiber) into the epoxy resin. Here the epoxy resin (LY556) used as a matrix material and corresponding hardener (HY951) are mixed in a ratio of 10:1 properly with continuous mechanical stirring. The used epoxy resins are commonly known as Bisphenol-A-Diglycidyl-Ether, and it belongs to the 'epoxide' family. In this work, the fabrication of the composites is done by a simple mechanical stirring technique. The mixture of chopped natural fiber, epoxy resin and hardener is prepared as per the requirement of the filler material in the weight percentage of 2, 4 and 6 wt% separately. To prepare the specimen for the sliding wear test the mixture has to pour in different test tube in room temperature and allow it for curing for 24 h. Before pouring the mixture, the inner surface of the test tube has to be wax coated for easy removal of the specimen.

Sliding Wear Test

The sliding wear tests are performed using a standard pin-on-disk test rig as shown in Fig. 1, as per the ASTM-G99-17 standard [19]. The resistance to dry sliding wear of these newly fabricated composites was measured using this setup, which is able of creating a sliding environment. The unit primarily consists of a rotating disk made up of very

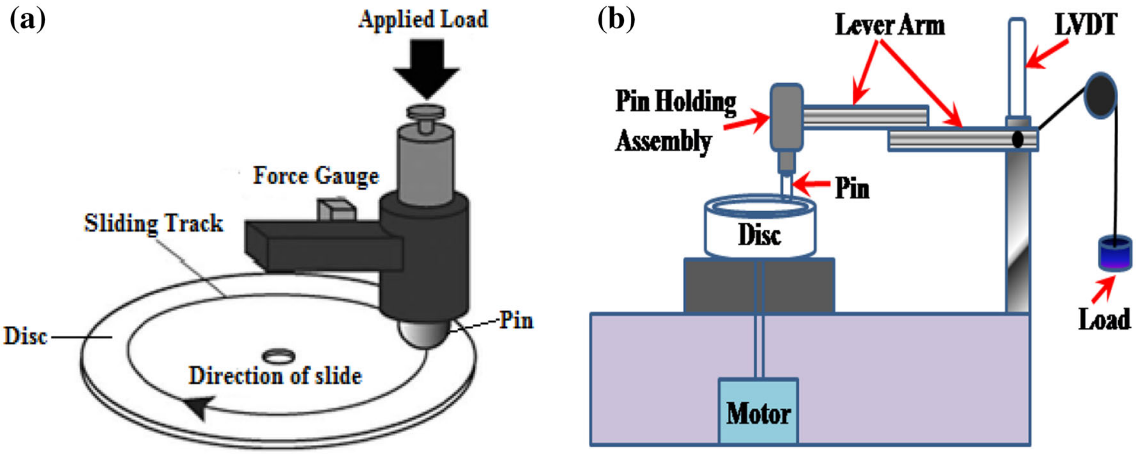

Fig. 1 Schematic representation of **a** pin-on-disk arrangement; **b** sliding wear test rig

hard material on which one end of the cylindrical-shaped test material (called a pin) will rub under different applied loading. The other end of the specimen was attached with a holder with a provision to set its position depending upon the required radius of rotation. The specimens were made dirt-free with acetone, dried and weighed by means of a precision weight assessing instrument (to an accurateness of ± 0.01 mg) prior to and later than the sliding test. Then, the specific wear (W_s) rate was computed by volume loss (ΔV) per unit sliding distance (d) per unit load (L) as follows:

$$W_s = \frac{\Delta V}{dL} \tag{1}$$

Taguchi's Method of the Experimental Study

Taguchi's experimental design model is an extremely important tool for a systematic approach to reduce and optimize the design parameters which eventually time of the repeated test run and overall cost. It also analyzes the influence of control factors on performance output. The sliding wear tests on the composites are performed considering four parameters like sliding velocity, sliding distance, normal load and amount of filler content with three levels each. Here the above four factors with their selected levels are mentioned in Table 1 in agreement with Taguchi's L9 orthogonal array. In this study, after calculating the specific wear rate, further the results are converted into a signal-to-noise ratio (S/N). To get the minimum wear rate it has to follow smaller is better to estimate S/N ratio as follows:

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

where n = number of observations.
y = observed data.

