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Research article

Effect of fiber layer formation on mechanical and wear properties of natural fiber filled epoxy hybrid composites

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A R T I C L E I N F O

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Layer formation
Tensile
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Wear rate

A B S T R A C T

Natural fiber-reinforced polymer matrix composites are gathering significance in future trend applications such as automotive, aerospace, sport, and other engineering applications due to their superior enhanced mechanical, wear, and thermal properties. Compared to synthetic fiber, natural fiber is low adhesive and flexural strength properties. The research aims to synthesize the epoxy hybrid composites by utilizing the silane (pH = 4) treated Kenaf (KF) and sisal fiber (SF) as layering by uni, bi, and multi-unidirectional via hand layup techniques. Thirteen composite samples have been prepared by three-layer formation adopted with different weight ratios of E/KF/SF such as 100E/0KF/0SF, 70E/30KF/0SF, 70E/0KF/30SF, 70E/20KF/10SF, and 70E/10KF/20SF respectively. The effect of layer formation on the tensile, flexural, and impact strength of composites is studied by ASTM D638, D790, and D256 standards. The unidirectional fiber layer formed (sample 5) 70E/10KF/20SF composite is found maximum tensile and flexural strength of 57.9 ± 1.2 MPa and 78.65 ± 1.8 MPa. This composite is subjected to wear studies by pin-on-disc wear apparatus configured with a hardened grey cast-iron plate under an applied load of 10, 20, 30, and 40 N at different sliding velocities of 0.1, 0.3, 0.5, and 0.7 m/s. The wear rate of the sample progressively increases with increasing load and sliding speed of the composite. The minimum wear rate of 0.012 mg/min (sample 4) is found on 7.6 N frictional force at 0.1 m/s sliding speed. Moreover, sample 4 at a high velocity of 0.7 m/s with a low load (10 N) shows a wear rate of 0.034 mg/min. The wear-worn surface is examined and found adhesive and abrasive wear on a high frictional force of 18.54 N at 0.7 m/s. The enhanced mechanical and wear behavior of sample 5 is recommended for automotive seat frame applications.

1. Introduction

The polymer-based composites possess organic base polymer bonding with short or continuous fiber. Based on the fiber

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reinforcements, the polymer matrix composites are fiber composite, nanocomposite, and hybrid nanocomposite. At the earliest, the synthetic fiber-reinforced polymer matrix found distinctive properties rather than monolithic materials [1,2]. However, synthetic fibre's disposal and environmental stability is the major drawback in petroleum, natural gas, and coal mineral industries [3,4]. Similarly, synthetic fiber is high-cost, has a short life span, and is non-biodegradable [5]. To overcome the above drawback, researchers are finding natural fiber as the best alternative to synthetic fiber [6,7]. Recently, jute, hemp, leaf fiber, pineapple, date palm fiber, bamboo, sisal, ramie, coir, and flax have been utilized as sustainable reinforcement in the polymer matrix and is gathering importance in several industries like in the automotive, medical field, construction, packing, and furniture applications [8–11] due to their benefits of less density, high tensile strength and stiffness, good flexural strength, nontoxic, economical, renewable, and readily available from nature [12–17]. However, the above-mentioned natural fibers have a drawback of moisture absorption, which results in poor interfacial bonding and instability with polymer matrix [18] and to minimize the drawback, chemical-based surface treatment like silane, alkali, benzoylation, acetylation, peroxide, maleated coupling, isocyanate, sodium chloride, and calcium hydroxide was adopted [19,20]. Among the various fiber, the Kenaf and Sisal fibers were commercially available at low cost and had good sustainability reinforced with different polymer matrix composites are found to enhance mechanical and thermal properties [21–23].

Moreover, Kenaf fiber was good compatibility with epoxy and phenolic resin [24]. Anand et al. [25] fabricated epoxy hybrid composite bonded with Kenaf/Jute fiber via hand layup route and its composites were evaluated by ASTM standards. The chemical-treated Kenaf/Jute fiber epoxy composite was found to enhance tensile (53.64 MPa), flexural (866.286 MPa), compressive (604,564 MPa), and impact (0.79 J) strength. The moisture absorption (2 h) of treated hybrid composite has good results compared to untreated composite. The effect of agro-waste rice husk filler on epoxy composite's physical, mechanical, and tribological characteristics was analyzed by ASTM standards. The composite contained 6 wt% of agro-waste rice observed as having maximum mechanical and tribological properties. The mechanical strength (tensile) of the composite was improved by 34.42% and limited the wear on 5.5 m/s at 20 Naverage load [26]. Conventional hand layup technique developed Kenaf/bamboo fiber/epoxy hybrid composite void content, mechanical and acoustic behavior was evaluated and woven treated Kenaf/bamboo fiber (70:30 wt% ratio) found reduced void content (3.20%) compared to untreated fiber [27].

