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Frictional characterization of teak wood dust-filled epoxy composites

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ABSTRACT

Composites of teak wood dust particles of 150 μm, 212 μm, and 300 μm sizes with 10 % weight fractions were developed by a hand moulding technique. A wooden mould was prepared for casting the composite pins of 8 mm diameters and 50 mm length. Sliding wear tests were conducted on a pin on disc friction and wear monitor. It was observed that the composite with mesh size 150 μm of teak wood dust exhibited the least wear rate. Furthermore, the lowest coefficient of friction was also seen in the composite with a 300 μm size wood dust filler. The composite with 212 μm size wood dust showed an increase in the coefficient of friction but at higher loads dropped down probably because of the formation of transfer film between the composite and the steel disc. The composites with 150 μm and 300 μm size dust particles were in close ranges of friction coefficients, i.e. 0.64 and 0.71, respectively. Thus though the coefficient of friction was high for a 150 μm size filler composite, the wear increased at a steady rate and may stabilize after running for more than a 5 km distance later. Out of the above three composites the wood dust of a 150 μm composite may thus be a better choice for frictional applications.

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1. Introduction

The quest for light weight and high strength materials is never ending for due consideration owing to their wide applications. Therefore a polymeric composite material has its importance in the applications of light structures. These composite materials (notably aramid, carbon and glass fibre reinforced plastics etc.) now dominate the aerospace, automotive, construction, and sporting industries. However, these fibres have serious drawbacks such as non-renewability, non-recyclability, non-bio-degradability etc. These shortcomings have been highly exploited by proponents of natural fibre composites. Though mechanical properties of natural fibres are much inferior to those of other fibres, their specific properties, especially stiffness, are quite comparable to artificial fibres.

The aim of this study is to determine the friction and wear characteristics of saw dust-epoxy composite. This study is important for thermoplastic manufacture of furniture, residential deck board, rails and balusters, transportation structures, poles and cross arm, wearing surfaces and other related industrial applications to find out suitable materials which show good friction and wear properties.

