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An Investigation on Tribology Properties of Abutilon Indicum Fibre Reinforced Polymer Composites

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Abstract:

This research work investigates the tribological characteristics of Abutilon Indicum Fiber (AIF) reinforced composites with epoxy as the binding agent. The Abutilon Indicum fiber reinforced tribo-composites were manufactured by compression molding technique. These composites were fabricated by varying the fiber volume fraction ranging from 5%, 10%, 15% and 20% respectively and considering the fiber length as a fixed factor due to its short length. This research paper illustrates the effects of different fiber volume fractions (5,10,15 and 20%) on the tribological properties such as Specific wear rate (SWR) and Coefficient of friction (μ) of Abutilon Indicum fiber reinforced composites. Sliding wear tests were carried out under dry environment conditions with pin-on-disc wear testing machine. The experiments were performed for each tribo-composites with different combinations of testing parameters, sliding loads in the range of (10, 20 and 30 N); sliding distances (1,2 and 3 km); sliding speeds (1,2 and 3 m/s). Shore D hardness of these composites was determined. Results conclude that the addition of AIFs in these tribo-composites enhanced the tribological performance with good wear resistance in relation with the pure epoxy-based composites. Specifically, composites produced with 15% volume fraction of AIFs displayed best results with higher resistance to wear at various operating conditions. Optimal fiber volume fraction of 15% was suggested in fabrication of composites for usage of AIFs as friction material and for other commercial applications. Additionally, the surface texture of these different tested composites was analysed by scanning electron microscopic images to examine the wear patterns and mechanism.

Keywords: Abutilon Indicum fiber (AIF); Tribology; Polymer composites; Wear; Volume fraction; Sliding distance and Sliding velocity.

Introduction:

Industrial needs and advanced technologies in the earlier decades have led to the innovation and development of several newer products. Industrial production in these days has also led to the emissions of wastes, slags in huge volumes and has caused significant hazards to the environment. Recycling or reusage of such wastes involves several processes and proves to be expensive and involves significant time. The hazardous wastes and carbon enriched gas emissions to the environment have urged the researchers and metallurgists towards developing products against the utilization of non-renewable resources and other form of synthetic materials [1–3]. Simultaneously, greener and eco-friendly materials derived from nature and other form of renewable resources are being utilized in diverse industrial fields such as automobile, construction and building materials, aerospace and other commercial applications. Materials utilized from one such form of renewable resources are the fibers which are derived from sources of nature such as plants, animals and other form of biological resources. Fibers derived from plants are ecofriendly, available in larger sources, lesser in cost, biodegradable and can be used as a reinforcement material for cleaner production of newer products [4].With this context, natural fiber reinforced polymer composites (NFPCs) have gained significant attention and have been used as a tribo-composite and other forms of mechanical parts.

Apart from the conventional form of natural fibers namely Jute, Coir, hemp, bamboo, silk, banana and kenaf, several other newer cellulosic fibers are identified as a suitable reinforcement material in composites. In this regard, Abutilon Indicum Fiber (AIF), a newer cellulosic fiber obtained from the 'Thuthi Plant' stem was characterized and its suitability evaluation for reinforcement in polymer composites was investigated in the earlier research studies [5]. Among different plants available in the southern hemisphere of indian sub-continent, Thuthi plants and its leaves are mainly grown for its medicinal purpose. Research investigations on the physico-chemical properties reveal that AIFs display higher thermal stability and can also be used as a reinforcement material in manufacturing of tribo-composites [6]. In recent years, NFPCs due to its light weight have extensively found its applications in specific commercial products like brake pads, automotive interiors, telephone stand, machine tools and other textile components [7]. Such products manufactured by NFPCs are subjected to combined static-dynamic nature of loads and are prone to fracture and damage due to the severe frictional force in between the surfaces. Hence in design and development of such commercial products and other machine elements, the phenomenon of tribology (Wear, Friction and lubrication) plays a significant role and henceforth the investigations on tribological performance of NFPCs have gained significant attention [8–10].

The control parameters associated with the tribological performance of composite materials are the sliding speed, sliding velocity, sliding distance and the environment conditions (dry and wet lubrication conditions). The tribological performance predominantly focusses on the evaluation of specific wear rate (SWR) and friction coefficient (μ) and its effects over the control parameters [11, 12]. Literature studies convey that various research works have been carried out in evaluation of tribological performance for a wide range of NFPCs, filler materials and other form of hybrid composites. Raw Cyperus pangorei (CP) fiber reinforced composites with 40% wt were fabricated by compression molding technique and its tribological performance was investigated. The shore D hardness of these composites is 87.25. Experiments performed under the conditions of 1-3 m/s speed; pressure of 0.13-0.38 MPa convey that, CP composites displays a non-linear reduction in friction and wear for the coupled effects of higher contact pressure for 1m/s sliding speed [13]. Rajeshkumar extracted Phoenix Sp. fibers and investigated its feasibility as a suitable reinforcement material in polymer composites with higher thermal stability [14]. Further, the tribological characteristics of Phoenix Sp. fibers were performed with the consideration of different levels of fiber length ranging from 10–30 mm and fiber composition between 10-40%. Investigations were conducted in Pin-on-disc wear testing machine with the processing conditions of sliding speed, sliding load and sliding distance. Optimal conditions with fiber length 20mm and fiber composition 40% produced desired results with reduction in wear rate and friction coefficient [15]. Fiber composition proved to be a pre-dominant factor than fiber length in assessment of tribology properties of Phoenix Sp. composites. Experiments on wear is conducted over the Grewia optiva fibers blended along with Bauhinia vahlii fiber and reinforced with epoxy matrix. Tests were performed with the Taguchi's experimental design (L27) and the optimal range of testing parameters are determined [16]. Minimum wear rate is achieved with the optimal combination of 4% wt of fiber, sliding load 15N, sliding distance of 2km and sliding velocity of 2.5m/s. The testing parameters which have a direct influence on the rate of wear is identified in the ranking of weight % of fiber, sliding velocity, distance and load. In recent years, bio-fillers are preferred as binding agents or reinforcement materials in the suitability assessment and performance of polymer composites. Vishal Ahlawat and other researchers manufactured composites with various weight percent (10%-30%) of Walnut shell powder (WSP) as filler materials and determined the tribological properties for development of friction materials [17]. In relation with the pure polymer specimen (0% WSP), there has been a proportional increase in the mechanical and tribological properties of the filled in composites. The outcomes of the tests reveal that specimens doped with 30% wt of WSP exhibit low specific wear and higher friction coefficient and it is best suitable for utilization of friction materials in brakes.