Khan et al. [28] synthesized the natural fiber composite with different stacking positions via hand layup technique for automotive and aircraft applications. The effect of stacking position on the tensile and flexural strength of the composite was studied and reported that the orientation order of kenaf-jute-kenaf lamina offers high tensile (43.21 MPa) and flexural strength (75.57 MPa). According to the past literature review, the natural fiber composites are prepared with different stacking positions resulting in improved mechanical properties. The present work is fabricating the epoxy hybrid composite with the multi, bi, and uni-directional formation of kenaf and sisal fiber (silane treated). The effect of fiber formation on the tensile, flexural and impact strength of the composite is studied and the optimum enhanced composite sample is subjected to wear behavior studies.

2. Material and methods

2.1. Epoxy and natural fiber selection

Low-density (1.15–1.2 g/cc) liquid phase epoxy resin (LY556) and (HY951) hardener is chosen (10:1) as a base matrix due to its good adhesive behavior, better dimension stability, and easy processing [11,14].

The natural Kenaf and sisal fiber were chosen as filler materials due to their low density (Kenaf - $\rho_{KF} = 1.5$ g/cc; sisal $\rho_{SF} = 1.3$ g/cc), good mechanical strength, and good thermal stability.

2.2. Silane solution treatment of fiber

Fig. 1 illustrates the processing of natural fibers. Initially, the natural Kenaf and sisal fibers are washed with distilled water and

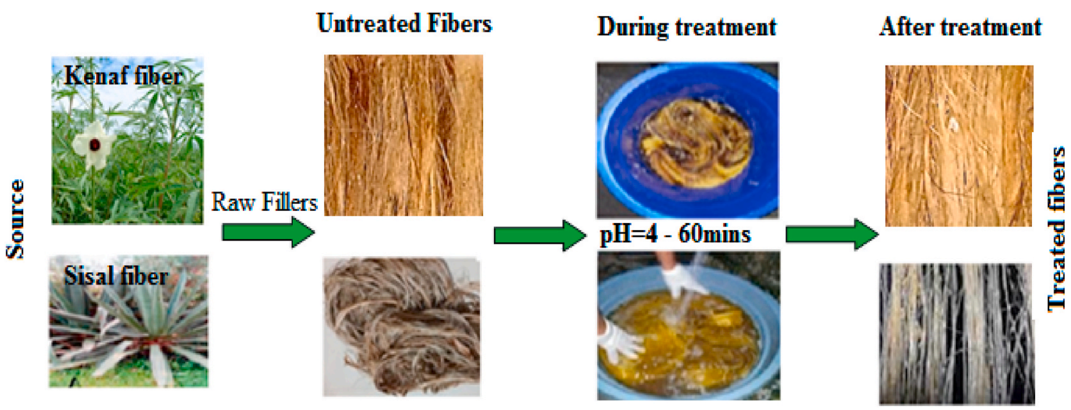

Fig. 1. Biodegradable natural fiber processing with Silane solution.

dried at ambient temperature for 24hr. After the fibers are kept in a separate bowl filled with (pH = 4) silane solution and processed for 60min. Finally, treated Kenaf and sisal fibers were dried at ambient temperature for 48 Hrs. The silane process helps control the hydrophilic characteristics of natural fiber and enriched its physical and mechanical behaviors.

2.3. Fabrication process

A low-cost hand layup technique assisted with a hot press route is adopted for epoxy hybrid composite fabrication. Table 1 represents the weight ratios of epoxy composite with their (uni, bi and multi-directional) formation of composites.

Fig. 2 shows the actual flow process diagram for epoxy hybrid composite fabrication. In the first step, epoxy resin and hardener are blended 10:1 ratio via manual stir. Next step, the rectangular mold pattern was placed over the steel base and releasing agent was applied manually.

