

Tribological Performance of Acrylic Acid Modified Short Rattan Fibre Reinforced Epoxy Composite

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ABSTRACT

In the present investigation, acrylic acid treated short rattan fibre reinforced epoxy (RF/Epoxy) composite was fabricated by taking various weight percentages (i.e. 5, 10, 15, 20, 25 wt%) of fibres using hand layup technique. Different mechanical properties such as tensile, flexural, and impact strength were investigated. By regression analysis it was found that 18 wt% of acrylic acid treated rattan fibre reinforcement (optimum fiber loading) gave 21.17%, 32.74% and 40.10% increase in above properties in comparison to untreated one. The tribological performances such as specific wear rate, friction coefficient and weight loss were analysed in terms of speed, load and sliding distance under multipass two body abrasion condition. It was observed that tribological performance was also better at optimum fibre loading similar to mechanical properties. The microstructure of worn-out surface of the composite was studied with the help of scanning electron microscope (SEM) and was found that with increasing sliding velocity, the surface deterioration and matrix breakage become predominant reducing the composite's wear resistance.

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1. INTRODUCTION

Today's growing environmental awareness and government restrictions have motivated the researchers to develop new innovative and eco-friendly natural fibre reinforced composite materials due to their outstanding features such as biodegradability, low weight to strength ratio, low cost, lightweight, renewable, recyclable, non-corrosive and easy processing [1-6]. Recently, several industries, such as automotive, construction and packaging industries are

focussing their attention to develop of new green natural fiber reinforced composite materials. Among numerous materials and applications, bio-based polymer composites are very important for automotive industry [7-10], where natural fiber composites (NFC) are being used for manufacturing several components. As far as tribological application is concerned, polymer composites reinforced with synthetic fibres have been extensively used for a long period having excellent friction and wear properties [11-16]. However, production and

consumption of synthetic fibres generate environmental repercussions including greenhouse gas emissions, air and water pollution. Hence, research is being focused to explore friction and wear properties of polymer composites reinforced with natural fibres.

From the tribological point of view, few works have been reported on the tribological properties of natural fibre reinforced polymer composites (NFRP) which include: betelnut [17], kenaf [18], sisal [19], sugarcane [20,21], coir [22], bamboo [23] etc. Furthermore, Matejka et al. [24] have shown that the composite with 23.6% of jute fiber and 6.3% of hazelnut shell (in powder form) can be a suitable brake lining friction material for light motor vehicles. From the study of oil palm fibre reinforced polyester composite [25,26], it is found that oil palm fibres enhance the wear performance of polyester by three to four folds. This is due to the presence of oil palm fibres at the surface of the composite forming a mixed layer of broken fibre and polyester debris which protect the polyester regions during sliding. In another work on cotton/polyester composite [27], it is observed that the specific wear rate of polyester declines significantly with the addition of cotton fibre. This is due to better structural integrity of cotton reinforced polyester.

Rattan is a vital portion of plant and forest resources making its availability, the third largest in tropical forests behind timber and bamboo [28]. Rattan is a multipurpose biomass resource with excellent qualities, like short production cycle, sustainability, high economic value, superior physical and mechanical properties, and cultural value [29-31]. To the authors best knowledge some works have been done on rattan fibre reinforced polymer composites [32-40] to study their mechanical and thermal properties. However, studies on their tribological properties are scanty in literature. Keeping in view of the above facts, the current work aims to study the effect of fiber loadings on mechanical and tribological behaviour of rattan fibre reinforced epoxy composite. The tribological performances such as specific wear rate, friction coefficient and weight loss were analysed in terms of speed, load and sliding distance. The microstructure of worn-out surface of the composite was studied with the help of scanning electron microscope (SEM) to show some features of wear mechanism.

2. MATERIALS AND METHODS

2.1 Materials

Epoxy resin (LY556) and hardener (HY951) were purchased from CF Composites, New Delhi, India. The density of epoxy resin and hardener are 1.15 g/cm³ at 25 °C and 1 g/cm³ at 20 °C respectively (obtained from manufacturer's test report). The chemicals such as sodium hydroxide, benzene, acrylic acid, etc. were purchased from Kolkata, India. The stems of rattan were collected from local agricultural resources (Sambalpur region, Odisha, India).

2.2 Chemical treatments of rattan fibres

The collected stems of rattan were allowed to soak in water for about 30 days to extract the fibre by retting process. The extracted fibres were washed several times for the complete removal of debris and then dried at room temperature for 24 hr. These fibres are termed as untreated fibres. Then, these were treated with 5% (by weight) NaOH solution [41]. After this, the fibres were rinsed in distilled water and dried at 80°C for 12 hours in a hot air oven to wipe out remaining moisture. The alkali treated fibres were soaked in water/benzene solvent (45:5 cm³) for 15 minutes at 85°C to reduce hydrophilic nature of the fibre thereby strengthening fibre-matrix adhesion in a solution of water and benzene. Then, the fibres were treated with 0.3 M acrylic acid and oven dried at 80°C for 24 h to remove if any moisture present on the fibre surface [42].