However, the NFPCs manufactured and assessed for tribological applications requires sufficient strength, stiffness and stability. Several novel cellulosic fiber reinforced polymer composites produced displays a contrary effect with limited mechanical properties. In this regard, to overcome such limiting factors composites are manufactured with addition of conventional fibers and other synthetic fibers such as glass, carbon, Kevlar etc. The other methodology towards resolving this limitation is the surface modification of the extracted cellulosic fibers with the aid of suitable chemical treatment methods such as alkaline, silane, benzoylation, permanganate etc. Several research studies are performed by manufacturing hybrid composites with addition of glass or carbon fibers and other filler materials [18–20]. Research papers on tribological characterization of different hybrid composites such as Jute/Sisal/E-glass fabrics; Musa Acuminata/Jute fibers; Bamboo/Glass fiber; Coconut Coir/Banana/Glass fiber and Jute/glass fibers manufactured by compression molding method are performed and have displayed best results with remarkable mechanical properties, lower wear rate, higher friction coefficient and can also be applied as friction materials in brakes and mechanical parts [21–24]. The minimal specific wear rate, higher friction coefficient was found in hybrid composites than the composites manufactured by single plant fibers. The surface texture of these hybrid composites observed from scanning microscope image displays a very minimal impact of wear debris found over the surface [25, 26].

Henceforth, it is evident from the literature reviews that, several research investigations on the tribological studies for a different classes of Natural fiber reinforced polymer composites (NFPCs) have been reported. It is of utmost importance to identify, extract and develop a new class of high-performance materials which are lesser in weight for machine elements and other bearings. In this research paper a new novel cellulosic fiber, Abutilon Indicum Fiber (AIF) reinforced polymer composites are fabricated by compression-molding process and its tribological performance is evaluated and reported. This study focusses on the variation in fiber volume percent ranging from 5% to 20% and its impact over the tribological properties. The experiments were conducted for varying sliding velocities of 1-3 m/s; sliding load 10-30N and with distance ranging from 1-3 km. Tribological studies on untreated AIF cellulosic fibers have not been investigated earlier and this research paper provides sufficient scope for developing high performance friction materials for brake pads and other mechanical parts using AIF reinforced polymer composites.

Materials and Methods:

The Abutilon Indicum fibers (AIF) were identified from the stem of 'Thuthi plant' in the agricultural regions of a village Sulakkarai Medu located in Virudhunagar district in the southern states of India. The extraction process of AIFs is investigated in the earlier research studies and its physicochemical properties are determined. Based on the earlier research studies, these fibers are identified as a potential material in production of composites. The different phases of extraction of AIFs are presented in Figure 1.

Epoxy resin derived from the Petro-chemical products is preferred as the matrix material in fabrication of AIF reinforced composites. Epoxy resin and araldite hardener purchased through M/s Covai Seenu Mart Coimbatore, India are blended in the ratio of 9:1 and further applied in manufacturing of composites. The chemical composition of the fibers estimated are cellulose, hemi-cellulose, lignin, wax, ash content and moisture. The physical, chemical and other properties of AIFs determined from the earlier research studies and also the properties of epoxy resin are presented in Table 1.

In this study, Abutilon Indicum fiber composites were fabricated by compression molding technique. The composites were fabricated in the steel mold with the dimensions of 100 mm x 50 mm x 10 mm. In the initial stage, the mold release agent silicone is applied over the entire surface of mold towards easier dismantling of composites from the mold after the curing process. Fibers with different weight fractions of 5%, 10%, 15% and 20% were aligned in the mold and the epoxy matrix were poured in the mold for compaction. Subsequently, the filled in mold was closed and uniform thickness of the specimens were produced with the aid of hydraulic press in contact with the mold for 9 hours and pressure of 3 bar at room temperature. In addition, with the natural curing of the fabricated composites, curing was further performed in the hot air oven for 500C for 4 hours in order to achieve the homogeneity in the composites. Assessment of the tribological properties of AIF reinforced composites were carried out in relation with the Pure epoxy-based specimens (0% AIF reinforcement) in accordance with the ASTM standards. The cured composites with weight fractions were cut with the dimensions of 25 mm x 10 mm x 10 mm. Tribological tests for estimation of specific wear rate under dry environment conditions is performed on the specimens with 10 mm x 10 mm contact area. The sequence of processes involved in fabrication of AIF reinforced composites is shown in Figure 2 and the details of composites fabricated is presented in Table 2.

In this study, experiments are carried out in determination of hardness and tribological properties namely specific wear rate and friction coefficient of the untreated AIF composites. The hardness of the untreated composites is estimated with the aid of PTC model 307L durometer. The hardness tests were performed as per the ASTM D 2240 standards in the durometer (Shore D scale). The magnitude of Shore D hardness of the AIF filled and unfilled composites were measured across five different regions in the surfaces and its average value is considered. The experimental set up for Shore D hardness measurement of these specimens is shown in Figure 3.

The tribological tests were performed for the combinations with various levels of sliding velocity, sliding distance and sliding loads with the Pin-on-Disc apparatus under dry lubrication environmental conditions [27, 28]. The experiments were carried out on these five different composites as per the ASTM G 99 standards. Prior to conducting the experiments, the counterface is polished with the SiC abrasive paper and simultaneously the composites were polished with abrasive paper to achieve enhanced contact among the composites and the counterface. The specimens cut for the dimensions of 25 mm x 10 mm x 10 mm were arranged in contact (with a cross-section area 10 mm x 10 mm) for sliding against the EN 31 steel disk [29]. The experimental setup arrangement in conducting the tribological tests for estimation of specific wear rate (SWR) and friction coefficient (μ) is shown in Figure 4.