In the conventional experimental method, in order to study four factors at three levels each, it is required to perform a total of 81 tests run. But with the help of Taguchi's experimental design approach, it reduces down to only 9 test runs which give the optimum results keeping the advantage in running time and total cost.

Scanning Electron Microscopy

The worn surfaces of the composite specimens are inspected under a scanning electron microscope (SEM) JEOL JSM-6480LV to get the morphology after wear. The specimens are thoroughly made dirt-free with acetone prior to being observed under SEM.

Table 1 Control factors and their selected levels

Notation	Control factor	Level			Unit
		I	II	III	
A	Sliding velocity	84	126	168	cm/sec
B	Sliding distance	10	15	20	Meter
C	Normal load	400	800	1200	*N*
D	Filler content	2	4	6	Wt %

Results and Discussion

Sliding Wear Test

The natural fiber-filled epoxy composites fabricated and experimented upon in this work are found to have the adequate potential for a wide variety of applications, particularly in sliding wear environment. If the place of use is hostile with sliding wear situations, then natural fiber-filled composites are to be preferred due to their fairly good wear resistance. These composites, in general, may also be recommended for applications like linings for pipes carrying coal dust, conveyer belt roller, sliding door panels, partition boards, false ceilings, exhaust fan blades, lightweight vehicles, etc.[20]. However, the content of fiber in such composites is to be decided judiciously keeping the strength and intensity of wear attack in mind.

The specific wear rate is acquired for all the nine test runs alongside the corresponding *S/N* ratio are articulated in Table 2. These investigations are made by means of MINITAB16 software and from the analysis of data obtained from Table 2, it is observed that the general mean for the S/N ratio of the wear rate is recorded to be − 3.703 db. The mean effect plot for *S/N* ratios of each control factor is illustrated in Fig. 2. The response table for the *S/N* ratio estimated using the 'smaller is better' characteristics are revealed in Table 3. Supported the obtained delta value of each control factor, a rank was assigned to each process parameters indicating their implication on the performance output. During this study, the filler content is established to be the foremost significant factor trailed by the sliding velocity. More significance of filler content and sliding velocity on dry sliding wear of epoxy composites reinforced with natural or other fibers is also reported by other researchers [21, 22], whereas sliding distance and normal load have ranks of three and four, respectively, with comparatively fewer influence on erosion rate than filler content and sliding velocity. Also, graphical analysis of Fig. 2 indicates that sliding wear was minimum under an arrangement of impact velocity 84 cm/sec (*A*1), sliding distance 400 m (*B*1), normal load 10 N (*C*1) and filler content 6 wt % (*D*3).

Morphological Analysis of Worn Surfaces

The scanning electron microscopy (SEM) micrograph of the worn surfaces of Ficus benghalensis fiber-reinforced composite is illustrated in Fig. 3. In Fig. 3a, the swallow wear track is observed whereas in Fig. 3b deep wear tracks are observed. From Fig. 3a, it can be seen that a fine powder was generated with a combination of crushed fiber and matrix. From Figure 3a, it can be seen that the sliding wear led to surface roughening and high friction. Figure 3b shows both fiber and matrix were damaged along the direction of the wear track and a large delamination region in the middle of the wear track indicates severe wear. These variations in wear are due to variation in fiber loading under the same sliding speed. It is understandable that with increased sliding velocity and applied load, the polymeric resin softens due to frictional heat generation. As a result, the harder fibers easily tear the matrix and gradually get aligned along the sliding direction [21, 23].

Conclusion

The experimental investigation of the Ficus benghalensis natural fiber reinforced epoxy composites has led to the subsequent specific conclusions:

- Successful fabrication of different polymer composites reinforced with short ficus benghalensis fiber with varying loading of 2, 4 and 6 wt% were effectively possible made up by hand stirring technique.

