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Dry sliding wear properties of Jute/polymer composites in high loading applications

Karthikeyan SUBRAMANIAN[1], Rajini NAGARAJAN[1],
Jacob SUKUMARAN[2], Winowlin THANGIAH[1], Patrick DE BAETS[2]
[1]Centre for Composite Materials, Department of Mechanical Engineering, Kalasalingam University, Krishnankoil, Tamilnadu, India
[2]Department of Mechanical Construction and Production, Ghent University

Abstract

In the last few decades natural fiber composites has gained its importance due to its low cost and their availability as additives with minimal processing. Amongst the various natural sources the Jute fiber is chosen in the present research due to its fiber structure and good physical and mechanical properties. In this background natural fiber composites of unsaturated polyester were reinforced with jute fibers. While most research on green composites focuses on the structural characteristics, the present work investigates the suitability of the material to be used as a tribo-composite. Tailor made hybrid composites were made with chemically treated (NaOH) jute fiber and 2 wt % PTFE filler (tribo lubricant) to obtain the better tribological characteristics in high loading condition. Tribotests were performed on flat on flat configuration where 100Cr6 steel was used as counterface material. A pv limit of 400 MPa-mm/s (10KN and 100 mm/s) was attainedin a flat-on-flat configuration for studying the tribological properties. The static and dynamic coefficient of friction was found to be 0.15 and 0.07 respectively.An exponential increase in temperature was observed throughout the test. The material failure was observed within 500 m of sliding distance where pulverization of matrix due to thermal degradation is evident. Wear mechanisms such as fiber breakage, polymer degradation, fiber thinning and fiber separation was observed. From the present investigation the low cost Jute fabric composites havinglow frictional coefficient seemed to be a alternative to the bearing materials working at higher contact pressure and low velocity.

Keywords

Jute fiber, Taylor made hybrid composite, PTFE , NaOH treatment

1. Introduction

Customarilyall the equipment manufacturersare very often providing maintenance and replacement of moving components particularly bearings to avoid the tribologicalcatastrophe. Eventfully, it can only reduce the probability of failure rather being eliminated thoroughly. So, the losses in terms of economic and energy [1], efficiency of equipment [2], time consumption ofmanufacturing process [3] are inevitable due to the lack of material design in tribo system. Hence, the development ofnew material system is always important to increase the life span and performance of the components.Polymeric tribo-compositeis the one which progress rapidly and find its suitability in many tribo-engineering applications due to itsinherent properties of self lubricity and resistance to impacts and shocks and anti corrosion [4, 5].

Nowadays, it is essential to compose the material withsufficient structural integrity in addition to the lubricating properties for designing the tribological components such as gears, cams, bearings and seals, etc., used in aerospace, automotive and chemical industries [6-8].In the new material design hybridization of both fibres and fillers (solid lubricants) in polymer matrix were demonstrated as a strong alternative material to be used in medium loading tribological applications [9-11]. Among various fibre orientations the weaving pattern of fabric reinforcement has shown better wear results [12, 13].Numerous works have been reported on glass [14, 15], carbon [16- 18], aramid fiber [19, 20] reinforced with differentpolymer system using various processingmethods to attain the betterment of friction and wear properties.Solid lubricants (SLs) such as poly (tetrafluoroethylene) (PTFE), graphite and molybdenum disulfide (MoS_2) were identified as a most filler in polymer matrix resulting significant reduction in friction and wear characteristics [21–23].

Recently, surface designing of composites exhibited the positive sign in the aspect of tribo-performance without appreciable compromising the strength of a composite [24]. In many of the situations, the tailor made composites have shown good sliding wear characteristics with the combination of high strength carbon fiber with PTFE, graphite and MoS_2 in various thermoplastic polymers [25-27]. However, the fabrication of these composites requires specialized chemical solvents, temperature, pressure and time consumption (curing cycle) and it extent the manufacturing process cost. At the same time, the reports on fibre reinforced tailor made composites using thermoset matrix are scanty and it also provides a scope to produce the composites with low cost hand lay-up technique.

