Review Article

Study on tribology of natural fiber reinforced polymer composites: A review

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Abstract:

Today tribologists are interested in exploring new range of materials which can be suitable for engineering purposes where friction and wear are major obstacle. Apart from conventional materials, new range of materials includes composites like MMCs, CMCs and PMCs. Among all types of composites PMCs have become a potential candidate for such applications, because of easy processing and less cost. Though lot of work is going on different types of PMCs, but natural fiber reinforced polymer composites are gaining lot of interest. Natural fiber reinforced polymers are eco-friendly, biodegradable and sustainable in nature. The world wide availability, accessible agro waste is responsible for the new interest in research in sustainable technology. By this paper focus on tribological properties of natural fiber and their applications. Tribology study is very necessary to improve the strength and life of components which are made by natural fibers composites.

Keywords: Wear, Composites, Mechanical behavior, Compression molding.

Introduction:

Composites have already proven their worth as weight-saving materials, the current challenge is to make them cost effective and environment friendly. Innovative manufacturing techniques currently being used in the composites industry is a result of efforts of scientist and engineer to produce economically attractive composite [1]. Now days because of environmental laws and regulations and disposal of composites (ceramics, plastics, synthetic fibers etc.) became serious problem for many industries. To overcome this situation many researchers found that natural fiber and hybridization is a good solution. Natural fibres are ecofriendly in nature because of its biodegerability [2-4]. Many researchers replace the amount of synthetic fibers with natural fiber. The properties of NFPCs depend on various factors like fiber type, orientation of fibre, aspect ratio of fibres and interface bonding. Few drawbacks of NFPCs are high water absorption and lower mechanical properties, which limits their applications. Impact of chemical treatment on the tribology and water absorption of NFPCs are also highlighted in this study. Presently NFPCs are being used for several advance applications like automobile, aerospace, defense, construction industry and for structural purposes. Chemical treatment of the natural fiber improves the adhesion between the fiber surface and the polymer matrix which ultimately results in enhanced physical and mechanical properties of the NFPCs [5, 6]

It is noteworthy to mention that the tribological performance of a material depends on various factors coming under the category of surface and materials. Accordingly, polymer blends, chemical processing, addition of filler, interfacial adhesion and manufacturing techniques are the factors related to material that affect the tribological performance. Table 1 shows role of treatment on various natural fiber reinforced polymer composites in tribological applications. The benefits may include low cost of natural fillers, low density, as well as availability [7-11].

Table 1. Role of various natural fiber reinforced polymer composites in tribological applications [1-13].

Fiber	Matrix	Conditions	Test conducted	Manufacturing Method	Tribological application	Ref.
Linen/Jute	Polyester	Untreated	Dry friction Wear test	Casting process	Bearing	3
Banana and Kenaf	Polyester	NaOH, sodium Lauryl sulphate	Mechanical	Hand lay-up	Clutch	4
Rice straw dust/ Rise husk	Phenolic	Untreated	Wear test	Hot pressing	Brake pad	5
Sugarcane/ Glass	Polyester	Untreated	Friction assessment and screening test	Hand lay-up	Bearing	6
Sisal	Phenolic	Silane coupling	Adhesive friction and wear	Hot compression	Brake pad	7
Betelnut	Polyester	Untreated	Constant speed tester	Hand lay-up	–	8
Musaceae fiber	Polyester	Untreated	Mechanical Pull-out	Hand lay-up	–	9
Calotropis gigentea fruit fiber	Polyester	Untreated	Mechanical Wear	Compression molding	–	10
Coir sheath	Unsaturated Polyester	Alkali, silane	Three-body abrasive Wear		–	11
Sea shell nano Powder	Poly - Methyl methacrylate	Untreated	Wear Micro-hardness	Mold	Dental	12
Grewia optiva fibers	PLA	Untreated	Wear test	Hot compression	–	13

The applicability of tribological testing setup in various natural fibers reinforced polymer composites and its tribological applications have been summarized and illustrated in Table 2. The table also provides details of the conditioning of natural fibers and their corresponding consequence on friction and wear characteristics [1]. In particular, it provides a different insight into the aspect of eco-friendliness and is found to be a useful reference guide for tribologist, technical and scientific personnel involved in the development of natural fiber based hybrid composites on the tribological behavior. Besides, the information on the effect of various manufacturing methods on the performance of tribological properties at different testing conditions was presented in Table 2.