2.3 Fabrication of composite

For the fabrication of short rattan fibre reinforced epoxy composite (RF/Epoxy), hand lay-up technique was used. The resin was prepared by proper mixing of epoxy resin and hardener in the weight ratio of 10:1 with the help of a mechanical stirrer. Acrylic acid-treated fibres were chopped to approximately 1-3 mm in length for short fibre reinforcement analysis and dried in an oven before mixing with prepared resin. Fibres were mixed with prepared epoxy resin mixture at different weight fractions 5 % to 25 % at each 5 % interval (i.e. 5, 10, 15, 20, 25 %) and poured into a steel mould of dimension 170 × 150 × 3.2 mm³. Then, the mixture was compressed to 3.2 mm by compression molding machine with the help of a

cover plate and left for 24 hours for curing. After proper curing, the samples were taken out of the mould and cut to the desired shapes and sizes with the help of Jig Shaw cutting Machine. Fig. 1 shows Composite panel preparation process.

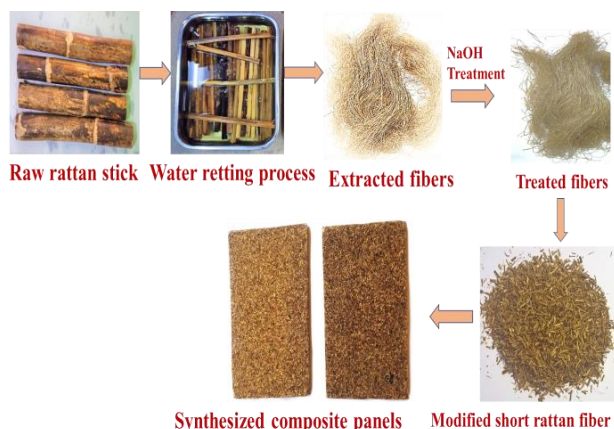


Fig. 1. Composite panel preparation process.

2.4 Testing of mechanical properties

2.4.1 Tensile test

The tensile tests were performed using servo-hydraulic static testing machine (*INSTRON* 3382) with a load cell of 5 kN. The tensile test specimens of 165 mm in length and 3.2 mm in thickness were prepared as per ASTM D 638 specification. Five samples were tested at each fibre loading, e.g. 5, 10, 15, 20, 25 wt% at a cross head speed of 2 mm/min, out of which average readings were taken at each fibre loading. All the tests were carried out at room temperature (23 ± 2 °C) with a controlled humidity of $54 \pm 5\%$.

2.4.2 Flexural and impact test

The flexural specimens having dimensions $127 \times 12.7 \times 3.2$ mm³ were prepared according to ASTM D790-99 standard and the tests were conducted at different fibre loadings i.e. 5, 10, 15, 18, 20, 25 wt% in the same machine similar to the tensile tests at a cross head speed of 1 mm/min. The impact test was carried out for above fibre loadings on Izod impact tester (Tinius Olsen IT 504, USA) according to the ASTM D256 standard at a hammer velocity of 3.46 m/s and hammer weight of 0.905 kg. The notched specimens having dimension of $63.5 \times 12.5 \times 3.2$ mm³ were used for the test. Similar to tensile and flexural tests, five specimens were tested at each fibre loading and the average readings were recorded.

2.5 Tribology testing

2.5.1 Abrasive wear test

The dry sliding wear test was conducted by ASTM G-99 specifications using pin-on-disc testing machine under multi-pass two-body abrasion conditions to obtain the abrasive wear characteristics of RF/Epoxy composites. The equipment facilitates to measure friction and wear characteristics in sliding contacts. Sliding occurs between the fixed pin shaped test specimen and a rotating disc. Normal load, rotational speed and wear track diameter were changed following the testing conditions. Frictional force and wear (displacement) were monitored through electronic sensors and recorded with the help of data acquisition software and displayed on a computer. To perform the entire test, the cylindrical pin type specimens of length 35 mm and diameter of 10 mm were prepared and positioned in the sample holder. Then, the specimen holder along with the specimen was placed on a fixed track with a radius of 50 mm. Abrasive paper of 400 grade (i.e. fine grade of grit size ≈ 23 μ m) was used to the rotating disc using a two-sided adhesive tape which was replaced after each test and then the specimen was allowed to abrade for the total sliding distance. The loads (i.e. 5, 10, 15, 20 N) were applied [43] on the loading pan using dead weights to press the specimens to attach to the rotating steel disc, causing the pinned specimen to wear during sliding at different sliding velocities. The sliding velocities of 0.523, 1.047, 1.570 and 2.094 m/s corresponding to 100, 200, 300, and 400 rpm for the test duration of 5 min were calculated as per the following equation.

$$v = \frac{2\pi r N}{60} \quad (1)$$

where, r = track radius and N = rpm.