Next step, Silane-treated Kenaf fiber was placed uni-directionally evenly along the epoxy matrix. Similarly, the remaining layers were stacked and bonded with an epoxy solution. Finally, the layers were compressed axially with an applied load of 20 KN at 50 °C·In the last step, the developed composites were cured by ambient temperature. A similar procedure was repeated for bi and multi-directional composites.

2.4. Characterization of developed composite samples

2.4.1. Ultimate tensile strength

Fig. 3 represents the ultimate tensile strength of a) the test sample fixed by the UTM jaw and b) the ASTM D638 dimension. The ultimate tensile strength (UTS) of developed composites is evaluated by an Instron-3367 tensile testing machine with 30 KN capacity and was equipped with an intelligent controller system. The three trails are tested by each composite sample.

2.4.2. Ultimate tensile strength

The flexural strength of developed composite samples is tested by an Instron compression testing machine (ASTM D790–100 × 12.7 × 3.5 mm^3) with uniform cross slide movement of 3 mm/min under test room condition maintained with 25 ± 1 °C with 52 ± 5% of relative humidity. Fig. 4 illustrates flexural strength test samples. In each sample, 3 trials are tested and the mean is considered.

2.4.3. Impact strength

The ASTM D256 standard evaluates the impact toughness (strength) of prepared composites are shown in Fig. 5.

2.4.4. Wear properties

The rotary type Ducom-pin-on-disc wear tester equipped with a grey cast-iron plate counter-face is utilized to evaluate the wear behavior (ASTM G99-05), and a Scanning electron microscope (SEM)is utilized to locate the wear debris area. The actual wear experimental setup is shown in Fig. 6.

3. Results and discussions

3.1. Influence of fiber orientation on ultimate tensile strength (UTS) of prepared composite samples

Fig. 7 illustrates the ultimate tensile strength of developed composite samples. It has been noted in Fig. 7 that the UTS of the uni-directional developed sample 1 composite was found to be 46.5 ± 0.8 MPa. The ultimate tensile strength of sample 2 and sample 3 shows between 39.2 ± 0.7 to 39.8 ± 0.9 MPa. The decreased ultimate tensile strength of composite samples 2 and 3 was due to the presence of the fiber layer and its bonding strength. However, samples 4 and 5 significantly increased by 24.2% and 24.5% compared to sample 1. Sample 5 (epoxy-70/Kenaf-10/sisal-20) is found to have a higher UTS of 57.9 ± 1.2 MPa. The improved UTS of the composite is the reason for effective interfacial strength between matrix and filler materials [9,10]. Sample 5 could withstand the maximum tensile force (1.48 KN) during the evaluation. Compared to bi and multi-direction fiber formations, the tensile strength of the uni-directional composite is enhanced and sisal fiber resists the high tensile force (1.48 KN).

The epoxy composite's bi-directional and multi-directional fiber orientation was found to have similar variations for unidirectional fiber formations. The ultimate tensile strength of bi-directional fibre formation sample 1 was found 43.4 ± 0.8 MPa, and sample 2 was

Table 1
Layer formation details of epoxy hybrid composite fabrication with different weight ratios.

Sample	Composites	Weight ratio percentages in Wt.%			No of layers		Layer formation		
		Epoxy	Kenaf fiber	Sisal fiber	Kenaf fiber	Sisal fiber	Stage 1	Stage 2	Stage 3
1	Epoxy	100	0	0	0	0	Uni-directional	Bi-directional	Multi-directional
2	Epoxy/Kenaf	70	30	0	3	0			
3	Epoxy/Sisal	70	0	30	0	3			
4	Epoxy/Kenaf/Sisal	70	20	10	2	1			
5	Epoxy/Kenaf/Sisal	70	10	20	1	2			

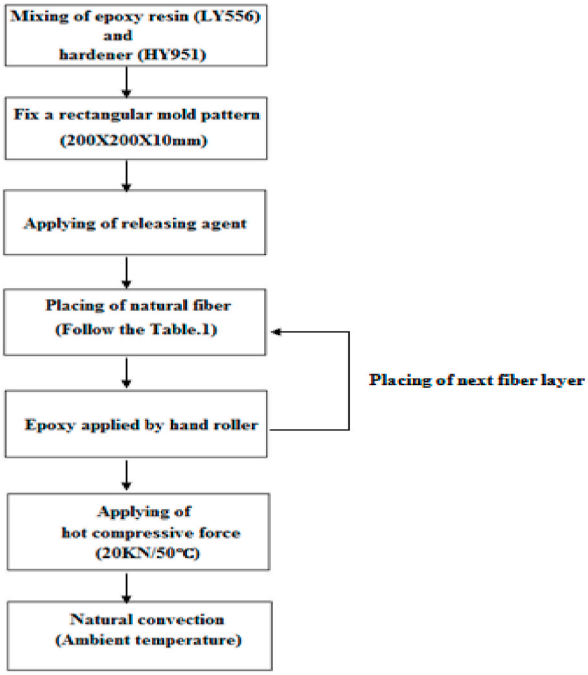

Fig. 2. Flow process diagram for composite fabrication by hand layup.