Table 2 Experimental design (L9) with the specific wear rate and signal-to-noise ratio

Test run	Sliding velocity (*A*)	Sliding distance (*B*)	Normal load (*C*)	Filler content (*D*)	Sp. wear rate (*Ws*) (mm^3/N-m)	*S/N* ratio (db)
1	84	400	10	2	1.8223	− 5.2124
2	84	800	15	4	1.4175	− 3.03046
3	84	1200	20	6	0.921	0.71481
4	126	400	15	6	0.8854	1.05721
5	126	800	20	2	2.4154	− 7.65978
6	126	1200	10	4	1.7154	− 4.68731
7	168	400	20	4	1.8953	− 5.55356
8	168	800	10	6	1.02953	− 0.25278
9	168	1200	15	2	2.7253	− 8.70829

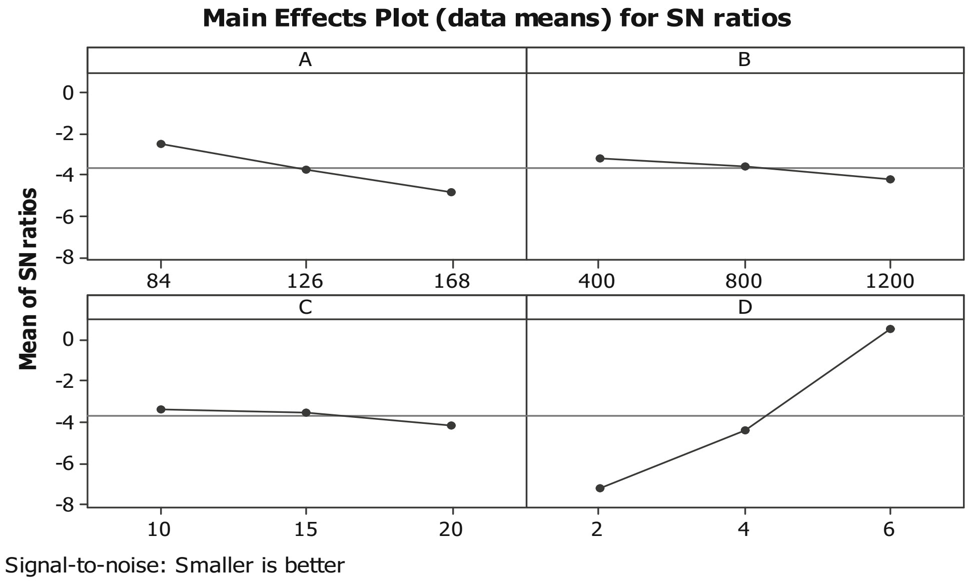

Fig. 2 Mean effect plot for *S/N* ratio under smaller is better characteristics

Table 3 Response table for the signal-to-noise ratio

Level	A	B	C	D
I	− 2.5094	− 3.2362	− 3.3842	− 7.1935
II	− 3.7633	− 3.6477	− 3.5605	− 4.4238
III	− 4.8382	− 4.2269	− 4.1662	0.5064
Delta	2.3289	0.9907	0.7820	7.6999
Rank	**2**	**3**	**4**	**1**

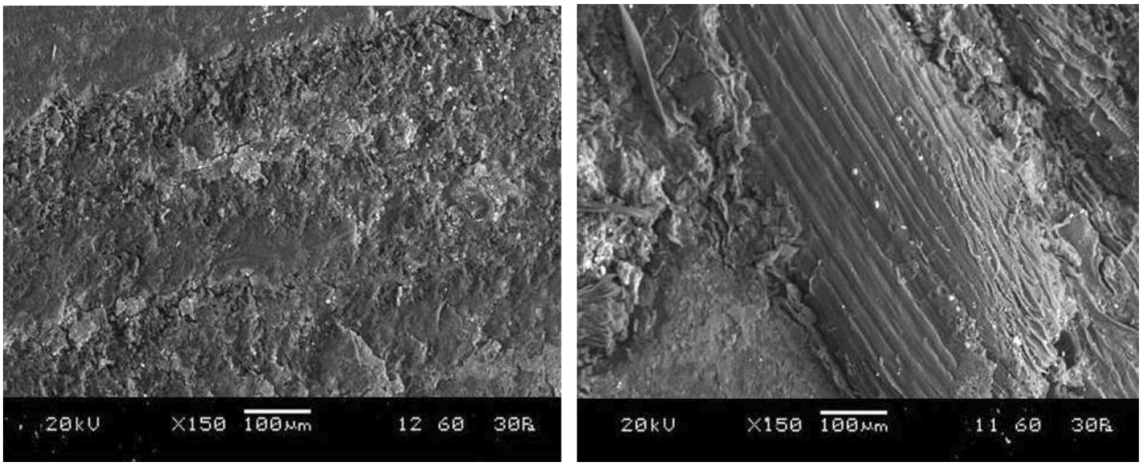

Fig. 3 SEM micrographs of worn surfaces wear at sliding velocity of 168 cm/sec; **a** Composite reinforced with 4wt % fiber and **b** Composite reinforced with 2wt % fiber

- With a raise in the proportional fiber loading, the erosion wear resistance enhanced in fabricated composites indicating good filler characteristics.
- The erosion wear rate of the investigated PMCs is very influenced by the filler content followed by the sliding velocity, while sliding distance and normal load have comparatively less importance on wear rate.