Although there are several reports in the literature which discuss the mechanical behaviour of wood/polymer composites, however, very limited work has been done on the effect of wood dust types on friction and wear characteristics of polymer composites. Against this background, the present research work has been undertaken, with an objective to explore the potential of wood dust types as a reinforcing material in polymer composites and to investigate its effect on the friction and wear behaviour of the resulting composites. Most of the studies on natural fibre composites involve study of mechanical properties as a function of fibre content, effect of various treatments of fibres, and the use of external coupling agents. In the literatures, many works devoted to the properties of natural fibres from micro- to nano-scales are available. A number of investigations have been conducted on several types of natural fibres such as kenaf, hemp, flax, bamboo, and jute to study the effect of these fibres on the mechanical properties of composite materials. Mansur and Aziz [1] studied bamboo-mesh reinforced cement composites, and found that this reinforcing material could enhance the ductility and toughness of the cement matrix, and increase significantly its tensile, flexural, and impact strengths. Fracture properties and characteristics of sisal textile reinforced epoxy composites were studied by Li et al. [2]. The study concluded that proper fibre surface treatment could improve the fracture properties of this kind of eco-composite. Mechanical and fracture properties of Australian bamboo was studied by Low et al. [3]. It investigated the microstructure, mechanical, impact and fracture properties. Mosadeghzad et al. [4] studied the effect of surface treatment and filler loading on mechanical properties of the acacia saw dust unsaturated polyester resin (UPR) composite based on recycled polyethylene-terephthalate (PETP). The results showed that both tensile and flexural moduli were increased with increasing filler contents whereas the strength was decreased. This was overcome by treating the sawdust fillers with 10 % sodium hydroxide (NaOH). Study on the wear-resisting property of wood Cu/Ni electroplate coating was done by Huang et al. [5] which showed that the treated metal-wood surface has higher wear-resisting property and hardness. Biswas et al. [6] worked on the effect of ceramic fillers on mechanical properties of bamboo fibre reinforced epoxy composites. In this study, a series of bamboo fibre reinforced epoxy composites were fabricated using conventional filler (aluminium oxide Al_2O_3) and silicon carbide (SiC) and industrial wastes (red mud and copper slag) particles as filler materials. The result showed that the inclusion of fibre in neat epoxy improved the load bearing capacity (tensile strength) and the ability to withstand bending (flexural strength) of the composites. Kranthi et al. [7] studied the wear performance of a new class of epoxy based composites filled with pine wood dust. According to the study pine wood dust possesses good filler characteristics as it improves the sliding wear resistance of polymeric resin, and filler content, sliding velocity and normal loads are the important factors which affect the specific wear rate. A comparison of properties between glass-epoxy-fly ash and fly ash-epoxy composite has been made by Singla and Chawla [8]. Compression and impact tests have been carried out with varying weight fractions of fly ash and glass reinforcements in epoxy. SEM has been done to analyze the fractured surfaces. Chemical resistance to acids, alkalis and solvents to jute-glass and varying weight fractions of silica filled composites have been analzed by Kumar and Madhu [9]. It was concluded that all the composites have shown better chemical resistance to acids and alkalis except to toluene. A study on the dry sliding wear of oil palm empty fruit bunch (OPEFB) epoxy composite was done by Kasolang et al. [10]. The result showed that the mass loss was significantly higher for smallest fibre size (100 μm) examined at 30 N and at other fibre sizes, the mass loss values were relatively close due to the distribution and orientation of fibres. Wang et al. [11] studied the effect of coupling agent on bonding properties of wood/polyethylene composites. The result showed that the -OH, -C-O- and C=O functional groups were appeared on the treated surface and the surface roughness was increased after mechanical polishing treatment and coating treatment, resulting increase in the shear bonding strength for the treated sample significantly. Hisham et al. [12] studied the flexural mechanical characteristic of sawdust and chip wood filled epoxy composites and found that a good quality of saw wood (SW) and chip wood (CW) fibre composite can be used for furniture utilities. Nagieb et al. [13] investigated the effect of addition of boric acid and borax on fire-retardant properties and studied the mechanical properties of urea formaldehyde saw dust composites. The experimental results showed that the water absorption and bending strength decreased as the flame retardant increased. A study on the microstructures and properties of wood ceramics prepared from bagasse and epoxy resin composite was done by Zhang et al. [14]. The carbon yield ratio of the wood ceramics decreased with the increase of the content of bagasse. While the volume shrinkage ratio and volume electrical resistivity increased with the increase of the content of bagasse. Wimonsong et al. [15] worked on thermal conductivity and mechanical properties of wood sawdust/polycarbonate composites. The study showed that the Young's moduli of composites were in general higher than the neat PC except for the one with γ-aminopropyl trimethoxy silane treatment. The tensile moduli of composites were increased as the filler loading increased and the addition of wood sawdust resulted in the tensile strength reduction of the composites, and also the thermal conductivity was reduced significantly with the increment of wood sawdust contents. Girisha et al. [16] have studied the mechanical performance of natural fibre reinforced (treated and untreated) hybrid composites. Tamarind fruit fibre and arecanut fibres were reinforced to epoxy. For treated fibres it was observed that tensile strength and flexural strength have increased with increase in fibre volume fractions. However beyond 40 % reinforcement the strength has decreased. Impact properties of 50 % reinforced composite has yielded the best result. Bhaskar et al. [17] worked on the evaluation of properties of polypropylene-pine wood plastic composite. Incorporation of maleated polypropylene (MAPP) coupling agent in composite formulation improved the stability. Vafaeneezhad et al. [18] considered carbonized wood from oak tree to prepare carbon/epoxy composites. From experiments it was observed that addition of epoxy has increased the sliding wear resistance. Artificial neural network was developed to validate the experimental findings. It was found that sliding distance, normal load and carbonization temperature played important role affecting the wear characteristics of the composite. Coir dust with 10 %, 20 %, and 30 % concentration both treated and untreated types were tested by Chandra Rao et al. [19] on a pin on disc type friction monitor. In order to minimize the experimental time and cost, Taguchi method was used. Abrasive wear characteristics were studied with varying load up to 30 N and varying velocities. It was seen that treated filler composites showed better wear resistance compared to untreated ones. With increase in dust content the wear rate decreased but with increase in load the wear rate has increased. Mishra [20] investigated the friction and wear characteristics of teak wood dust-filled epoxy composites of three different types of specimens. It was observed that wood dust-filled with 10 % of 300 μm size composite has exhibited better wear performance.