Moreover, the reports from the World Commission on Environment & Development (U.N.) insist to develop the innovative research area of ‘sustainable’ or ‘green’ tribology, dealing with the energy conservation, ecological protection as well as significant increase in efficiency of products with quality and life.Hence, the usage of traditional man made reinforcement such as glass, carbon and aramid fibers need to be minimized with the suitable alternative posses green environmental impact. From the literature it is evident that only little published information available on the behavior of the jute fiber composite [28] as reinforcement in the degradable resin matrix system especially in the aspect of tribological application. Only few studies have been so far reported for thermoset polymer based composites and also the addition of SLs as a secondary reinforcement with jute fiber [29, 30]. However, this does not provides a full understanding of the lubricating mechanism and also the particle generation process. The present work mainly focused to develop the jute fabric/polymer composite with polyester using cost effective hand lay-up method. The influence of Polytetrafluoroethylene (PTFE)fillers with 2 wt % of fillers on friction and wear resistance properties under dry sliding conditions was studied. Before the inclusion of tribo filler, the jute fibers was treated with NaOH alkali for the betterment of interfacial adhesion between the fiber and matrix of jute/polyester composites. To understand the effect of mechanical strength on tribological properties of composites the dry sliding wear study was carried out using heavy loading testing setup. The friction properties such as static and dynamic co-efficient of friction were studied under run in and steady state conditions. In this study though three materials will be selected for the mechanical characteristics the target material for tribological study will be chosen based on its mechanical characteristics.Hence the material with superior mechanical characteristics among the three will be tested for its tribological behavior.

2. Materials and Experiment Details

Materials used

The jute fiber in the form of bi-direction fabric was used as primary reinforcement for thermoset resin. The Polytetrafluoroethylene (PTFE) tribological filler was also used as secondary reinforcement which was obtained from Sigma Aldrich (P) Ltd, Bangalore, India. Unsaturated isophthalic polyester resin was used as resin, which was purchased from Vasivibala resins (P) Ltd, Chennai, India. For 100 grams of resin, approximately 1% of Methyl Ethyl Ketone Peroxide (MEKP) and Cobalt Naphthenate were mixed at room temperature curing.

Chemical treatment

Two different alkali chemical treatments were carried out on jute fibers to understand the interfacial adhesion between the fiber and matrix. The chemicals NaOH, calcium hydroxide powder were procured from Sigma Aldrich (P) Ltd, Bangalore, India. The untreated jute fibers were placed in a solution with 10 % NaOH concentrations. Prior to fabrication of composites, all the treated fibers were thoroughly washed with distilled water and dried in hot air oven at 80 °C for about 2 hrs.

Development of Hybrid Composite

In this work a cost effective fabrication method called hand layup technique was employed for fabricating the Taylor made jute/polyester composites. From the preliminary results the 30 weight percentage of fiber was found to be optimum fiber content which possess better mechanical properties [31]. Hence, in this work around 8 number fabric mat for the size of 200 X 150 was used for making the composites of thickness 7 mm. The hollow square of 200 X 150 mm^2 mold was prepared with the required thickness using thick asbestos sheet and it glued over the plain aluminum sheet metal plate. At beginning, a thin layer of wax coating was provided over the aluminum plate for the easy removal of laminated plate after the fabrication of composites. Secondly, the fibers were subjected to pinned hole in such a way to facilitate the flow of matrix. Subsequently the polyester matrix was mixed with curing agent and spread over the fiber matsuntil the desired thickness is reached. Fig.1 shows the process of hand layup technique and fabricated jute/polyester composite plate within the mold cavity. In similar manner, the tailor made composites was also prepared byusing PTFE filled matrix at the surface of top layer. Finally, the compressed mold was allowed for curing at room temperature for another 24 hours. Then, the test specimens of the required size were cut from the fabricated composite plate. In the same manner, the alkali treated composites were developed by keeping the overall fiber content constant.