These composites, in general, may also be recommended for applications like linings for pipes carrying coal dust, conveyer belt roller, sliding door panels, partition boards, false ceilings, exhaust fan blades, lightweight vehicles, etc.[20].

References

1. J.A. Brydson, *Plastics Materials*, vol. 7 (Butterworth-Heinemann, UK, 1999)
2. K. Friedrich, *Advances in Composites Tribology, Composite Materials Series*, vol. 8 (Elsevier, Amsterdam, 1993)
3. M.F. Ashby, D.R.H. Jones, *Engineering Materials 2: An Introduction to Microstructures, Processing and Design*, vol. 3 (Butterworth-Heinemann, UK, 2006)
4. K. Friedrich, *Friction and Wear of Polymer Composites*, vol. 1 (Elsevier Science Publishers, Amsterdam, 1986), pp. 233–287
5. J. Bijwe, J.J. Rajesh, A. Jeyakumar, A. Ghosh, U.S. Tewari, Tribo. Int. **33**, 697–706 (2000)
6. S.N. Kukureka, C.J. Hooke, M. Rao, P. Liao, Y.K. Chen, Tribo. Int. **32**, 107–116 (1999)
7. A.S. Singha, V.K. Thakur, Bull. Mater. Sci. **31**(5), 791–799 (2008)
8. R.G. Padmanabhan, M. Ganapathy, Int. J. Res. Appl. Sci. Eng. Technol. **3**, 426–432 (2015)
9. A.K. Sinha, H.K. Narang, S. Bhattacharya, J. Polym. Eng. **37**(9), 879–895 (2017)
10. M.K. Gupta, A. Bharti, Curr. Trends FashionTechnol. Text. Eng. **1**(3), 1–4 (2017)
11. S. Dixit, R. Goel, A. Dubey, P.R. Shivhare, T. Bhalavi, Polym. Renew. Resour. **8**, 71–78 (2017)
12. G.H. Michler, F.J. Baltá-Calleja, *Mechanical Properties of Polymers Based on Nanostructure and Morphology* (CRC Press, New York, 2005), pp. 547–596
13. T. Vijay Kumar, K.V. Ramana, R.B. Chowdary, Int. J. Adv. Eng. Stud. **1**(1), 256–258 (2012)
14. R.G. Padmanabha, G. Umashankar, Global J. Eng Sci. Res Manage **2**(12), 106–112 (2015)
15. S. Arun Prasath, V. Balamurugan, S. Sanjay Ganesh, A. Udhaya Murthy, In: Inst. Phys. Conf. Ser.: Mater. Sci. Eng., 402, 012135 (2018).
16. T. Raja, P. Anand, J. Test. Eval. **48**(1), 647–655 (2020)
17. M.N. Islam, A. Pramanik, J. Adv. Manuf. Syst. **15**(3), 151–160 (2016)
18. X. Li, L.G. Tabil, S. Panigrahi, J. Polym. Environ. **15**, 25–33 (2007)
19. ASTM G99–17, *Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus* (ASTM International, West Conshohocken, PA, 2017)
20. Sandhyarani Biswas (2010) Processing, Characterization and Wear Response of Particulate Filled Epoxy Based Hybrid Composites. Ph.D. Thesis, National Institute of Technology Rourkela, Odisha, India.
21. S. Kumar, V.K. Patel, K.K.S. Mer, B. Gangil, T. Singh, G. Fekete, J. Nat. Fibers (2019). https://doi.org/10.1080/15440478.2019.1612814
22. Y.Z. Wan, G.C. Chen, S. Raman, J.Y. Xin, Q.Y. Li, Y. Huang, Y.L. Wang, H.L. Luo, Wear **260**, 933–941 (2006)
23. A. Purohit, A. Satapathy, J. Compos. Mater. **51**(7), 899–911 (2017)