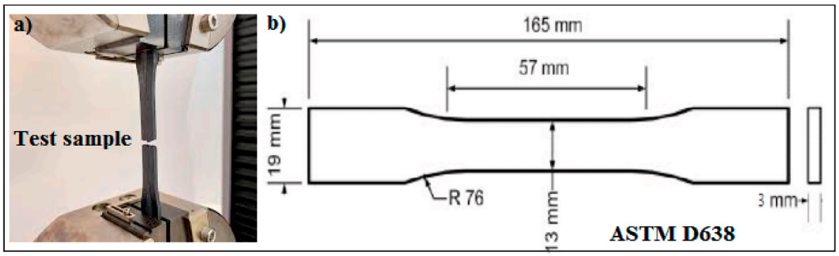

Fig. 3. Ultimate tensile strength test a) test sample b) Dimension of ASTM D638.

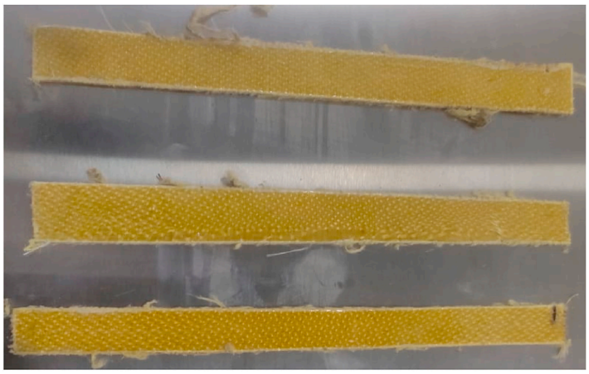

Fig. 4. Flexural strength of composite test sample.

decreased by 16% because the mono fiber (Kenaf fiber) is a bi-directional formation with our chance to break at high tensile force [18]. The UTS of sample 3 was found 48.81 ± 0.8 MPa. However, the mono fiber-filled epoxy composite showed the minimum variations in tensile strength. The ultimate tensile strength of sample 4 and sample 5 was enhanced by the addition of both Kenaf and sisal fiber.

It was noted from Fig. 7, that the ultimate UTS of multidirectional composite samples is larger than the UTS of bi-directional

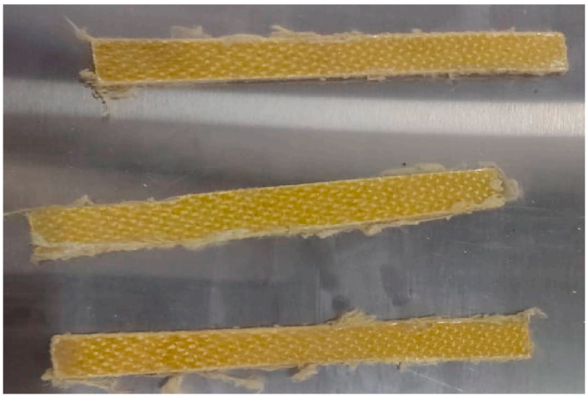

Fig. 5. Impact strength of composite test sample.

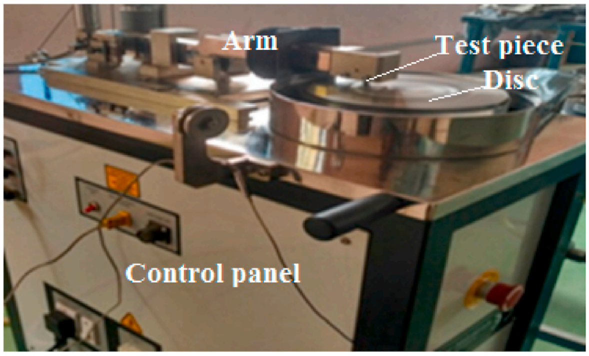

Fig. 6. Actual wear experimental setup.