The experimental parameters associated in this study are different levels of sliding velocity, sliding distance and sliding load. The different levels of input parameters associated with the experiments is presented in Table 3. The highly precise and accurate digital weighing apparatus with precise least count of 0.0001 g was utilized in measuring weights of the specimens prior and after conducting the wear tests for the different combinations of testing parameters.

Initially, the experiments were conducted for the pure epoxy specimens (0% AIF content) for different combinations of input parameters and the tribological properties, specific wear rate (SWR) and friction coefficient (μ) are determined. Further, tribological tests for different combinations were conducted for AIF reinforced composites with composition of fibers ranging from 5-20%. The friction coefficient (μ) and the specific wear rate (SWR) of the composites is estimated from the equations (1) and (2).

$$\text{Coefficient of friction } (\mu) = \text{Measured frictional force} / \text{Normal applied load} \quad (1)$$

$$\text{Specific Wear Rate (SWR)} = W_I - W_F / \rho \times F_N \times D_S \quad (2)$$

Where, W_I - Initial weight of the specimens before wear test (kg); WF - Weight of the specimens after wear test (kg); ρ - Density of AIF composites (kg/mm3); FN - Applied load (N) and DS- Sliding distance (Km). In relation with the results of the pure epoxy specimens, the wear and friction values for different processing conditions of the AIF reinforced composites are analysed and its deviation is computed [30].

AIF composites tested for tribological performance are identified with worn out surfaces and other form of debris present over the surfaces. The wear mechanism, surface texture and worn-out morphology of these tested AIF specimens are analysed and further investigated with Scanning electron microscope (SEM) techniques. The morphology analysis of the worn-out surfaces was performed by SEM – Make TESCAN VEGA3, Czech Republic at 20 kV accelerating voltage. The composite specimens with cross-section 10 mm x 10 mm are coated with layers of gold on the surfaces.

Results and Discussions:

In this research work, the tribological studies essentially comprises the investigations towards determination of Specific wear rate (SWR), coefficient of friction (COF) of the material and morphology characterization of the worn-out surfaces. Prior to performing the tribological studies, it is significant in determination of the hardness of the AIF reinforced composites. Hardness is a factor which indicates the wear resistance of any material, where higher hardness values are desired for every material classes. As illustrated in Figure 3, the experiments are conducted for measurement of Shore D hardness of the AIF reinforced composites for different composition of the AIF reinforced composites. The results of the Shore D hardness of untreated AIF composites and pure epoxy specimens (with 0% AIF reinforcement) are presented in Table 4. Pure epoxy specimens were fabricated and the tribological characteristics are determined to assess the performance and suitability of the composites in relation with the variation in Abutilon Indicum fiber content.

It is observed that the hardness values of the AIF reinforced composites increase consistently with a proportional variation in the increase of weight fraction of the fibers. The maximum hardness value of 78.22 is observed for 15% weight fraction of AIF reinforced composites. Such results could be attributed to the effects of good interfacial bonding and higher stiffness between the fibers and the epoxy resin. However, beyond 15% weight fraction of fibers, the hardness values tend to decrease by up to 74.76. Such a trend with slight reduction in hardness values for 20% weight content could be the effects of fiber agglomeration and debonding between the fiber and the epoxy resin. The effects of fiber agglomeration exhibit an improper mixing, uneven distribution of epoxy resin and fibers which thereby exhibits pores over the surfaces limiting the strength of the composites. Thus, based on the above results, it could be observed that 15% weight reinforcement of AIF composites have higher hardness and displays a better wear resistance.

Wear is a critical phenomenon which occurs when the surfaces of any two materials are in sliding contact against each other, leading to a consistent removal of material over the two surfaces. Wear is an undesired phenomenon in materials and thereby reduces the performance and functionality of the mechanical system. In this research work, the tribological characteristics of AIF reinforced composites are investigated by determination of specific wear rate and friction coefficient. SWR is expressed as volume of wear per unit of sliding distance and sliding load. In AIF composites, fiber length is an insignificant factor due to very short length and its random orientation. SWR of AIF reinforced composites are expressed as a function of fiber reinforcement (in %), sliding distance, sliding load and sliding velocity. AIF composites reinforced with varying volume fraction of fibers ranging between 5 to 20% are fabricated and further the experiments are performed for different combinations of sliding speed, sliding velocity and applied load. Figure 5 presents the SWR values for effects of varying fiber reinforcement in AIF composites for different combinations of tribological factors which are: load applied, distance and speed.

Composites fabricated without any fiber reinforcement (Pure epoxy specimens) exhibits higher magnitudes of specific wear rate. Further, the SWR decreases with the proportional increase in fiber content. AIF composites with 15% volume fraction exhibits the best wear resistance with minimum values of SWR. Such effects of higher wear resistance could be the better interfacial bonding among the fiber and matrix which prevents the epoxy resin while sliding and minimizes the removal of polymer content in the composites. AIF composites with 15% volume fraction displays higher wear resistance and higher hardness irrespective of the different combinations of load and velocity. However, beyond 15% an increase in SWR values is observed in the AIF composites with 20% reinforcement. Such contradictory behaviour could be due to fiber agglomeration which thereby leads to poor interfacial bonding with fiber and the epoxy resin and significant content of fiber over sliding interface. Sufficient quantity of fibers in the composites exhibits pull-out effect from the epoxy resin by the movable disk in operation. Effects of fiber agglomeration and poor bonding results in an increase in SWR values. Additionally, from figure 5 it is evident that increasing trend in wear values are observed for a proportional increase in the applied load. Irrespective of the fiber volume fraction, at higher applied loading condition the fibers in the composite surfaces gets peeled away resulting in wear debris and worn-out regions over the surfaces. Such worn-out surface exhibits higher values of SWR. In relation with the sliding velocity, increase in SWR values are observed for higher velocity values. This could be due to the effects of significant weight loss over the composite surface. % reduction in SWR values for the AIF reinforced composites with different fiber reinforcement for different combinations of tribological parameters in relation with the pure epoxy specimens is presented in Table 5.

