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Two-body abrasive behavior of areca sheath fibre reinforced polyvinyl alcohol composites

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Tribological properties of randomly oriented benzyl chloride modified short areca sheath (AS) fibre reinforced polyvinyl alcohol (PVA) composites have been studied. The test specimens are prepared using various weights of fibres (0, 10, 20, 30 and 40 %) by injection molding process. Fibre content of 27 wt% is found to have better tensile strength, as determined by regression analysis. The tribological behavior under multipass abrasion condition and the impacts of applied load & sliding distance on specific wear rate and weight loss have also been investigated. It is found that 27 wt% of fibre loading shows better resistance to wear similar to tensile strength. Scanning electron microscopy is used to capture the images of wear surface at optimum fibre loading to have an idea about the wear mechanism of the composite.

Keywords: Areca sheath fibres, Polyvinyl alcohol, Tribological behavior, Two-body abrasive test, Wear mechanism

1 Introduction

Recently, various natural fibres reinforced polymer composite materials gain popularity mainly because of their ecofriendly, bio-degradable and sustainable characteristics. Hence, these composites are associated with various application areas. One such area is tribological applications, like bearings and gears etc., where liquid lubricants can't be utilized as a result of different constraints. With respect to tribological application, natural fibre polymer composites have come across for various types of wears, out of which abrasive wear is considered as the most important area. This abrasive wear includes the loss of material that occurs when one body slides over the other.

Till date, many investigators have focused their attention to study the mechanical as well as tribological properties of various natural fibre/polymer composites. As regards to tribological properties, particularly work has been done on abrasive wear behavior of natural fibre/polymer composites. Yousif *et al.*[1] have studied the wear and frictional behaviour of a new epoxy composite based on treated betel nut fibres, subjected to three-body abrasion using different abrasive particle sizes and sliding velocities. They found that the abrasive wear of the composite depends on the size of abrasive particles and sliding velocity. Yousif and El-Tayeb[2] have investigated the wear and frictional characteristics of oil palm fibre reinforced polyester composite. They observed that the presence of oil palm fibre in the polyester enhances the wear property by about 3-4 times compared to neat polyester. In addition to that, many studies have been reported on abrasive wear characteristics of different natural fibres reinforced in polymers. These include works on coir[3], cotton[4], kenaf[5], jute[6], bamboo[7, 8], surgarcane[9] and wild cane grass[10]. As far as areca sheath fibre reinforced polymer composite is concerned, some works have been done on evaluating mechanical and biodegradable properties rather than on tribological properties[11-16]. The aim of the present work is therefore to study the abrasive wear behavior of chemically modified areca sheath (AS) fibre reinforced polyvinyl alcohol (PVA) composite.

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2 Materials and Methods

2.1 Materials

The polymer matrix (polyvinyl alcohol) was obtained from Central Tool and Training Center, Bhubaneswar, India. Areca sheaths have been collected from local villages in Odisha, India. Chemicals such as sodium hydroxide and benzyl chloride for fibre modification have been procured from Mohapatra Chemicals, Bhubaneswar, India.

2.2 Methods

2.2.1 Composite Preparation

The Areca sheath (AS) fibres have been extracted by retting; the fibres were soaked in water for 10 days to soften the surface and to make the extraction of fibres easier. Then, the raw fibres were extracted with the help of a metal brush, washed thoroughly in water to remove dirt, if any, present in the fibre and then dried in an oven at 70°C to remove the moisture completely. The fibres thus obtained are called as untreated fibres.

The untreated areca sheath fibres were soaked in 5% NaOH solution for 1h at 80°C. The fibres were cooled to room temperature (28°C) and continually washed with tap water to separate NaOH solution absolutely from the fibre surface. These fibres were later oven dried at 70°C for 24 h. The subsequent fibres have been termed as alkali pre-treated fibres. Then, these fibres were again soaked in 10% NaOH and benzyl chloride solution for 15 min. After that the subsequent fibres were submerged in ethanol for 1h to extricate benzyl chloride absolutely from the fibre surface. Finally, the fibres were washed with distilled water and dried in an oven at 80°C for 24 h. Then, the composites (AS/PVA) specimens were prepared by injection molding at 170°C with an injection speed of 40 mm/s, considering various weight percentages of benzyl chloride treated fibres (10, 20, 30 and 40 wt%) and neat PVA for two-body abrasion wear test.

2.2.2 Testing of Mechanical Properties

The tensile tests of the composites specimens were performed in servo-hydraulic tensile testing machine Instron 3382 having load cell capacity of 5 kN. Twenty samples of benzyl chloride treated PVA/AS composites were tested and the average value was recorded.