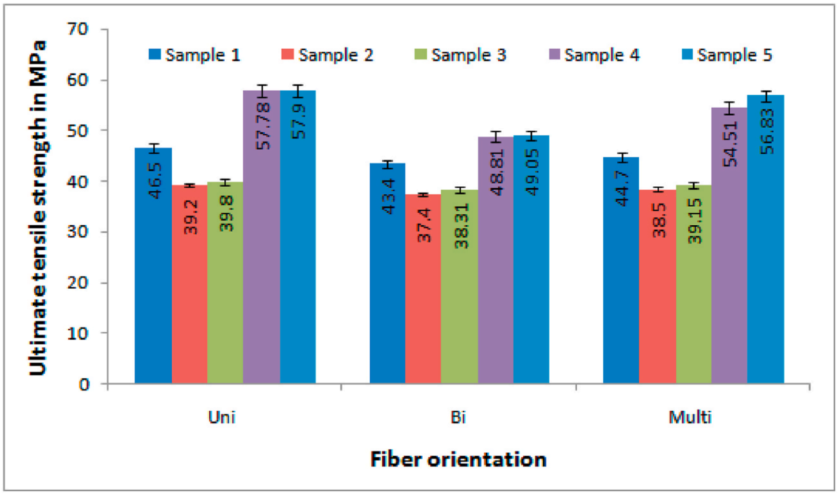

Fig. 7. UTS of fabricated composite samples.

composites. The UTS of sample 1 was found to be 44.7 ± 0.7 MPa and 38.5 ± 0.9/39.15 ± 1.1 MPa was noted by sample 2/sample 3. The decreased UTS of the composite sample was due to the poor interfacial reactions between the matrix and reinforcement filler [14]. Sample 5 found maximum tensile strength and increased by 15.86% compared to the bi-directional developed composite sample 5. However, sample 5 fabricated by unidirectional fiber reinforced composite contained 70 wt % epoxy/10 wt % Kenaf/20 Wt. % sisal fiber showed the maximum UTS as compared to bi/multi-directional fiber orientation. Moreover, unidirectional fiber bonded composite tensile strength was increased by 5% compared to Bamboo/Kenaf Fiber boned Epoxy Hybrid Composites [27].

3.2. Influence of fiber orientation on flexural strength (FS) of composite samples

Fig. 8 illustrates the FS of unfilled and fiber-filled composite developed by different formations via the hand mold route.

The flexural strength of sample 1 was found to be 62.8 ± 1.12 MPa on unidirectional formations and decreased by 59.61 ± 0.8 MPa&58.54 ± 0.9 MPa for the fiber formations of multi and bi-directional. Similarly, samples 2 and 3 were decreased progressively with changing of fiber formations as bi and multi-directional fiber orientation. Sample 4 and sample 5 was increased progressively and found maximum flexural strength of 78.19 ± 1.1 MPa and 78.65 ± 1.8 MPa.The enhancement of epoxy composite by Kenaf/sisal fiber was 4.7% compared to Kenaf/Jute hybrid composite [28]. The chemical-treated natural fibers are the prime reason for the increased flexural strength of composite as well facilitate good adhesive properties. The flexural strength of the unidirectional composite is larger than the FS of the bi and multi-directional orientation. However, the sample 4 and 5 composites noted high flexural strength compared to epoxy and mono fiber (KF or SF)bonded epoxy composites.

3.3. Influence of fiber orientation on the impact strength of composite samples

Fig. 9 shows the impact toughness of the epoxy composite developed by the different formations of Kenaf/sisal fiber. The impact toughness of sample 1 (epoxy composite) synthesized by a unidirectional process was found 29.4 ± 0.5 kJ/m^2 and it was decreased by 10.17 ± 0.6 kJ/m^2 (sample 2). The increased impact toughness of the epoxy composite is the reason for the natural fiber ability to endure the maximum sudden high-impact load [18].

It may due to porous content in the internal surface of the composite after the molding process. Further, change in stacking lamina based on the formation Table .1. The impact strength of unidirectional developed samples 3, 4, and 5 were progressively increased by 12.5%, 25.6%, and 25.9% as compared to unidirectional fabricated sample 2. However, the impact strength of samples 2, sample 3 and samples 4 & 5 were lower than the impact strength of sample 1.