Thus out of the above review an attempt has been made in this investigation to:

- Development of teak wood dust-filled epoxy composites with different mesh sizes and constant volume fraction (10 % by weight).
- Casting of cylindrical pins of 8 mm diameter for frictional characterization by developing a suitable wooden mould.
- Carrying out short run and long run tests in a pin on disc friction and wear monitor to evaluate the coefficient of friction and wear characteristics of these materials sliding against mild steel plate.
- Choosing the best out of the above three specimens for specific application.

This paper describes the calculation of mechanical properties of the composite as applied to random distributed particle reinforced composites along with weight fractions and volume fractions of the reinforcement, development of a suitable mould for casting composite pins, experimental work carried out on a pin on disc machine for determining the coefficient of friction and wear rate. Lastly the results obtained have been discussed and conclusions have been drawn out of the findings. Recommendations have also been made for expected applications of these composites.

2. Mechanical properties of the composite

The composite is usually prepared based on calculation of weight fractions or volume fractions. Weight fraction of the reinforcement:

$$w_r = \frac{W_r}{W_r + W_m} \cdot 100 \tag{1}$$

Weight fraction of the matrix is:

$$w_m = \frac{W_m}{W_r + W_m} \cdot 100 \tag{2}$$

where W_r is weight of reinforcement, and W_m weight of the matrix. Weight of the composite is:

$$W_c = W_r + W_m \tag{3}$$

Further as per rule of mixtures, the density of the composite ρ_c is obtained by:

$$\rho_c = \rho_m \cdot v_m + \rho_r \cdot v_r \tag{4}$$

where ρ_m is density of the matrix, ρ_r is density of the reinforcement, v_m is volume fraction of the matrix, and v_r is volume fraction of the reinforcement. Further:

$$v_m = \frac{V_m}{V_m + V_r + V_v} \cdot 100 \tag{5}$$

and

$$v_r = \frac{V_r}{V_m + V_r + V_v} \cdot 100 \tag{6}$$

Volume of the composite is:

$$V_c = V_m + V_r + V_v \tag{7}$$

where V_m is volume of the matrix, V_r is volume of the reinforcement and V_v is volume of voids. Modulus of elasticity of the composite is:

$$E_c = E_r \cdot v_r + E_m \cdot v_m \tag{8}$$

where E_r is modulus of elasticity of reinforcement and E_m is modulus of elasticity of matrix.

The properties of teak wood dust and epoxy are shown in the Table 1 and Table 2, respectively. By using the Eq. 4 and Eq. 8 the density and elastic modulus of the composites have been found out and given in Table 3.

Table 1 Properties of teak wood dust [20]

Properties	Value
Density (g/cm^3)	0.8
Young's modulus of elasticity (GPa)	10.5
Tensile strength (MPa)	95

Table 2 Properties of epoxy [20]

Properties	Value
Density (g/cm^3)	1.2*10^3
Young's modulus of elasticity (GPa)	20
Tensile strength (MPa)	75

Table 3 Composite properties

Specimens	Density (kg/m^3)	Elastic modulus (GPa)
Sp-1 (300 µm)	1120	18.58
Sp-2 (212 µm)	1140	18.58
Sp-3 (150 µm)	1160	19.05

3. Experimental investigations

3.1 Materials

The teak wood dust of different sizes, i.e. 150 μm, 212 μm, and 300 μm (Fig. 1) measured through sieve shaker were considered as reinforcing material (10 % by weight) in fabrication of the composite. Epoxy (CY 230 and Hardener-HY-951 supplied by Hindustan Ceiba Geigy, Ltd.) has been used as matrix material. A wooden mould has been developed in house to cast the pins for wear testing (Fig. 2). After mixing epoxy and wood dust in the proposed ratio the composite was cast by pouring into the split mould and allowed to cure at room temperature for 24 hours. The pins were ejected out after solidification (Fig. 3).