Before and after each test, the weight of the sample was measured with an electronic weighing machine with an accuracy of ± 0.001 mg, and the loss of weight in grams was noted. A total of five tests were conducted for each fibre loading and applied load and then, the average value was recorded for analysis. The test parameters and test conditions used in this study are listed in Table 1.

Table 1. Details of test parameters in friction and wear test.

Material	Fibre loading (%)	Load (N)	Sliding speed (m/s)	Sliding distance (m)
RF/Epoxy composite	0	5	0.523	157.90
		10	1.047	314.10
		15	1.570	471.00
		20	2.094	628.20
	5	5	0.523	157.90
		10	1.047	314.10
		15	1.570	471.00
		20	2.094	628.20
	10	5	0.523	157.90
		10	1.047	314.10
		15	1.570	471.00
		20	2.094	628.20
	15	5	0.523	157.90
		10	1.047	314.10
		15	1.570	471.00
		20	2.094	628.20
	18	5	0.523	157.90
		10	1.047	314.10
		15	1.570	471.00
		20	2.094	628.20
25	5	0.523	157.90	
	10	1.047	314.10	
	15	1.570	471.00	
	20	2.094	628.20	

2.5.2 Calculation of wear and friction characteristics

The specific wear rates (SWR) of the RF/Epoxy composites were calculated based on their weight loss data by varying load, sliding distance and sliding velocities respectively. The test sample was subjected to run on the rotating disc for a specific test condition after noting down the initial weight. The worn out test specimen was cleaned with acetone soaked in tissue paper and then dried in the air before weighing. Then, the weight loss in grams (i.e. difference in weight) was calculated using the following equation.

$$\Delta W = (m_i - m_f) \tag{2}$$

Where ΔW = Weight loss after each test in gram. m_i and m_f are specimen weights before and after abrasion tests respectively.

The SWR (W_s) was determined using the following equation:

$$SWR = (\text{Weight loss}) / (\text{Density of composite} \times \text{applied load} \times \text{sliding distance}) \tag{3}$$

Frictional force at the sliding interface was calibrated every five seconds using a load cell mounted on the load lever. The friction coefficient (FC) was calculated using following equation:

$$\text{Frictional coefficient} = \frac{\text{Frictional force}}{\text{Applied load}} \tag{4}$$

The surface morphology of worn-out RF/Epoxy composite was studied by using SEM Quanta FEG 650 instruments at 10 kV. The specimen surface was carbon coated to obtain a conducting surface for the electron for microscopic observation.

3. RESULTS AND DISCUSSION

3.1 Determination of optimum weight percentage of RF/epoxy composite

The tensile strengths of RF/Epoxy composites with varying weight percentages of acrylic acid treated rattan fibre were plotted in Fig. 2. From the figure it was observed that the tensile strength increased with fibre loading and then decreased. To obtain the optimum weight percentage of fibre, the tensile strength data were fitted with weight percentage of fibre by a second-degree polynomial curve with regression coefficient (R^2 -value) of 0.9688 which gave the maximum tensile strength (i.e. 47.5 MPa) at 18 wt% of fibre loading.

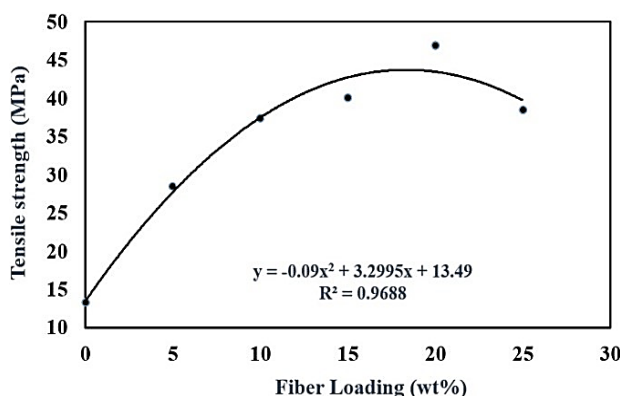


Fig. 2. Tensile strengths of RF/Epoxy composite at various wt% of fibre loadings.

After determining the optimum weight percentage (i.e. 18% of rattan fibre) the composite specimens at 5%, 10%, 15%, 18%, 20% and 25% weight fraction of rattan fibre were fabricated and tested to determine other mechanical and tribological properties.

3.2 Mechanical properties of RF/epoxy composite

The mechanical properties such as tensile strength, Young's modulus, flexural strength, flexural modulus and impact strength were conducted as per ASTM standard. The test samples before and after tensile and flexural tests are presented in Fig. 3 and 4 respectively. The test results are presented in the form of bar charts in Fig. 5.