The impact toughness of the bi-directional synthesized composite has lower than the unidirectional composite samples. The graph revealed in Fig. 9, the impact toughness of the composite decreased gradually with an increase in fiber layer of more than one KF. The impact toughness of composite sample 3 was found 9.1 ± 0.5 $kJ/m^{2.}$ It was noted from Fig. 10; the impact strength of multi-directional orientation sample 1 was 21.984 kJ/m^2 and the mono combinations of Kenaf fiber/epoxy were limited by 33.75 %and SEC sample 3 was limited by 10.72% compared to sample 1 (unidirectional).

Based on the evaluated results for the mechanical behavior of epoxy composite, the sample 5 epoxy hybrid composite developed by uni directional found enhanced ultimate tensile strength (57.9 ± 1.2 MPa), and flexural strength (78.65 ± 1.8 MPa). But the impact strength of sample 5 was lower than the impact strength of sample 1.

3.4. Influence of fiber orientation on the wear rate of composite samples

The wear rate of the epoxy hybrid composite containing 70E/10KF/20SF (sample 5) is measured by 10 N, 20 N, 30 N, and 40 Nloads with 0.7 m/s (Fig. 10).

The composite's wear rate progressively increased with an increase in load from 10 N to 40 N at 10 N intervals. The wear rate of the composite was found to be 0.034 mg/min on the applied average load of 10 N and was increased to 0.036 mg/min by 20 N load. The increased wear rate was because high sliding speed leads to increased wear. Further improvement in average load, the sample wear rate was improved by 0.038 mg/min and 0.041 mg/min at a constant sliding speed of 0.7 m/s. The maximum wear rate of 0.041 mg/min was found on the 40 N applied average load with a relational frictional force of 18.54 N was noted. However, the composite wear

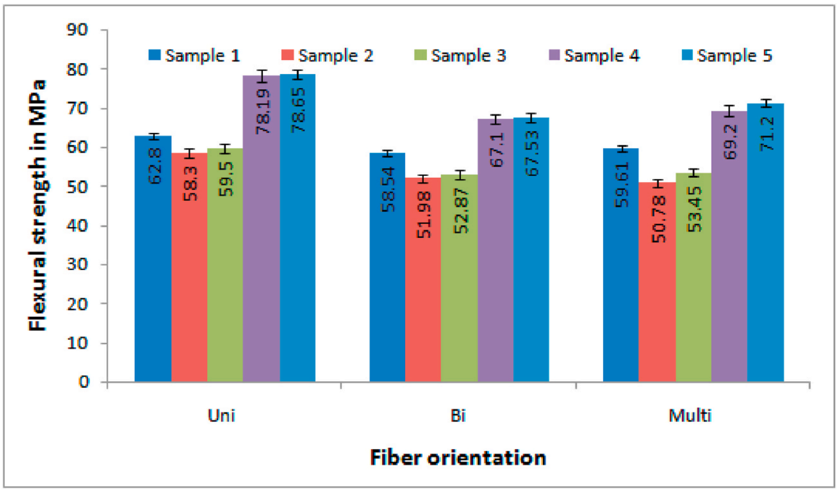

Fig. 8. Flexural strength (FS) of composite samples.

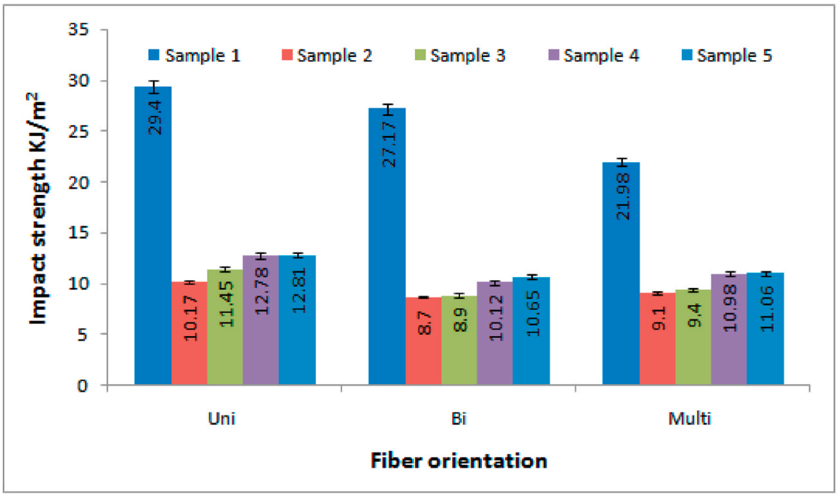

Fig. 9. Impact strength of composite samples.