2.2.3 Abrasive Wear Test

The wear testing machine used was pin-on-disc machine which consists of a horizontally rotating disc against which a static pin (sample) of cylindrical shape was pressed with the application of load. Abrasive paper of 400 grade (23 µm grit size) was pasted on the disc which is used as abrading counterface. The test machine made the disc to rotate around the disc center and pin remains constantly pressed against the disc; the distance of sliding is taken to be 377 m. The parameters for wear test are presented in Table 1.

The friction coefficient (µ) has been calculated using the following equation at the contact point in a regular interval of 5 s using a load cell mounted on the load lever:

Table 1 — Test parameters for dry sliding wear test

Test parameter	Value
Load, N	5, 10, 15, 20
Sliding velocity, m/s	0.392, 0.471, 0.549
Sliding distance, m	94.25, 188.5, 282.75, 377.00
Track radius, mm	50

$$\mu = \frac{F_f}{F_n} = \frac{\text{Frictional force (N)}}{\text{Normal Load (N)}} \qquad \ldots (1)$$

Prior to the test, the samples were washed in acetone and thoroughly dried before measuring the initial weight of the samples. A digital weighing machine was used to measure the weight of the specimens with 0.001 mg least count. After measuring the initial weight, the sample was subjected to run on particular test condition. Then, the weight difference before and after test was calculated which is taken as the weight loss for that particular test. The specific wear rate (W_s) was calculated using the following equation:

$$W_s = \left[\frac{\Delta W}{\rho F_n S_d}\right] m^3/Nm \qquad \ldots (2)$$

where F_n is the normal load (*N*); S_d, the sliding distance (*m*); ΔW, the weight loss (kg); and ρ, the density of the composite (kg/m^3).

2.2.4 Investigation of Abraded Surfaces

Scanning electron microscope (SEM) of model HITACHI SU3500 was used to investigate the worn out surfaces of the abraded samples of 27 wt% fibre loading of PVA/AS composite at a load of 10 kN and sliding velocities of 0.392, 0.471 and 0.549 m/s respectively.

3 Results and Discussion

3.1 Tensile Strength of Composites

The tensile strengths of PVA/AS composites at different fibre loadings have been plotted against different wt% of benzyl chloride treated fibres (Fig. 1). As pointed out by Shalwan and Yousif [17] in their work, the tensile strength of PVA/AS composites first increases with fibre loading and after reaching a maximum value, it decreases. The optimum fibre loading, at which maximum tensile strength of the composite is achieved, has been obtained by regression analysis by fitting a 2nd degree polynomial curve (*R* value 0.982) to the data points. The optimum weight percentage of fibre obtained from the plot is 27 wt%, at which the tensile strength is 46.52 ± 1.02 MPa.

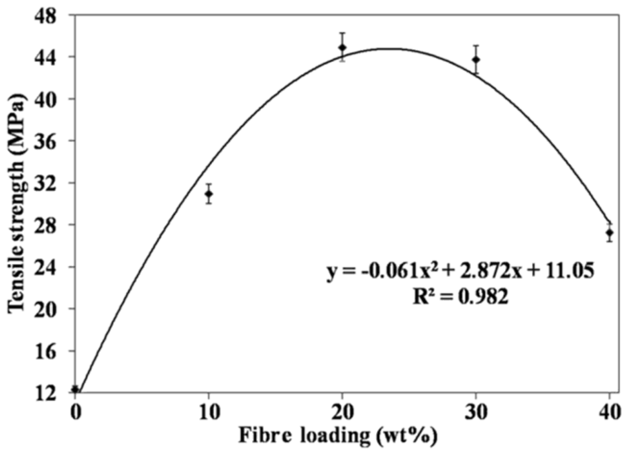

Fig. 1 — Tensile strength of PVA/AS composites at different fibre loading

3.2 Abrasive Wear Behavior

In order to study the tribological behavior of PVA/AS composites, the composite samples have been prepared using the same procedure but taking different fibre wt% (0, 10, 20, 27, 30 and 40%). The effect of load and sliding distance on specific wear rate has been examined.

3.2.1 Effect of Load on Wear Behavior

The impact of load on specific wear rate (*W*s), friction coefficient (μ) and weight loss (ΔW) of PVA/AS composite at various fibre loadings and sliding speed of 0.471 m/s have been studied (Fig. 2). The comparative outcomes for sliding speeds of 0.392 and 0.549 m/s are not reported here to avoid replication; finding being the similar.