Fig. 1 Teak wood dust of three sizes: 150 μm (left), 212 μm (center), and 300 μm (right)

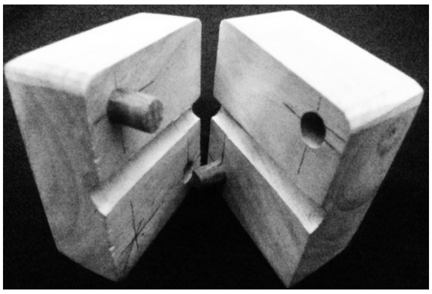

Fig. 2 Wooden mould for pins

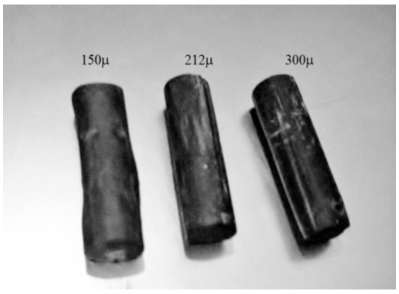

Fig. 3 Composite pins (150 μm, 212 μm, and 300 μm)

3.2 Experimental procedure

The tests were carried out in pin on disc wear and friction testing machine (Fig. 4 and Fig. 5) supplied by M/s Magnum Engineers, Bangalore, India, having the following specifications:

- Load range: up to 100 N,
- Friction force measurement: up to 100 N,
- Wear measurement: 2000 μm (± 2 mm),
- Sliding speed: 0.26-10.0 m/s,
- Disc speed: 100-2000 rpm,
- Diameter of track: 40-90 mm,
- Disc size: diameter is 100 mm and thickness is 8 mm, disc material is EN-31 (58-60 RC),
- Pin: diameter is 3-10 mm and length is 25 mm,
- Software: MAGVIEW-2011 data acquisition software.

For evaluation of friction coefficient under dry sliding condition the speed and time were kept constant, i.e. 400 rpm and 3 min with varying the load up to 5 kg. Similarly for estimating the wear, the pins were slid against mild steel disc for 5 km of sliding distance keeping the speed at 400 rpm (1.5 m/s sliding velocity) and load of 30 N.

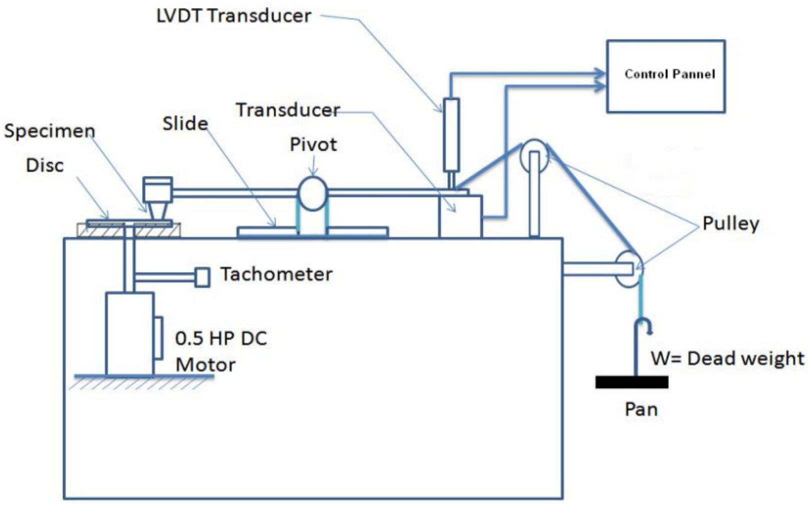

Fig. 4 A schematic diagram of the pin on disc apparatus

Fig. 5 Friction and wear monitor [20]

4. Results and discussions

The readings from the control panel of the pin on disc apparatus with respect to friction force, speed, wear, and time have been taken during conduct of the wear tests. The dead weights placed on the apparatus gave direct measurement of the normal reaction. Hence the coefficient of friction could be calculated. Thus the coefficient of friction and wear in microns were obtained for three different specimens (Table 4 and Table 5):

- Specimen-1: composite with teak wood dust of 300 μm,
- Specimen-2: composite with teak wood dust of 212 μm,
- Specimen-3: composite with teak wood dust of 150 μm.