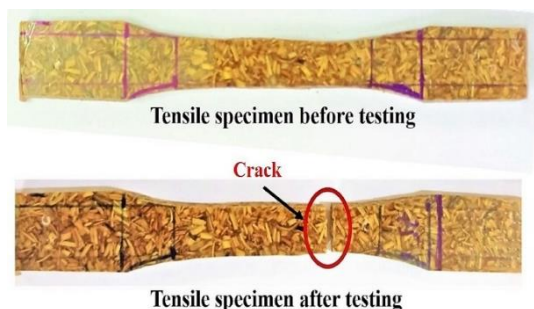


Fig. 3. Before and after test image of tensile specimen.



Fig. 4. Before and after test image of flexural specimen.

Following the common law of short fibre reinforced polymer composites, it is evident from the results that the properties peaks occur at optimum (i.e. 18 wt%) fibre content. After that all the properties show a decreasing trend. The maximum values of tensile strength, flexural strength, and impact strength of acrylic acid treated RF/Epoxy composite at optimum fibre loading are 47.5 MPa, 121.89 MPa, and 3.304 kJ/m² respectively. These values are 21.17%, 32.74%, and 40.10% higher than the corresponding untreated RF/Epoxy composite at optimum fibre loading. Similarly, the Young's modulus and flexural modulus increase by 41.44% and 14.66% respectively. The reason for maximum values of mechanical properties at optimum fibre loading may be due to the fact that at this stage the fibres have reasonable amounts which act as stress transferring medium and also have proper interfacial adhesion between the fibre and matrix. On the other hand, the reason for decreasing trend

in the mechanical properties after optimum fibre loading may be due to insufficient matrix coverage which causes voids to appear thereby leading to poor interfacial adhesion. Further, at higher fibre content, the fibres act as flaws which develops stress concentration areas due to crazing. These are responsible for decreasing in mechanical properties of composites.

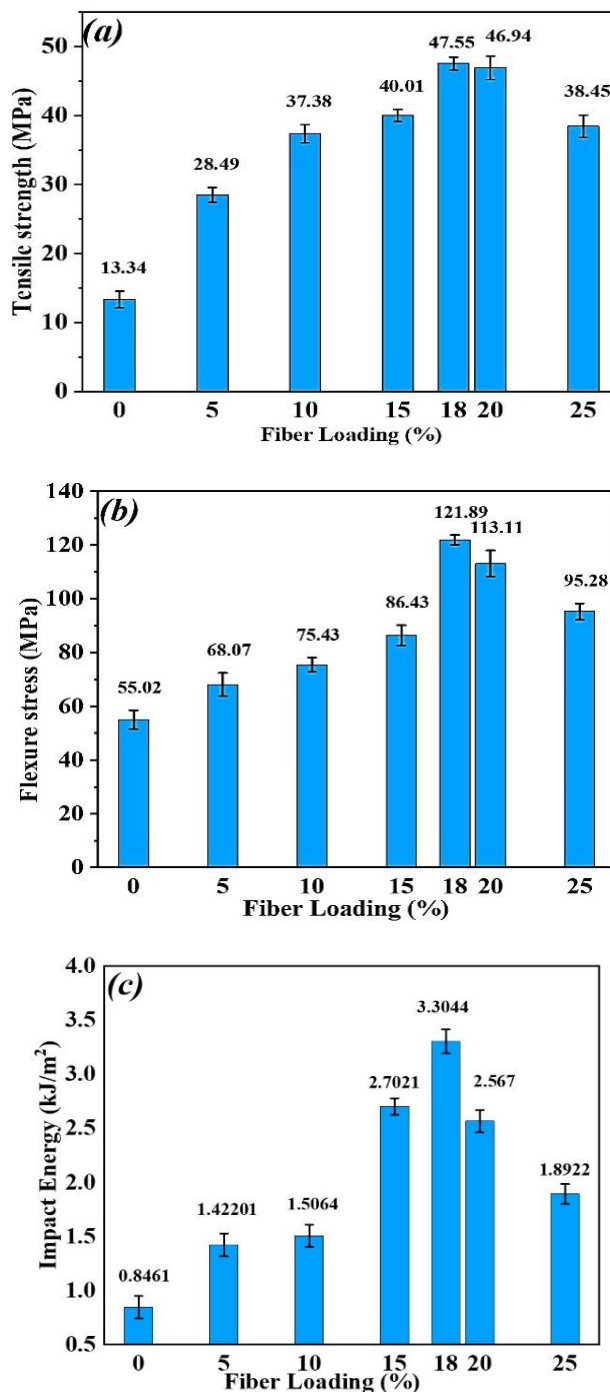


Fig. 5. Bar chart of RF/Epoxy composite at different fibre loadings: (a) Tensile Strength, (b) Flexural Strength, (c) Impact Strength .