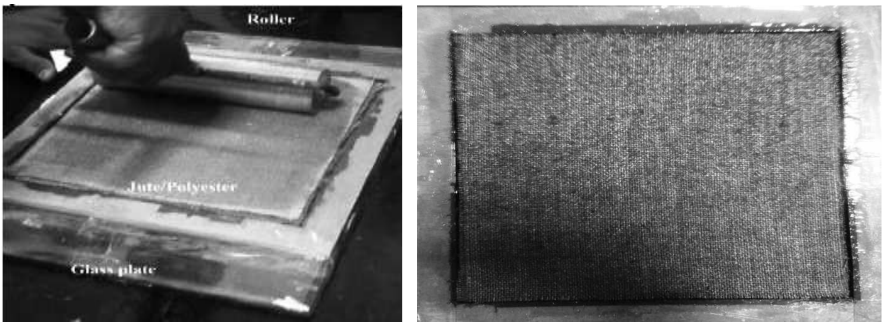

Figure 1. (a) Process of hand-layup technique (b) Jute/polyester composite laminate

Mechanical Testing

The fundamental mechanical properties such as tensile, three point bending and impact tests were performed in (Instron, Series-3382) a universal testing machine with respect to the ASTM – D 638, ASTM – D 790 and ASTM- D256 respectively. The rectangular shaped tensile specimens were prepared using a dynamic cutter machine with dimensions of 250 mm X 20 mm X 3mm. Three-point bending was carried at room temperature with the specimen size of 127 mm X 12.7 mm X 3mm. The cross head speed was selected as 5 mm/min. The Charpy-Impact test was performed to understand the impact strength of composites.

Dry sliding weartesting details

The dry sliding wear test of jute/PTFE filled polyester hybrid composites were performed using medium scale flat (MSF) testing machine, Laboratory Soete, Ghent University, Belgium. The specifications of the MSF machine was also presented in Table 1. A 100 chromium steel was used as a counter plate on both of the sides of vertical actuator. Two identical wear samples of size 50 X 50 mm^2 at 7 mm thickness as seen in Fig.2 were used on both sides of the sample holders. A protruded length of 2 mm is the maximum allowable pre-defined thickness which can be removed in the wear testing. A k-type thermocouple was used at the rear side of the counter plate which was identified to be the place of maximum temperature accumulation.

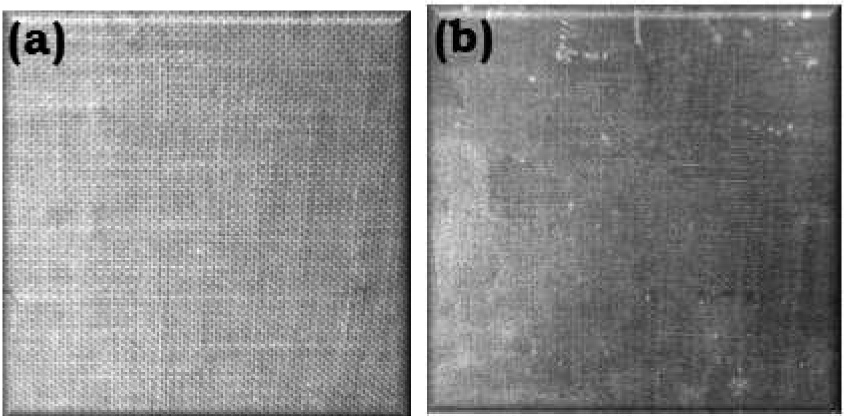

Figure 2. Contact surface of Jute/ polyester composites (a) Back side (b) Front side

The details of reinforcing fiber and filler and the matrix with the weight percentage of content are presented in Table1.