Figure 2(a) shows that the specific wear rate (W_s) declines with increase in load and fibre content but it has been further noticed that the minimum wear exists at optimum fibre loading (27 wt%), where tensile strength shows the optimum value. This is because of the better interfacial bonding amongst fibre and matrix, which plays a critical part in wear process. Similar results are also obtained by Ratna *et al.*[18] while studying the abrasive wear behavior of composites made by reinforcing locally available fibres such as rice straw, elephant grass and vakka, into unsaturated polyester resin material. The friction co-efficient shows the similar results as in case of specific wear rate [Fig 2(b)]. It decreases with the increase in load because of the fact that, as the load increases the surface roughness and wear debris increase, which may be responsible for decrease in friction coefficient. The findings of Chowdhury *et al.*[19] also support the above result. With increase in load, the abrasive particles penetrate more inside the softer matrix, for which more material is removed, thereby representing it as loss of weight (ΔW) of the composites. The weight loss decreases with fibre content up to optimum fibre loading (27 wt %), after which it again increases [Fig (2c)]. This is due to the reason that with increase in fibre content, the matrix-fibre adhesion increases, which diminishes the material evacuation. This trend proceeds till 27 wt% of fibre content, which is the ideal value of AS fibre in PVA matrix that gives the noteworthy wear resistance. It is further observed that the loss of material increases with increase in load for each fibre loading. Figure 3 shows maximum wear resistance (minimum wear rate) at optimum fibre loading (27 wt %) which supports the novelty of above evidence.

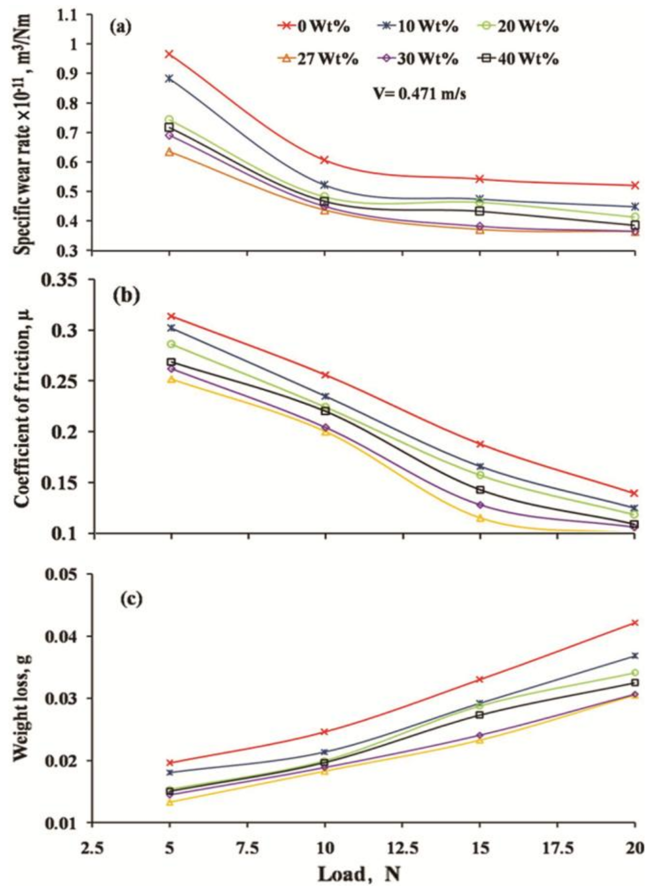

Fig. 2 — Effect of load on (a) specific wear rate (W_s), (b) coefficient of friction (μ), and (c) weight loss (*ΔW*) at 0.471 m/s sliding velocity

3.2.2 Effect of Sliding Distance on Wear Behavior

Figure 4 shows that the specific wear goes on decreasing with the increment of sliding distance. In