Table 2. List of measurement techniques related to friction and wear characteristics [14-35].

Parameter	Measurement device	Study	Ref
Surface roughness	Optical interferometer	Fiber diameter	14
	Atomic force microscope	Uniform distribution of clay	15
Surface tension	Goniometer	Contact angle	16
Testing of lubricants friction	Four-ball wear tester	Effect of load	17
Friction and wear tests	Pin-on-disc	Dry sliding friction	18
	Block-on-disk	Dry / Wet contact	19
	Dry sand rubber wheel	Three-body abrasive wear	20
	Pin-on-drum	Abrasive wear test	21
	Linear tribo-machine	Three-body abrasive wear	22
	Block-on-ring	Dry sliding wear	23
	Universal micro-tribometer (ball-on-disk)	High temperature tribo-test	24
Surface wettability	Contact angle system Water contact angle measurement	Surface contact angle	25
Chemical analysis	X-ray photoelectron spectroscopy (XPS)	Chemical changes	26
Imaging technique	Field-emission scanning electron microscopy	Morphological changes	27
		Interface between fiber	28
Temperature monitoring	Iron-constantan thermocouple	Temperature at edge of disc	29
	Infrared temperature measurement device	Surface temperature	30
Vibration monitoring	Accelerometer	Excitation magnitude of response	31
	Displacement transducers	Deformation measurement	33-35

Literature review:

Anshuman et al [2] revealed that the jute epoxy composites exhibited better tensile and compressive strength. Bundle strength of fibres decreases with increase in number of fibres in a Bundle. Tensile strength increases with Jute fibre reinforcement. Bending strength increases with increase in percentage of Jute fibre. Compressive strength increases with increase in percentage of Jute fibre. Not much change has taken place in impact strength after addition of fibre. These types of composites can be very useful for construction purpose, partition boards, wall, floor, window and door frames, roof tiles, mobile or pre-fabricated buildings which can be used in times of natural calamities such as floods, cyclones, earthquakes etc.

Bajpai et al. studied the wear behaviour of natural fibre/ PLA composites. They explored the possibilities of reinforcing thermoplastic biopolymer with locally available plant fibres for developing a wear resistant material. Three different types of natural fibres (nettle, grewia, optiva and sisal) were used and laminated composites were made using a hot compression technique. To study the thermal stability of composites TGA analysis was carried out. Wear and frictional characteristics of developed composites were investigated under dry contact condition at different operating parameters, such as applied load (10–30 N), sliding speed (1–3 m/s) and sliding distance (1000–3000 m). The experimental results indicate that incorporation of natural fibre mats into PLA matrix significantly improves the wear behavior of neat polymer. There was 10–44% reduction in friction coefficient and more than 70% reduction in specific wear rate of developed composites as compared to neat PLA. The worn surface morphology was studied using scanning electron microscope (SEM) to analyze the wear mechanism in different types of developed composites [36].

Berhanu et al. reported the effect of jute fabric reinforcement on the composite under the friction. The tribological behavior was assessed with a computerized pin-on-disc wear and friction tester at an operating dry condition and different working parameters of sliding speed (1–3 m/s), applied load (10–30 N), and sliding distance (1000–3000 m). SEM has been utilized to support the discussion of the outcomes. He conclude that, the addition of woven Jute fabric into PP matrix increases the wear resistance properties of polypropylene based composites as there was 3.5 - 45% reduction in coefficient of friction values and a decrease by 65% in the specific wear rate on account of the incorporation of the Jute fabric as reinforcement [37].