3.3 Tribological properties of RF/epoxy composite

3.3.1 Effect of load and fibre loading on specific wear rate (SWR)

The specific wear rate (SWR) of RF/Epoxy composite at different fiber loadings is depicted in Fig. 6 with respect to 0.523, 1.047, 1.570 m/s velocity with varying applied loads of 5, 10, 15 and 20 N at constant sliding distance of 471 m for the duration of 5 min. It is found that with increasing applied load SWR increases at all sliding speeds for both neat epoxy and RF/Epoxy composites. Again, it is revealed from Fig. 6a that at lower speed (i.e. 0.523 m/s) the SWR is less in comparison to higher speeds (i.e. 1.047 and 1.570 m/s) for all weight percentages of rattan fibres (Figs. 6b and 6c). It has been observed that the percentage increase in SWR for composite with 18 wt% fiber loading at constant sliding distance of 471m and velocity of 0.523m/s is 8.71%. This may be due to clogging of wear debris generated during sliding which leads to higher material removal thereby increasing SWR.

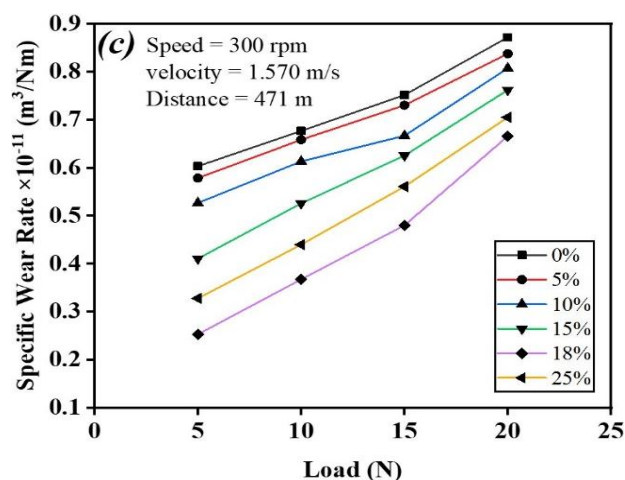
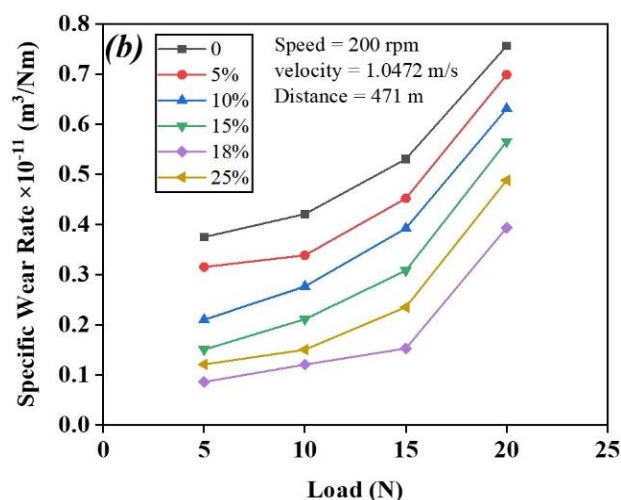
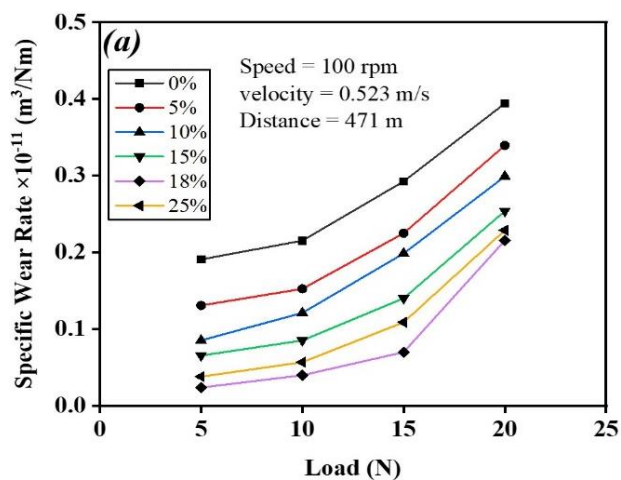


Fig. 6. SWR versus applied load for RF/Epoxy composites at (a) 0.523 m/s (b) 1.047 m/s and (c) 1.570 m/s

Further, Comparing the SWR of RF/Epoxy composite at different fibre loadings (Fig. 7), it is noticed that wear rate decreases with increase in weight percentage of fibres. After reaching a minimum value at optimum fibre loading (i.e. 18wt% of rattan fibre) it subsequently increases. It may be due to the fact that as the fibre content exceeds the optimum value, the fibres get agglomerated and the interaction between the fibre and the matrix is reduced. After optimum fibre loading, the interfacial adhesion between the fibre and matrix is inadequate to withstand sliding force as a result of which the SWR increases. Furthermore, it has been proved earlier by Shalwan and Yousif [44] that the mechanical and tribological performances of most of polymeric composites don't have a significant correlation. However, in the present work, it is observed that there is a good correlation between the mechanical and tribological behaviour of RF/Epoxy composite, particularly at optimum fibre loading.