The results convey that with the reinforcement of fibers with epoxy resin, the wear rate in pure epoxy specimens can be reduced by upto 27.6% to 91.3%. Higher wear resistance was identified for the composites with 15% reinforcement of Abutilon indicum fibers for various combinations of sliding distance, sliding velocity and applied load. It can be concluded that composites with 15% reinforcement of Abutilon Indicum fibers provides best results with higher wear resistance and higher hardness and good interfacial adhesion with the epoxy resin and can be preferred for manufacturing of composites.

In this research work, coefficient of friction (μ) of AIF reinforced composites is estimated as a function of volume fraction of fibers and the tribological parameters. Coefficient of friction is a property without any dimensions and provides the relationship between normal force and friction force for any two bodies which are in contact with one other. The μ value lies in the range of 0 to 1. Higher the friction value beyond 1 indicates a strong friction force between the different bodies in contact than the normal force. The friction coefficient is determined for various volume fractions of Abutilon Indicum fibers ranging from 5% to 20% and for specimens manufactured without any fiber reinforcement for different combinations of tribological parameters. Figure 6 illustrates the coefficient of friction values for various ranges of AIF reinforcement in composites foe different combinations of tribological parameters.

Reinforcement of AIF fibers induces a lower friction value in the composites. It is observed from Figure 6 that the coefficient of friction values decreases with proportional rise with reinforcement of AI fibers. The best results are obtained with the minimum friction value of 0.22 for 15% reinforcement of fibers in the composites. Pure epoxy specimens (0% reinforcement) exhibit a higher friction value of 0.85 and such higher value could be the effects of lower hardness and poor strength in the composites. Incorporation of Abutilon Indicum fibers in the composites enhances the film transfer over the counterface thereby reducing the interlocking ability and displays the lower values of friction. Abutilon Indicum fibers aids in the reduced friction in the composites. However, beyond 15% reinforcement of fibers in the composites leads to a gradual increase in the friction values. Such contradiction in friction values for composites with 20% AIF reinforcement could be the reduced strength, poor bonding and the effects of fiber agglomeration. Additionally, the AIF reinforced composites displayed an increasing trend in friction values for an increase in the applied load.

Since, the experimental tests were conducted without any lubrication over the environment, the temperature induced between the contact regions of composites and counterface increases with consistent increase in applied load which thereby induces thermal stresses in the composite surfaces. Such thermal stresses induced reduces the bonding between the epoxy resin and the fibers and a rise in friction values are observed. Further, it is observed from Figure 6 that the μ value increased with an increase in the sliding velocity value. Sliding wear tests performed with a consistent increase in speed induces a formation of worn-out surfaces and the epoxy resin gets cracked up from the fiber reinforcement thereby reducing its interfacial bonding and hardness. Such a reduction in hardness values in the composites produces a higher coefficient of friction values. The percentage reduction in μ values for the AIF reinforced composites with varying fiber reinforcement for various combinations of tribological parameters in relation with the pure epoxy specimens is presented in Table 6.

The results convey that fiber reinforcement with the epoxy resin, the friction values in pure epoxy specimens can be reduced by upto 62.4%. From the above results, it is evident that 15% weight reinforcement of AIF in composites proves to be an ideal choice with minimum wear rate. Tribological studies on untreated AIF reinforced composites conclude that, 15% volume fraction of fibers provides the best results and is the most critical factor followed with influence of operating parameters with ranking of applied load > sliding velocity > sliding distance.

The predominant wear mechanism of untreated AIF reinforced composites and the morphology of the worn-out surfaces were examined through SEM images. The surface texture of these worn-out surfaces of composites were captured for pure epoxy specimens and for composites with 15% fiber reinforcement. The micrographs were presented in Figure 7(a-c). It is evident from Figure 7(a) that, a thin layer of film is observed over the surfaces along with the wear debris. Such a thin film layer is formed by molten epoxy resin at higher temperature. Experimental tests performed under dry environmental conditions for higher sliding velocity generates higher temperatures thereby melting the epoxy resin. Such wear debris with an uneven surface texture reveals that there exists a significant weight loss upon testing and the material removal is brittle in nature. From Figure 7(b-c) for composites with 15% fiber reinforcement, debonding among fibers and epoxy resin, increased specific wear at higher loads, fracture and fiber breakage is present over the composite surface. Initially microcracks were identified which further propagates at higher sliding velocity and maximum loads thereby inducing the effects of debonding, fiber pullout and higher wear rate. Based on the micrographs of untreated AIF reinforced composites, the most dominant wear mechanism is debonding and fiber pullout. Such modes of wear in these composites are attributed due to poor interfacial bonding among fiber and epoxy polymer and also the presence of moisture content in the untreated Abutilon Indicum fibers. The presence of moisture content in these fibers can be controlled by surface modification of AI fibers by suitable chemical treatments. Fibers treated chemically eliminates the moisture content, enhances the interfacial adhesion and henceforth the wear resistance can be enhanced with better tribological properties.

Conclusions:

In this research work, the tribological performance of the untreated Abutilon Indicum Fiber reinforced composites are investigated and from the discussions of the results, the following conclusions are arrived below:

- The Shore D hardness value (upto 78.22) is higher for 15% volume fraction of fibers and this could be based on the effects of enhanced interfacial adhesion among fibers and epoxy resin for this composition.
- The fiber volume fraction is the most critical factor and highly influences the tribological performance of AIF reinforced composites. For a fiber volume fraction of 15% in these composites, the desired results are obtained with higher wear resistance (minimum values of specific wear and coefficient of friction μ).
- The specific wear rate and coefficient of friction values displayed an increasing trend in the composites produced beyond 15% reinforcement of fibers. The effects of fiber agglomeration are observed for composites produced with 20% volume fraction of Abutilon Indicum fibers thereby inducing poor bonding among the fibers and matrix.
- In comparison with pure epoxy specimens, the minimum values of specific wear rate and coefficient of friction are observed for 15% reinforcement of composites with percentage reduction upto 91.3 (for wear) and 62.4 (for μ).
- The sequence of parameters which influences the tribological performance of AIF reinforced composites are as: % reinforcement of fibers > Applied load > Sliding velocity > Sliding distance.
- Specific wear rate and coefficient of friction increased with an increase in applied load and sliding velocity. However, in relation with the sliding distance significant differences in tribological characteristics are not observed.
- Morphology analysis reveals that the pre-dominant wear mechanism identified in AIF reinforced composites are debonding across fiber-matrix interface, fiber pullout and breakage of fiber.