Table 1. Materials used for dry sliding wear testing

Type	Material	Content
Fiber Reinforcement	Alkali treated plain weave Jute fiber	30 wt %
Filler	PTFE ( )	2 wt %
Matrix	Unsaturated polyester	68 wt %

The addition of a filler in the form of a particulate or fibers in the matrix can offer more resistance to the wear loss of the composites.Wear tests of jute/ PTEF hybrid composites was carried out as per the tribologial testing conditions given in Table 2. The dry sliding properties such as wear, static and dynamic friction force and temperature at the counter plate were studied online. The wear data was performed at a constant load of 10kN for the NaOH treatedjute fiber /PTFE reinforced polyester hybrid composites, and it was selected based on the maximum surface area involved in the dry sliding. The counter surface disc was made of 100 chromium steel having dimensions of 200 mm length, 20 mm thick and surface roughness (Ra) of 0.1 - 0.2 μm. All the tests were conducted at ambient temperature. At least three tests with six samples of composites were subjected to the wear test and the average of the values is reported.

Table 2. Details of dry sliding wear testing conditions on MSF machine

Test Condition	Values
Stroke length	100 mm
Load	8 kN
Velocity	50 mm/ sec
Sliding distance	75 m

The data were recorded at the frequency of 500 Hz for friction force throughout the entire process. The static and dynamic coefficient were determined based on the formula used by Bonny [32] and is given in equation 1. The average value of 0.03 and 0.25 static and dynamic coefficient of friction was observed from the three repeated test with six samples.

$$F_{T,stat} = \frac{\left|F_{T,\min}\right| + \left|F_{T,\max}\right|}{2}$$

$$F_{T,dyn} = \sqrt{\frac{1}{T}\int_0^T (F_T(t))^2\,dt}$$

3. Results and discussions

Mechanical Properties

Generally, in polymer composite the tribological characteristics mainly depends on the mechanical properties of composites [33]. Accordingly, the fundamental mechanical properties of tensile, flexural and impact strength was studied. For the fabrication of the jute fiber reinforcement was used under two different alkali treated conditions namely NaOH and CaOH2. The chemical treatment of natural fiber can remove contaminates and lead to the fibrillation process. A fibrillation is the process of separating fibril with a high aspect ratio due to the reduced diameter. This can increase the surface to contact area between the fiber and matrix and it also assist the enhancement of interfacial adhesion between the fiber and matrix. Table 3 shows the mechanical properties of untreated (UTC), alkali (ATC) and calcium hydroxide (CTC) treated jute/polyester composites. As expected, the untreated composites posses lower mechanical strength compared to chemically treated composites. Among the alkali treatment, the ATC exhibits maximum mechanical strength and it can be due to the improved interfacial adhesion between fibre and matrix. In case of CaOH2 treatment the individual fiber strength might have got reduced due to the weakening affect of fibers because of the deterioration of fibers. The maximum flexural strength of 45 MPa was observed in ATC and it shows around 45 % and 60 % of raise over the other two composites. The flexural strength is the combination of both shear and compression. The influence of compressive strength was found to be more significant for getting the better tribological characteristics according to Klaus Friedrich et.al [22]. The removal of waxy layers over the fiber surface due to the alkali treatment can create the pores on surface and it facilitates the mechanical interlocking between the fiber and matrix. Hence, the possible combination of both chemical and mechanical bonding in the case of ATC serve as a crack arrester and take up more load effective stress transfer.

Table 3. Tensile, Flexural and Impact strength of untreated and treated jute/polyester composites

Condition	Flexural Test		Tensile test			Impact Test
	Flexural Strength (MPa)	Strain (%)	Tensile Strength (MPa)	Strain (%)	Young's modulus (MPa)	Impact Strength (KJ/m^2)
UTC	15.79	13.7	25.12	2.77	1627.93	6.8
ATC	20.44	12.63	44.6	3.38	2176.82	11.38
CTC	18.6	11.56	36.72	2.79	2570.64	8.37