The results have also been plotted graphically to give a better understanding as shown in Fig. 6 and Fig. 7.

Table 4 Variation of coefficient of friction with load

Load (kg)	Specimen-1	Specimen-2	Specimen-3
1	0.52870	0.468700	0.43388
2	0.55750	0.559700	0.51084
3	0.59248	0.694020	0.57949
4	0.62229	0.843042	0.64327
5	0.63915	0.872820	0.71206

Table 5 Variation of wear with sliding distance

Load (kg)	Specimen-1	Specimen-2	Specimen-3
1	71.4830	33.7410	1.4080
2	72.6330	100.907	41.286
3	79.1380	145.524	79.797
4	89.0808	162.124	169.192
5	104.932	175.803	241.926

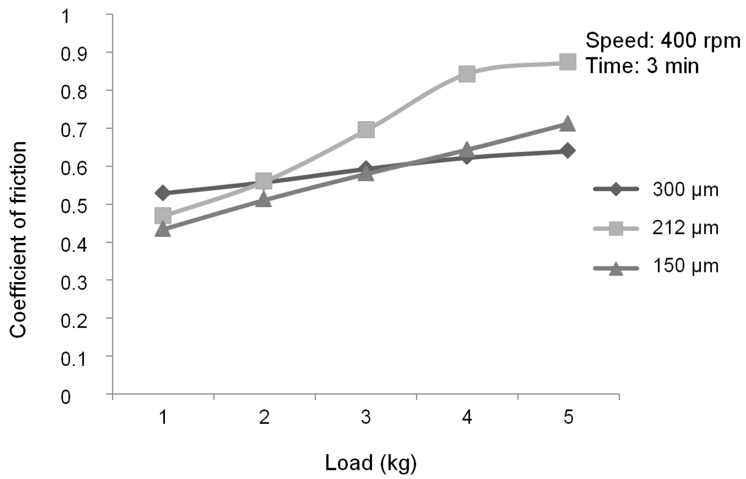

Fig. 6 Variation of coefficient of friction against load

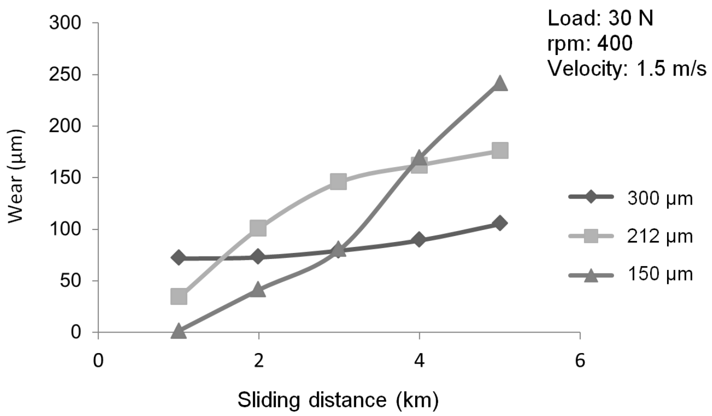

Fig. 7 Variation of wear with sliding distance

Out of the above results it is observed that the composite with mesh size 150 μm of teak wood dust exhibited least wear rate. Further lowest coefficient of friction has also been seen in the composite with 300 μm size wood dust filler. The composite with 212 μm size wood dust showed increase in coefficient of friction and at higher loads it may drop down probably because of formation of transfer film between the composite pin and the steel disc. The composites with 150 μm and 300 μm size dust particles are in close range of coefficient of friction, i.e. 0.64 and 0.71, respectively.

5. Conclusion

From the theoretical investigations it is revealed that composite with teak dust of 150 μm size has highest modulus of elasticity and density obtained by rule of mixtures. Further the co efficient of friction is also high for 150 μm size filler composite with least wear as compared to others. However it is observed that wear increases at a steady rate which may stabilize after running for more than 5 km distance. Out of the above three composites thus the wood dust of 150 μm composite is a better choice for frictional applications. This type of composites can be used as packing materials, interior decoration of houses and buildings, light weight furniture, aircrafts interiors and automobile components etc. Long run wear tests are to be carried out for ascertaining its application in high frictional environment in industries.

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