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Table 1: Abutilon Indicum Fibers and epoxy resin Properties

Properties	Abutilon Indicum Fiber	Epoxy Resin
Cellulose (Wt. %)	56.12	-
Hemi-Cellulose (Wt. %)	14.26	-
Lignin (Wt. %)	16.21	-
Wax (Wt. %)	0.38	-
Ash (Wt. %)	10.21	-
Moisture content (Wt. %)	8.75	-
Density (kg/m^3)	1170	1150
Diameter (μm)	175	-
Crystal size (nm)	2.20	-
Viscosity at 25^{0}C (centipoise)	-	815

Table 2: Composition of Abutilon Indicum Fiber reinforced composites

S. No	Wt. % of AIF reinforcement	Polymer content
1	0 (Pure epoxy)	100
2	5	95
3	10	90
4	15	85
5	20	80

Table 3: Different levels of testing parameters

Parameters	Level I	Level II	Level III
Sliding distance (km)	1	2	3
Sliding load (N)	10	20	30
Sliding velocity (m/s)	1	2	3

Table 4: Hardness of Abutilon Indicum Fiber reinforced composites

S. No	Composition	Shore D hardness
1	0% (Pure epoxy specimens)	71.01
2	5% reinforcement	74.25
3	10% reinforcement	76.81
4	15% reinforcement	78.22
5	20% reinforcement	74.76

Table 5: Decrease in % of SWR for AIF composites compared to pure epoxy

Sliding distance (km)	Fiber reinforcement (%)	1 m/s			2 m/s			3 m/s		
		10 N	20 N	30 N	10 N	20 N	30 N	10 N	20 N	30 N
1	5	46.5	38.2	27.6	45.1	34.3	31.7	43.8	37.5	28.3
	10	62.8	50.1	51.5	60.7	47.6	49.7	64.5	48.4	50.8
	15	85.7	76.3	72.6	82.4	74.2	68.3	84.8	74.5	71.3
	20	82.3	75.8	72.8	81.2	72.6	69.2	83.7	73.8	71.2
2	5	48.7	39.2	30.3	46	34.8	32.5	46.1	38.4	31.6
	10	64.2	46.8	47.1	67.5	43.4	47.3	68.5	45.9	47.0
	15	89.8	79.3	75.2	86.3	77.5	71.2	88.1	76.8	73.7
	20	89.1	73.5	71.6	85.8	76.2	71.0	87.3	75.9	73.2
3	5	52.3	44.1	33.8	48.4	39.2	37.3	49.2	41.2	35.2
	10	75.6	71.2	70.8	73.8	69.6	72.6	72.9	70.2	69.7
	15	90.6	82.8	80.5	89.9	77.9	75.8	91.3	80.8	78.1
	20	85.2	74.0	72.2	82.7	76.8	73.9	84.3	77.1	76.2

Table 6: Decrease in % of COF (μ) for AIF composites compared to pure epoxy

Sliding distance (km)	Fiber reinforcement (%)	1 m/s			2 m/s			3 m/s		
		10 N	20 N	30 N	10 N	20 N	30 N	10 N	20 N	30 N
1	5	25.1	21.8	20.3	15.2	19.4	18.2	15.5	17.5	22.4
	10	37.3	32.6	28.5	36.3	34.5	34.0	31.2	29.7	36.1
	15	55.1	49.2	56.0	52.8	47.4	59.8	60.1	53.7	62.4
	20	49.8	46.8	49.0	48.2	45.4	53.1	57.6	52.5	59.8
2	5	22.7	20.1	19.5	17.1	16.3	19.8	16.7	19.1	21.5
	10	39.8	35.3	32.6	34.2	33.1	29.8	38.1	38.5	40.9
	15	56.8	54.3	57.2	55.7	50.5	58.7	56.2	54.7	59.2
	20	52.3	49.2	51.1	52.0	49.8	53.5	54.8	51.3	52.5
3	5	23.4	24.9	21.0	13.5	18.0	16.1	14.2	18.6	21.8
	10	33.5	35.6	29.1	38.9	35.0	36.2	41.2	43.4	44.2
	15	58.7	58.6	54.3	56.5	53.4	57.3	57.0	55.2	60.8
	20	53.2	53.0	55.4	53.4	53.7	56.3	55.8	57.1	58.2

Figure 1: Abutilon Indicum Fiber (AIF) extraction (Reproduced with permission from Wiley, License Number: 5570010817842) [5]