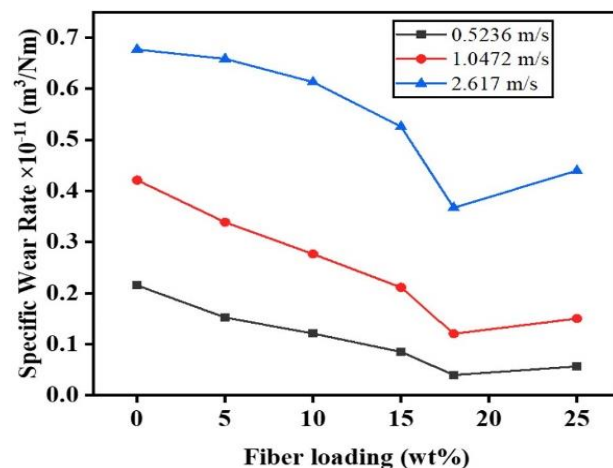


Fig. 7. SWR vs fibre loading of RF/Epoxy composites.

3.3.2 Effect of friction coefficient (FC) on load

The friction coefficients (FC) of RF/Epoxy composite at different fiber loadings with variations of applied loads at constant sliding distance of 471 m with respect to three sliding speeds (i.e. 0.523, 1.047, 1.570 m/s) have been plotted in Fig. 8.

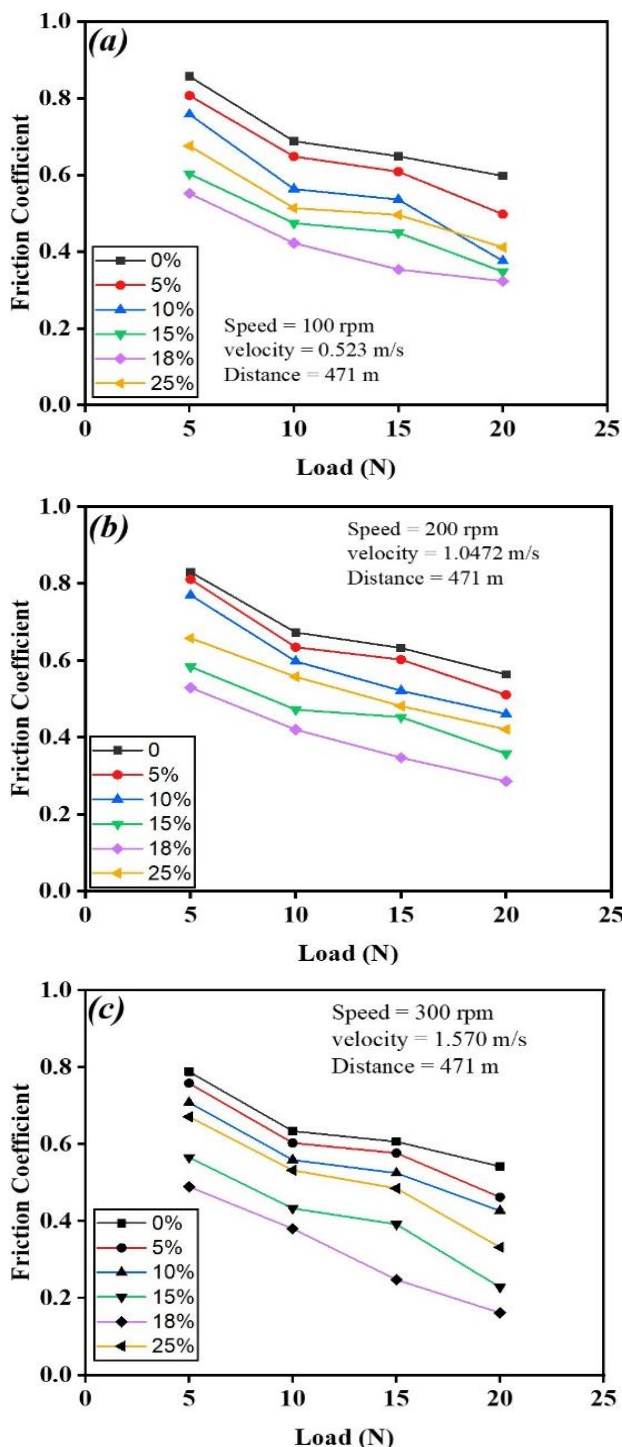
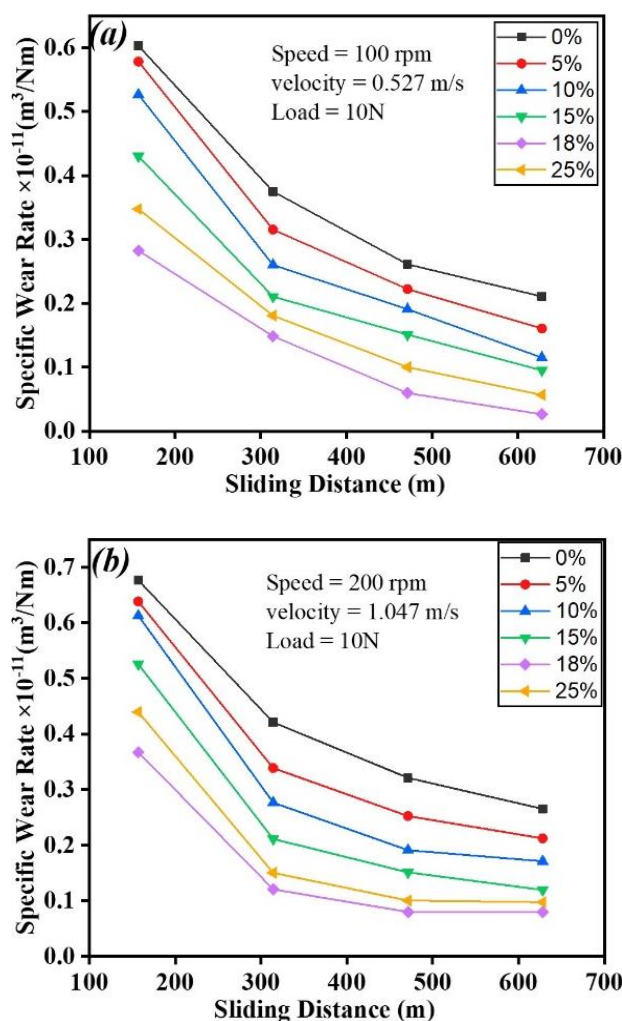