Tribological properties

In general, most of the physical, mechanical and tribological properties of the fiber reinforced polymer composites, depend on the interfacial adhesion between the fiber and the matrix [16,17]. And also, the tribological characteristics depend mainly on the fiber orientation, wt % of the fiber and interfacial adhesion [34-37] in fiber reinforced composites. In natural fiber reinforced composites, the presence of foreign impurities/substances that prevents the matrix from bonding firmly with the fibers, and the formation of strong a fiber/matrix interface. In the case of untreated jute fiber, this poor interfacial adhesion is the result of a waxy layer over the fibers and that leads to the poor interfacial bonding at the interface. Normally, the NaOH treatment is done for the removal of waxy layer and to create a rough surface over the fiber. It also lead to the formation of a strong interfacial bonding between the fiber and the matrix.

Knowing the superity in the mechanical characteristics of the ATC the tribologicalstudy was performed for alkali treated Jute/Polyester composite. In the aspect of achieving the better tribological characteristics into account, the tailor made composite was developed with the PTFE tribo-filler. Thereafter, the dry sliding wear test of alkali treated PTFE filled jute polyester hybrid composite was performedas per the testing conditions given in Table 2. The specific wear rate, static and dynamic friction force and temperature changes with respect to the sliding velocity of 50 mm/sec, are depicted in Figure 3. In both the cases the trend for the specific wear rate is to show a decrease with the velocity and chemical modification, respectively.

From Figure 3 it is seen that the variation of wear seems to be within the range and it shows the positive behavior of material towards wear resistance during start in condition. Similarly, static and dynamic coefficient of friction were found to be consistent up to the distance of 65 m beyond that the up rapt changes in all the data was observed. The same was also reflected on the data of contact temperature also. But, throughout the testing conditions a continuous linear increment of temperature was noticed and it turns to up normal at nearer to the end of testing distance.

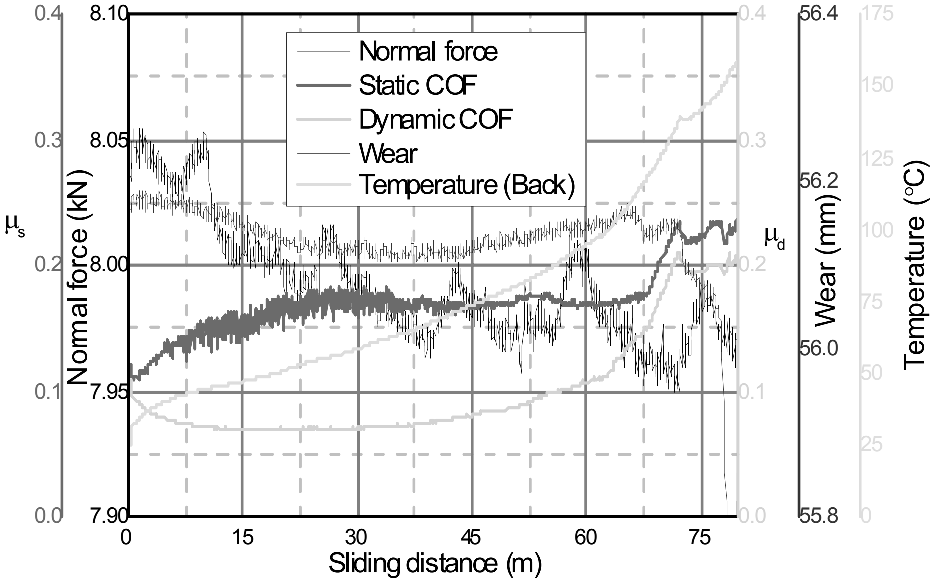

Figure 3. Tribological parameters of alkali treated jute/PTFE filled polyester hybrid composite

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Morphological Analysis of Worn out Surfaces