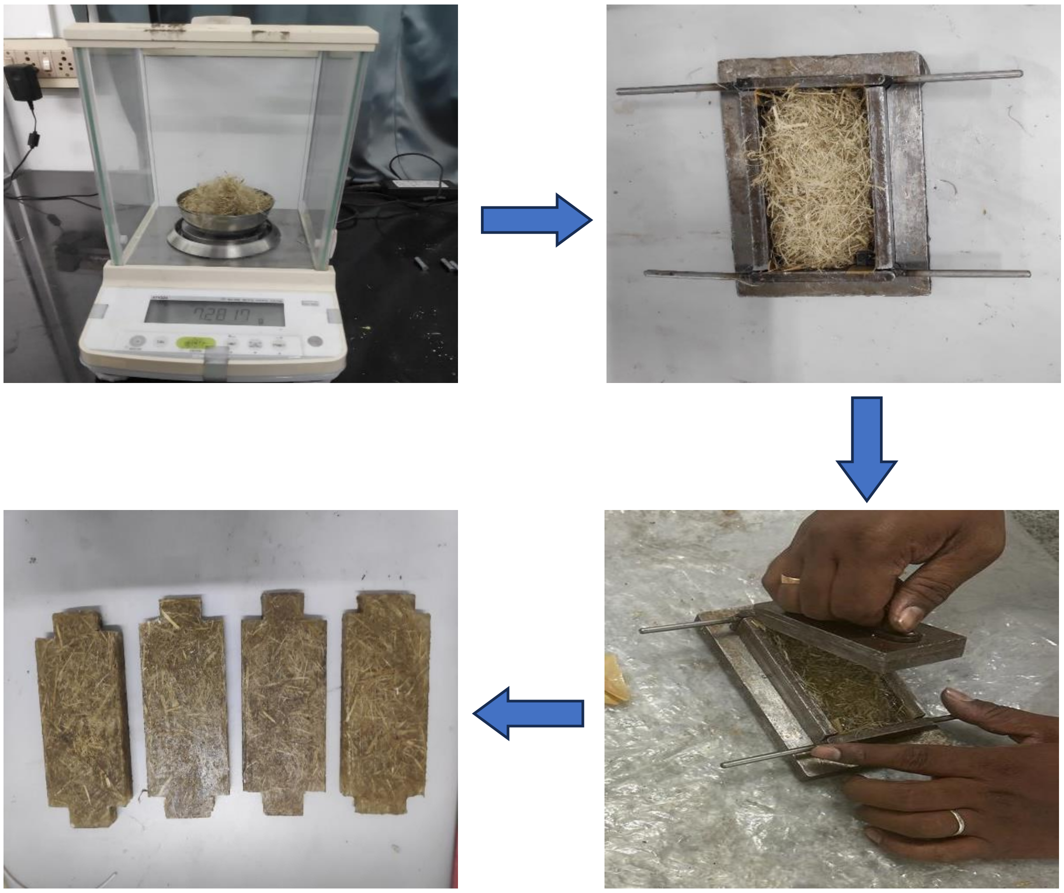


Figure 2: AIF reinforced Composites Fabrication

Figure 3: Experimental setup of Shore D hardness Measurement

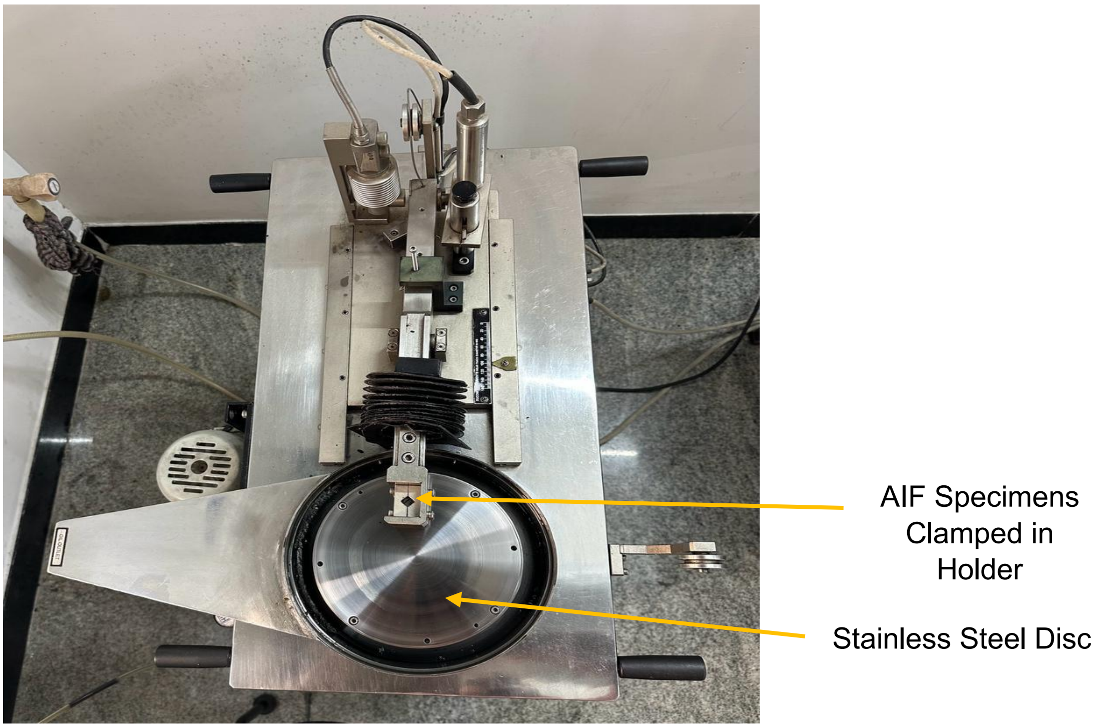


Figure 4: Pin-on-Disc Wear Testing Setup

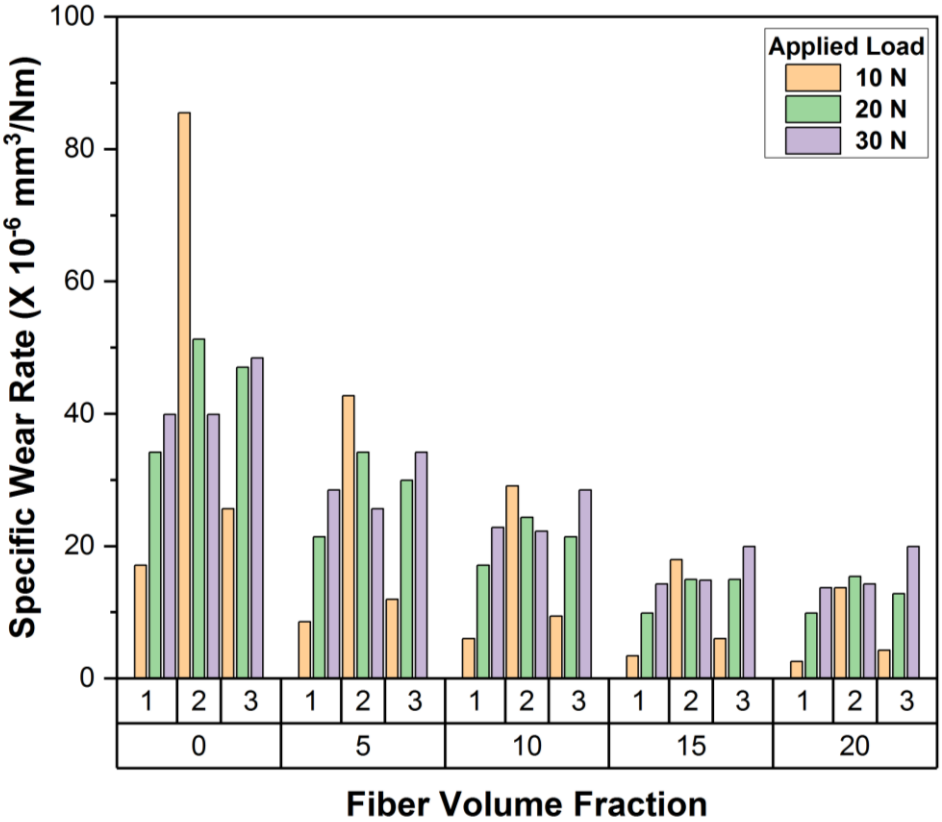


Figure 5: Influence of Fiber content on SWR for combinations of tribological parameters