Jia et al. worked on carbon reinforced polymer composite in which they studied the comparative wear behavior of dry sliding and water lubrication.

There are marked differences in the response of the wear materials when water lubrication is added in the sliding of polymer composites/stainless steel contact. The four polymer composites in this study hold the lowered friction coefficient and showed much better wear resistance under water lubricated sliding against stainless steel than under dry sliding. It could be concluded that the easier of the composite transfer onto the counterpart steel surface accounted for the larger wear rate of the polymer composite under dry sliding, its hindered transfer onto the steel surface and the boundary lubricating action of water accounted for the much smaller wear rate under water lubrication. Water fluid wash the surface and remove the debris from the rubbing region and prevent the accumulation of wear debris onto the counter face, while the coalescence of this debris from repeated interaction results in the formation of transfer film in dry sliding. So the transfer film cannot be tracked on the counter face under water lubrication [38].

Goriparthi et al. paying attention to improve the adhesion of jute fibre with polylactide (PLA). For this intention, surface of the jute fibre was modified by alkali, permanganate, peroxide and silane treatments. The surface tailored fibres were characterized by FTIR spectroscopy. Unidirectional composites were prepared with treated jute fibres and PLA matrix by hot pressing of solvent impregnated prepregs. Surface treatments resulted in enhancement of tensile and flexural properties and reduction in Izod impact strength. Dynamic mechanical analysis (DMA) results showed that, treated composites have higher storage modulus and lower tangent δ with respect to untreated composite. The degree of interfacial adhesion between the jute fibre and PLA was estimated using adhesion parameter obtained through DMA data. The results of thermo-gravimetric analysis (TGA) showed a higher thermal stability for silane treated composites. Experimental results on abrasive wear tests revealed that the wear resistance of composite is sensitive to fibre/matrix adhesion [39].

Chand et al. conducted the study to investigate the abrasive wear behaviour of jute fibre-reinforced polypropylene composites. Effect of addition of maleic anhydride-grafted polypropylene (MA-g-PP)-coupling agent by two different approach, sliding distance and load on abrasive wear performance of jute fibre–PP composites has been determined by using a SUGA abrasion tester. Use of coupling agent gives better wear resistance as compared to without the use of coupling agent. It has also been found that addition of MA-g-PP coupling agent during melt mixing gives better wear resistance as compared to the jute PP composites having MA-g-PP solution-treated jute fibres, which has been explained on the basis of highest thermal stability of jute–PP Composite having melt-mixed MA-g-PP. Abrasive wear performance of the composites has been explained with the help of surface microstructures of worn surfaces. And they concluded that chopped jute fibre reinforced PP composites have been successfully developed. Formation of linkage at the interface of matrix and jute fibres during deformation plays the significant role in wear process. Improvement in the wear resistance of JF/PP composites is obtained with the addition of MA-g-PP coupling agent.

It is also observed that MT composites showed more wear resistance as compared to CT composites [40].

Tong et al. worked with bamboo and the abrasive wear property of the cross section of bamboo stem was examined. The abrasive material used for tests was the mixture of quartz sand (96.5 wt.%) and powdered bentonite (3.5 wt.%) and contained a water content of 3 wt.%, simulating soil condition. The size of the quartz sand particles was 0.104–0.214 mm, 0.214–0.420 mm and 0.420–0.840 mm, respectively. The abrasive wear tests were conducted on a rotary disk type of abrasive wear testing machine. The relative sliding velocity was 1.68, 2.35 and 3.02 m/s, respectively. The outcome was the abrasive wear resistance of the bamboo stem's cross section was a function of the vascular fibre content of bamboo, the abrasive particle size and the relative sliding velocity. As the vascular fibre content of bamboo increased wear resistance of bamboo will increased. A higher sliding velocity or a larger abrasive particle size resulted in a higher abrasion. The effects of the impact strength and the tensile strength of bamboo on its abrasive wear were discussed. Scanning electron microscopy revealed that the geometric morphology of the abraded surfaces of the sections of bamboo stem displays a not-smooth structure. This not-smooth surface morphology suggests to develop anti-abrasion morphological surfaces of soil-engaging components [41].