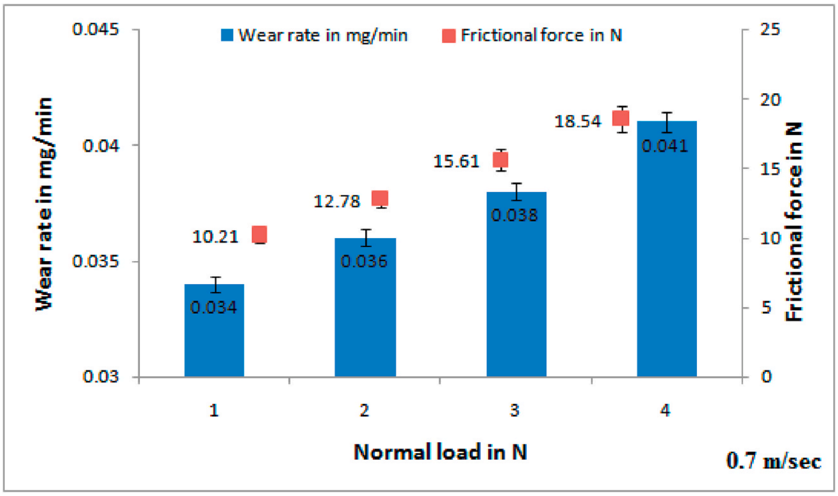

Fig. 10. Wear rate of sample 5 (unidirectional composite)at 0.7 m/sec

rate was slightly improved because both treated sisal and Kenaf fiber could withstand the high frictional force and were stable in higher temperatures.

Fig. 11 illustrates the wear rate of sample 5 (unidirectional composite) evaluated by the different sliding speeds of 0.1 m/s, 0.3 m/s, 0.5 m/s, and 0.7 m/s at the high load of 40 N. The wear rate of the composite was gradually increased and maintained minimum wear loss at maximum sliding speed. The wear rate of the sample 5 composite was evaluated by 0.1 m/s sliding speed found to be 0.012 mg/min at 40 N applied average load on the relational frictional force of 7.6 N. While the sliding speed increased from 0.3 m/s to 0.7 m/s, the wear rate increased by 0.03, 0.039, and 0.041 mg/min. The higher sliding speed leads to the diffuse the epoxy phase in the filler phase and resists wear against the high frictional force.

3.5. SEM evaluations for wear test sample 5 (unidirectional composite)

Fig. 12 illustrates the SEM image of wear-tested sample 5 (unidirectional developed composite sample) by 30 N load at 0.7 m/s sliding speed. The fiber materials were diffused and adhesive with an epoxy layer, as evidenced in Fig. 12. Because the Silane treated fibres withstand the high frictional force temperature. While compared to sample 1 (unidirectional), sample 5 is low wear surfaces with a small micro-crack noted.

However, few micro-cracks and porosity were observed in Fig. 8. The microporous and cracks may decrease the tribological characteristics.

Fig. 13 illustrates the SEM image of wear-tested sample 5 (developed y unidirectional fiber formations) at 40 N load/0.7 m/s sliding speed. While the increase in average load from 30 N to 40 N, SEM found abrasive wear. It was due to the high load forced to epoxy

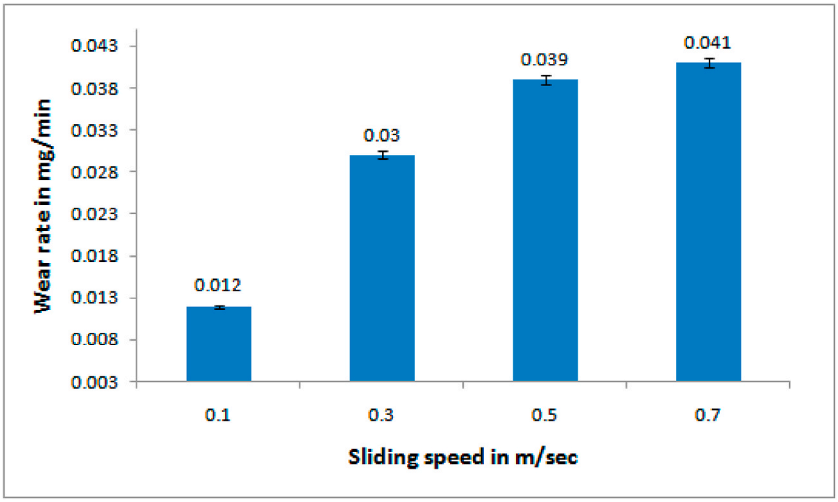

Fig. 11. Wear rate of sample 5 (unidirectional composite) at 40 N load.