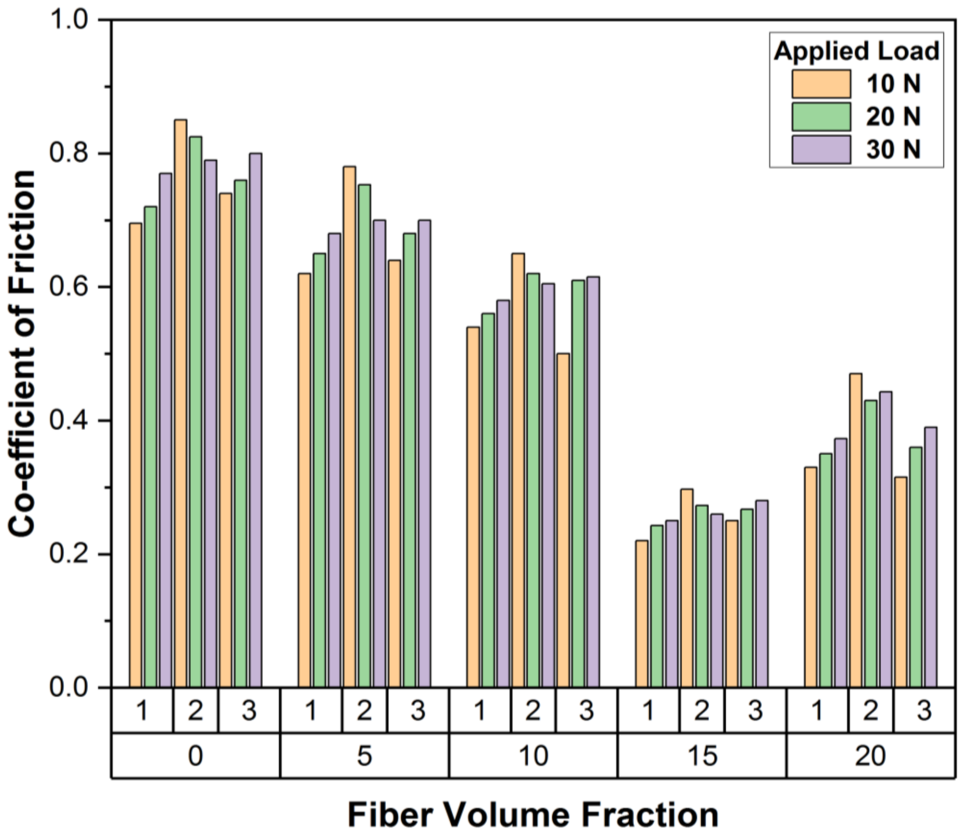
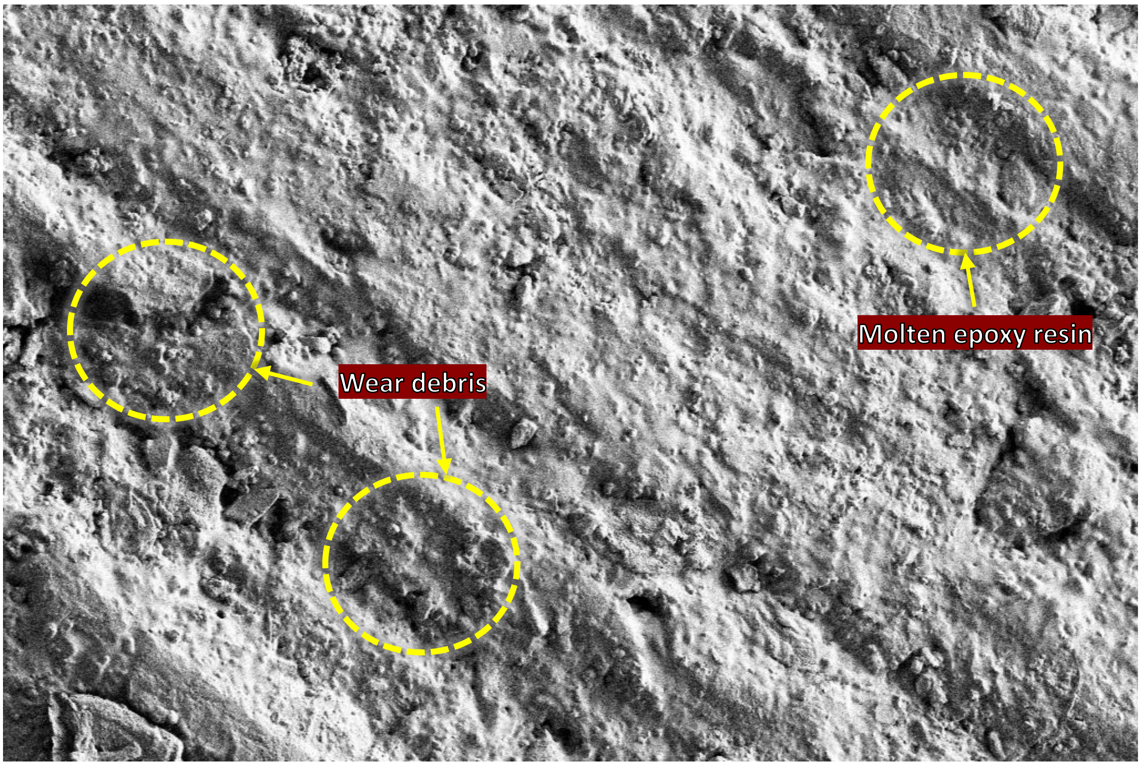
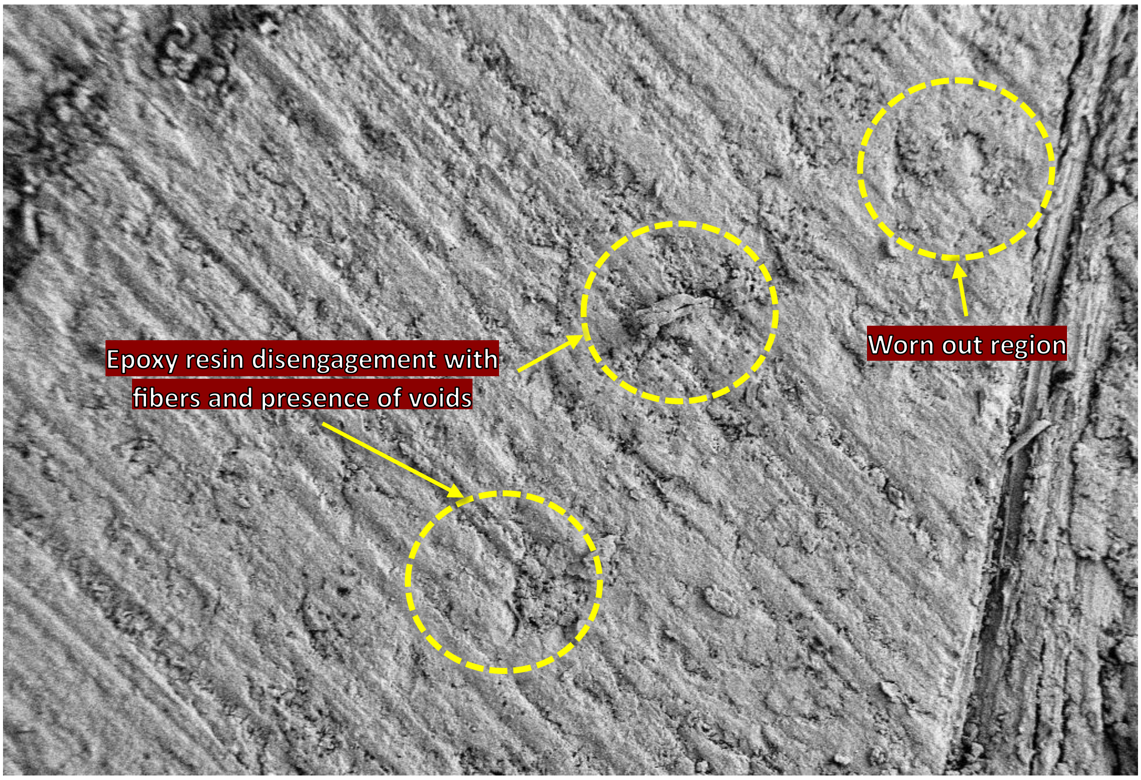