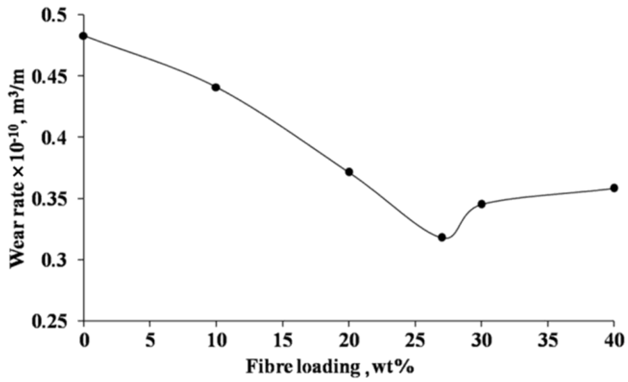

Fig. 3 — Variation in wear rate with fibre loading

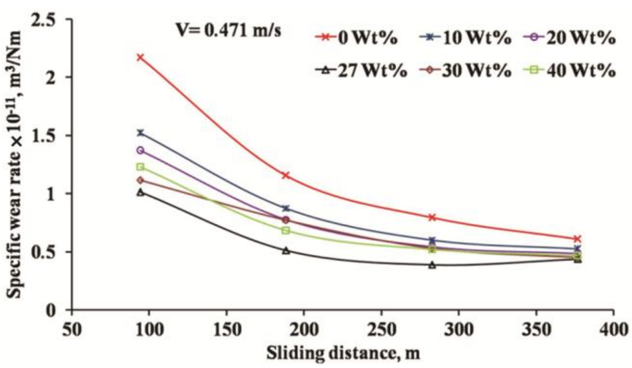

Fig. 4 — Effect of sliding distance on specific wear rate of PVA/AS composite

other words, the abrasion of material is very less with longer sliding distance. It can be seen that the specific wear rate is in the scope of 1.011×10^{-11} to 2.167×10^{-11} m^3/Nm. Similar to previous results, the specific wear rate also shows minimum value at 27 wt% (optimum loading) of fibre loading, because of highest tensile strength of the composite and good fibre-matrix bonding. It has been further observed that the specific wear rate diminishes up to the ideal loading of fibre after which the value increases.

3.3 Investigation of Wear Surface Texture

Figure 5 shows the SEM images of PVA/AS composites (27 wt% fibre loading) at a load of 10 kN and sliding velocities of 0.392, 0.471 and 0.549 m/s respectively. The sliding distance has been kept constant at 377 m. From the micrographs, it is observed that the fibre debonding increases with increasing sliding speeds. The wear is mostly in the form of debonding, matrix damage, presence of cracks and fibre pull-out. Moreover, the visibility of furrow and cutting action proves the abrasive wear mechanism. The harm to the fibre is prominent at higher speeds than at lower rates.

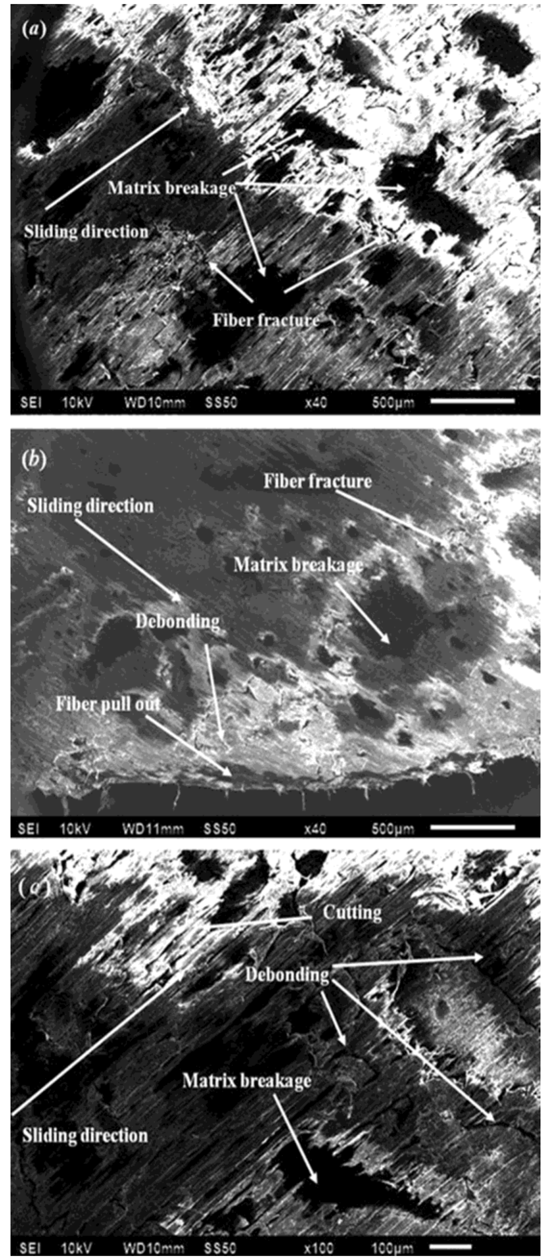

Fig. 5 — SEM images of worn surfaces at sliding velocity of (a) 0.392 m/s, (b) 0.471 m/s, and (c) 0.549 m/s

4 Conclusion

In this study, the tribological behavior of benzyl chloride treated areca sheath reinforced polyvinyl alcohol has been studied experimentally and the following inferences are drawn:

4.1 The tensile strength of PVA/AS composite first increases and after reaching a maximum value it starts decreasing. The maximum value of tensile strength is found 46.52 MPa at optimum (27 wt%) of fibre loading.

4.2 The specific wear rate demonstrates a diminishing pattern with increment in applied load and shows better wear resistance at optimum fibre loading.

4.3 The weight reduction increases with increment in applied load.

4.4 Coefficient of friction has been found to be lowest at optimum fibre loading which indicates highest wear resistance.

4.5 SEM images clearly show the furrow and cutting action which proves the abrasive wear mechanism. The harm to the fibre is prominent at higher speeds than at lower rates.

4.6 PVA/AS composites at 27 wt% (optimum) of AS fibre content can be used in wear and friction environment as it reveals better mechanical and tribological properties.

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