The photographs of the worn surfaces of jute/PTFE filled hybrid composites is shown in Fig.4 (a-d) with different wear failure mechanism. The images were taken using a digital camera with ring light illumination. Fig.4a. reveals that both fiber and matrix was damaged along the direction of wear track. The fiber delamination and batch of fiber separation, fiber pull out at boundaries and fiber fracture indicates the severe failure on fiber. The presence of pulverized white color debris shown in Fig.4b represents the crushed fibers. And it also highlights the severe matrix failure due to thermal degradation. In Fig.4c, the separation of fibers and the thinning of fibers was also observed in the small circular patches. However, there is no crack propagation between the layers was found in the laminated composited, indicating the strong interfacial adhesion, as shown in Fig.4a.The effect, especially due to interfacial debonding, not seemed to be more pronounced for the composites, indicates the possibility of using this material in high loading condition. Moreover, the alkali treated jute fiber composites possessed a higher load-bearing capacity, which was probably due to their better stiffness and strength. From Fig. 4d, it can be seen that a fine powder was generated with combination of crushed PTFE, jute fiber and matrix. The formation of transfer layer was not observed in the worn out surface of the composites and this may be due to the lower content of PTFE filler.

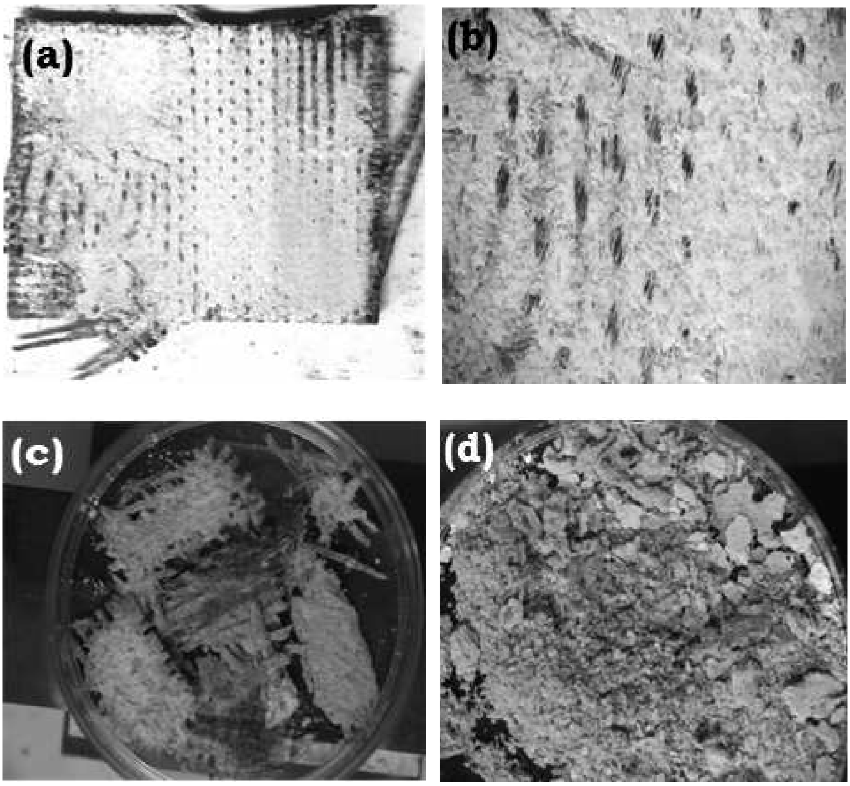

Figure 4. (a) Worn out surface of jute/polyester composite (b) Both fiber and matrix failure (c) Separated batch of fibers (d) Wear debris

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Conclusions

In a first time approach the alkali treated Jute fibers reinforced composite was studied for its tribologicalproperties at lowvelocity high loading condition. A low cost method of hand layup technique was used for the successful fabrication of PTFE filled jute/polyester tailor made composites. The lower value of friction force was found up to sliding distance of 75 mm. A linear increase in temperature was observed throughout the sliding distance.Only a unsteady wear loss was noticed before the severe failure of matrix and fiber. The wear failure mechanisms like, fiber fracture, fiber thinning and wear debris due to the thermal degradation of matrix was found to be dominant just before the end of the test.

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