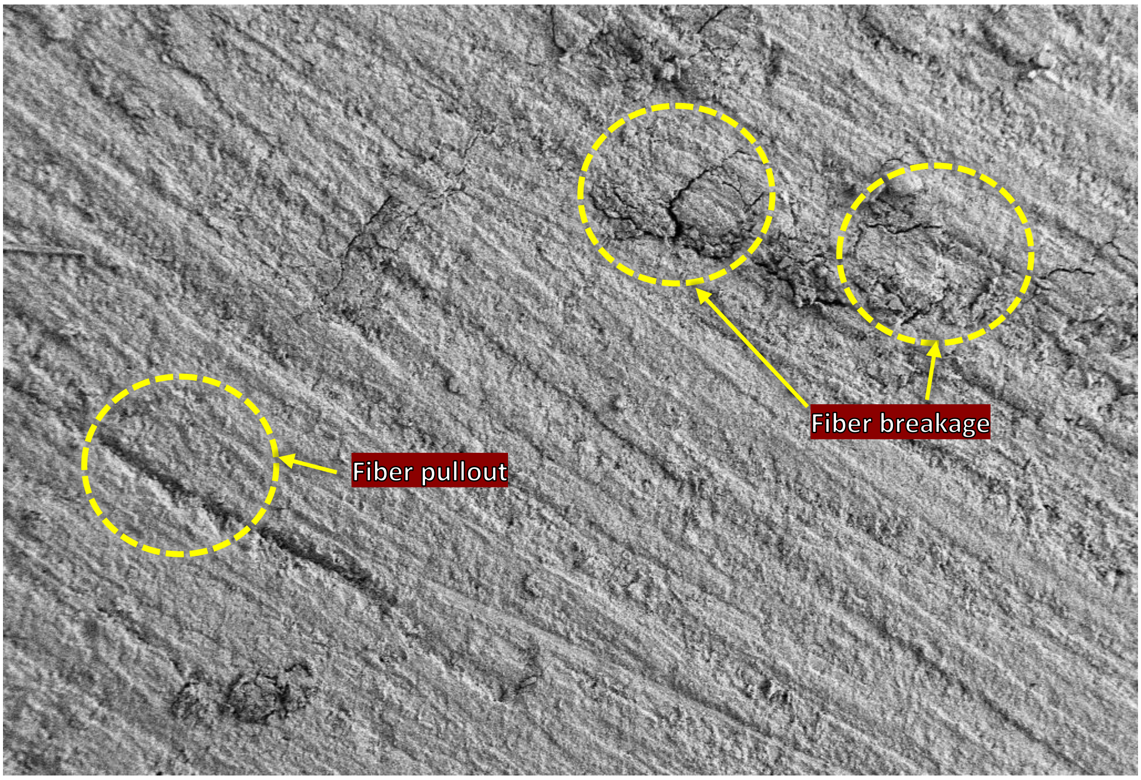
Figure 6: Effect of AIF content on Coefficient of Friction for combinations of tribological parameters


Molten epoxy resin
Wear debris

(a)


Worn out region
Epoxy resin disengagement with
fibers and presence of voids

(b)



(c)

Figure 7(a-c): SEM images of AIF reinforced composites