Hashmi et al. studied for sliding and friction wear behavior at different applied loads and graphite concentrations on the developed graphite modified polyester–cotton composites. Sliding wear tests were conducted using pin-on-disc apparatus. With cotton reinforcement specific wear rate of polyester reduced, which further decreased on addition of graphite. In case of cotton reinforcement the coefficient of friction of polyester resin increased and reduced significantly on addition of graphite in cotton–polyester composite. The temperature of contact surface reduced on addition of graphite in cotton–polyester composite. The diminution in wear rate of graphite modified polyester–cotton composite has been discussed with the help of scanning electron microscope (SEM) observations of worn surfaces, coefficient of friction and the temperature of contact surface. The conclusion had been drawn that (a) Incorporation of cotton fibres in the unsaturated polyester resin improves the structural integrity of material under sliding wear condition. The addition of graphite in the cotton–polyester composites further enhances the capability of material to withstand against sliding wear test. (b) The specific wear rate of polyester resin decreased with the cotton fibre reinforcement. The composites exhibited further reductions in specific wear rate against the normal load in the specimens those containing graphite. (c) The coefficient of friction increased with the addition of cotton fibre in the polyester resin and decreased on increasing graphite content in the composite. The graphite in the composite provided the lubricating effect under the dry sliding conditions against the steel disc, (d) Significant reduction in the contact-surface-temperature was observed on addition of graphite in cotton–polyester composites [42].

Yousif et al. worked on wear and frictional behavior of composites. In this work wear and frictional behavior of a new epoxy composite dispersed with treated betel nut fibres is reported. Composites were subjected to three-body abrasion test on Linear Tribo Machine by varying sizes of abrasive particle (500 µm, 714 µm and 1430 µm) and sliding velocities (0.026–0.115 ms-1). Load (5 N) is kept constant. The work revealed that the plastic deformation, pitting and pullout of betel nut fibres resulted, when sliding against grain sands were performed. The composite exhibited higher values in frictional coefficient when it was subjected against coarse sand. It was revealed that abrasive wear of the composite depends on the size of abrasive particles and sliding velocity too. Higher weight loss is found at high sliding velocities. The specific wear rate for the composite subjected to three different sand particles follow the order of: coarse > grain > fine sands respectively [43].

Syed et al. studied about physio-mechanical and wear properties composite and the composite has been made to use turmeric spent (TS) as reinforcing filler to fabricate polypropylene (PP) green composite for load bearing and tribological applications. Twin screw extrusion method was used to prepare PP/TS composites. Varying amounts of TS viz, 10%, 20%, 30% and 40% (w/w) is used. The fabricated PP green composites were evaluated for physico-mechanical and tribological properties. Experimentally obtained tensile values were compared with theoretically predicted values using different theoretical models. Increment in tensile modulus took place from 1041 to 1771 MPa with the increase in filler addition from 0 to 40 wt.%. Flexural strength and flexural modulus also improved after addition of TS into PP matrix. The water absorption characteristics of composites were determined. The abrasion resistance of PP/TS composites lowered by TS filler. The wear volume loss and specific wear rate as a function of abrading distance and load were determined. The surface morphology of tensile fractured green composites and their worn surface features were examined under scanning electron microscope [44].

Conclusion:

This paper explores the natural fiber reinforced polymer behavior on mechanical properties and tribology. This paper also includes the hybrid natural fiber reinforced polymer tribology study. The hybrid composites developed with the combination of natural and synthetic fibers shows enhanced mechanical strength and finds application in higher loading tribological applications. Moreover, the effect of layering sequence and chemical treatments of hybrid composites also exhibits reduction in moisture absorption due to the varying magnitudes of interfacial adhesion. However, this transfer layer exhibits positive and negative impact on friction and wear performances, which was decided on the basis of the adhesion strength between the polymer and counter surface.

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