Fig. 8. Fiction coefficient versus load of RF/Epoxy composites at (a) 0.523 m/s, (b) 1.047 m/s, and (c) 1.570 m/s.

From the results it is found that as load increases, FC decreases at different fibre loadings irrespective of sliding speeds. The reason for higher friction coefficient values at low loads may be due to better mechanical interlocking of asperities at the interface. As load increases further, the temperature at the specimen's contact surface increases proportionately, resulting in contact surface heating. Thus, at higher loads friction heat results in micro melting and mechanical damage, which lowers the FC value. Therefore, from the above investigation, it can be stated that addition of rattan fibre in the composite lowers the friction coefficients.

3.3.3 Effect of specific wear rate on sliding distance

Figs. 9 provides the variation of SWR with sliding distance of RF/Epoxy composite at constant load of 10N at three consecutive sliding velocities.



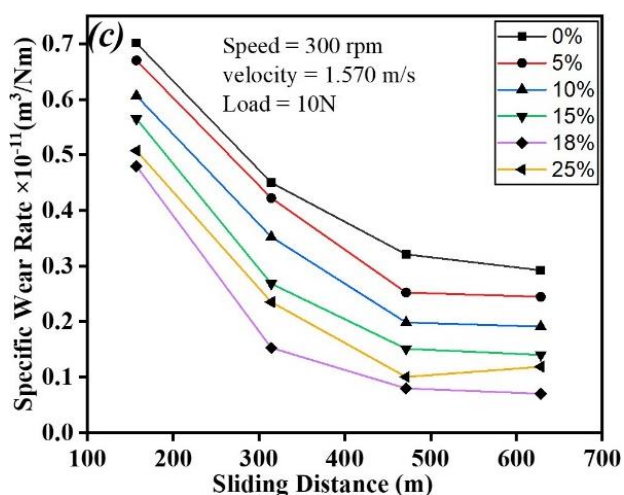


Fig. 9. SWR versus sliding distance (at 10 N) of RF/Epoxy composite at (a) 0.523 m/s (b) 1.047m/s and (c) 1.570 m/s.

The graphical results show that there is a decrease in SWR with sliding distances irrespective of sliding velocities. It has been observed from Fig. 9a that the percentage decrease in SWR for composite with 18 wt% fiber loading at constant load of 10 kN and velocity of 0.523m/s is 7.028%. This may be attributed to the multi-pass abrasion condition in which the severity of the abrasives decreases with repeated passes causing minimum wear for maximum test duration. As a result, the material removal rate decreases as the sliding distance increases. The results of coefficient of friction and specific wear rate of RF/Epoxy composites at different fibre concentrations are shown in Table 2.

Table 2. Coefficient of friction and specific wear rate of RF/Epoxy composites at different fibre loadings.

Fibre loading	Coefficient of friction (μ)	Specific wear rate $\times 10^{-11}$ (kN/m^2)
Neat epoxy	0.541-0.856	0.190-0.871
5%	0.462-0.806	0.130-0.837
10%	0.426-0.758	0.085-0.807
15%	0.227-0.602	0.065-0.761
18%	0.161-0.551	0.023-0.665
25%	0.331-0.675	0.037-0.704

3.3.4 Examination of worn surfaces' morphology

Fig. 10. Shows the microscopic observation of worn-out surfaces of the RF/Epoxy composite at optimum fibre loading (i.e. at 18 wt%) at 314.10 m sliding distance and 10 N load. From the figure it is observed that with increase in sliding velocity, the surface deterioration and matrix breakage become

predominant. The marks of ploughing and cutting are also visible in SEM images of RF/Epoxy composite, which confirms the abrasive wear mechanism. Further, all composite samples contain micro cracks and grooves which are due to the rubbing action of the composite sample with the disc. In addition to that almost rough surface is noticed at higher sliding velocities showing a higher material removal process, which is one of the causes of increasing the wear rate.