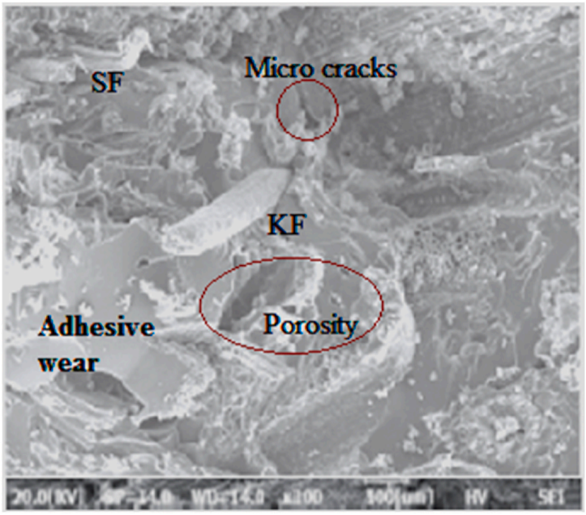

Fig. 12. SEM image of wear-tested sample 5 (unidirectional composite) at 30 N/0.7 m/sec

composite solid surface cut and plows the small patches. It was evidenced in Fig. 13. Moreover, a high frictional force of 18.54 N may lead to an increase in frictional surface temperature, results diffused fiber face.

4. Conclusions

The epoxy hybrid composite is synthesized by using silane-treated natural Kenaf and sisal fiber with uni, bi, and multi-directional fiber formations on different layers via hand layup technique. Among the various formations of natural fiber, the uni-directional composed epoxy composite found good mechanical behavior and specifically sample 5 tensile and flexural strength increased by 15.86% and 16.46% as compared to bi-directional orientation sample 5. Moreover, the sample 5 of the unidirectional composite is found to have optimum UTS and FS was hicked by 24.51% and 25.23% compared to sample 1 composite. The impact strength of the sample 5 composites is limited by 12.81 ± 0.5 kJ/m^2. The wear behavior of sample 5 (unidirectional developed composite) was successfully tested by 10–40 N normal load and varied sliding velocity (0.1, 0.3, 0.5, and 0.7 m/s). The wear rate of 0.041 m/min was found at 40 Naverage loads at 0.75 m/s sliding speed. The SEM image revealed the wear debris surface and identified adhesive and abrasive wear during high load and sliding speed.

Author contribution statement

R. Venkatesh: Conceived and designed the experiments.

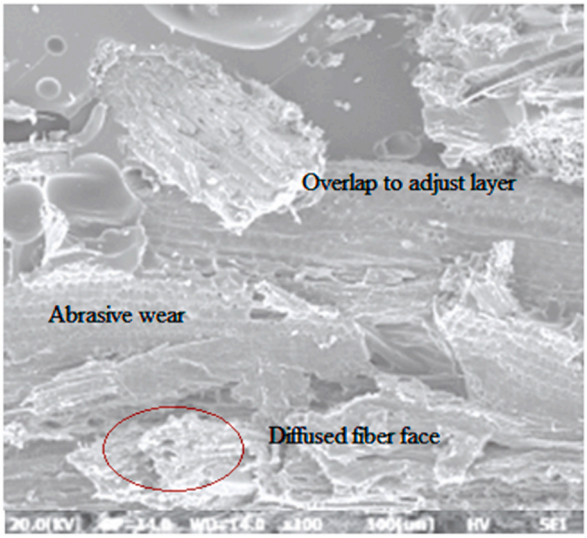

Fig. 13. SEM image of wear-tested sample 5 (unidirectional composite) at 40 N/0.7 m/sec

Suhas Ballal: Performed the experiments.
A.Mohana Krishnan: Analyzed and interpreted the data.
S.Prabagaran, S. Mohankumar: Contributed reagents, materials, analysis tools or data.
Elangomathavan Ramaraj: Analyzed and interpreted the data; Wrote the paper.

Data availability statement

Data will be made available on request.

Funding statement

The authors declared that no funding was received for this Research and Publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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