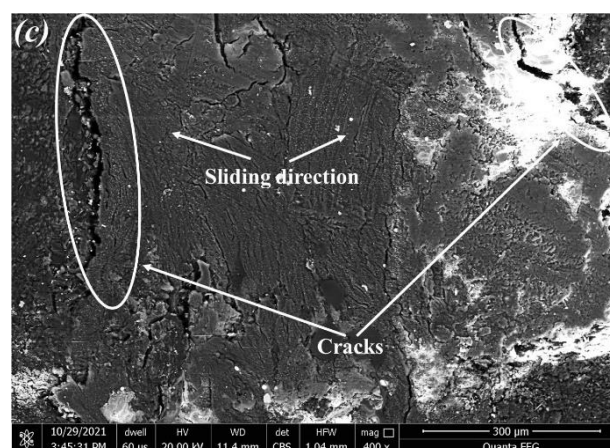
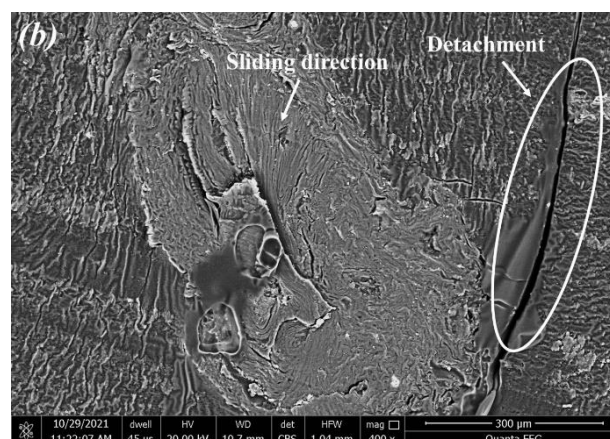
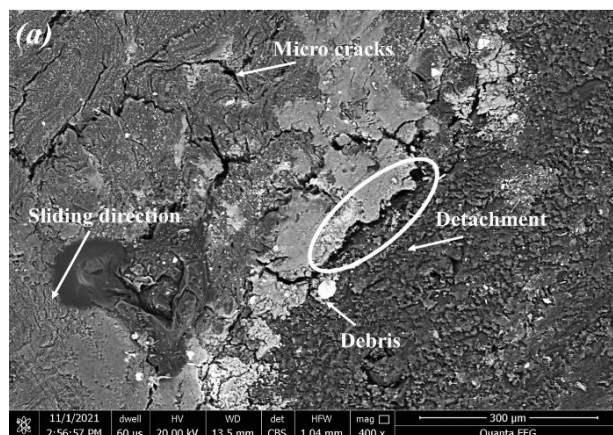


Fig. 10. SEM images of worn-out 18 wt% RF/Epoxy composite at (a) 0.523 m/s (b) 1.047 m/s and (c) 1.570 m/s.

4. CONCLUSION

In the present study, the friction and wear performances of RF/Epoxy composite have been evaluated and the following conclusions are drawn:

1. The maximum values of tensile strength, flexural strength, and impact strength of acrylic acid treated RF/Epoxy composite at optimum fibre loading (i.e. at 18 wt%) are observed to be 21.17%, 32.74%, and 40.10% higher in comparison to untreated one.
2. The specific wear rate (SWR) of RF/Epoxy composite is found to be directly proportional to the applied load and increases with increasing applied load and sliding velocity, whereas it decreases with increasing fibre content up to optimum fibre loading and then after increases. Further, this value drops proportionately as a function of the sliding distance and sliding velocity. The increase in SWR with load is more in comparison to decrease in SWR with sliding distance.
3. The friction coefficient at all sliding velocities decreases as applied load increases. The composite with optimum fibre loading shows lowest frictional coefficient which is due to mechanical interlocking of asperities at the interface.
4. From the current investigation it is observed that the tribological performances of RF/Epoxy composite are superior at optimum fibre loading (i.e. at 18 wt%). Further, it is found that there is a good correlation between the mechanical and tribological behaviour of the fabricated composite which is the novelty of the work.
5. From the worn out surfaces it is observed that with increasing sliding speed the surface deterioration and matrix breakage becomes predominant reducing the composite's wear resistance.
6. Based on tribological performance of RF/Epoxy composite particularly with 18 wt% fiber loading, it can be used as modern friction materials used in automobile braking system replacing asbestos from environmental point of view.

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