Corrigendum: Tribological characteristics of natural fiber composite - Review (IOP Conf. Ser. Mater. Sci. Eng. 954 (2020) 012048)

K.Mohan1 *, T.Rajmohan 2
1 Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya, Enathur, Kanchipuram - 631561, Tamil Nadu, India

Page 1:

The figure 1 should be read as,

In the Introduction section, the following text appears in below the graph:

"Figure 1: Number of articles published based on tribological evaluation of synthetic and natural fibers [4]."

This should read:

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Tribological characteristics of natural fiber composite - Review

K.Mohan¹ *, T.Rajmohan¹

¹Department of Mechanical Engineering, Sri Chandrasekharendra Saraswathi Viswa Mahavidyalaya, Enathur, Kanchipuram - 631561, Tamil Nadu, India.

¹ *mohank84@gmail.com

Abstract. The continuous research into green environment for engineering based applications the present work tasks to dedicate a gathering of improvements in the research of tribological behaviour of natural fibre reinforced polymeric composites. Information on natural fibres, composites and the wear characteristics such as specific wear rate and co efficient of friction were presented with respect to change of fiber weight or volume fraction, addition of nano fillers and fiber treatments. Various operating parameters and wear mechanism for various types of composites and their performance will be discussed.

1. Introduction

In tribological materials with low noise and self-lubrication capabilities, fiber-reinforced polymer composites (FRP) play an important role. FRP offers more possibilities to optimize the tribological performance of frictional parts through various possible material combinations. Because of this, FRP composites are widely used in different applications and most of the manufacturing parts are subjected to tribological testing based on their applications like clutch pad, brakes lining and brakes pad, including gears, bearings, and prosthetic joints, etc. [1]. The use of natural fibers as reinforcing materials in both thermoplastic and thermoset matrix composite provides optimistic environmental support with consideration for ultimate disposability and best use of raw materials[2-3].

Figure 1 Number of articles published based on tribological evaluation of synthetic and natural fibers [4]
Tribo materials have a unique property profile and have a wear, friction, lubrication and mechanical properties spectrum that are used to design materials for specific tribological applications. The researchers have focused more on the tribological properties of natural fiber-reinforced composites since the last few decades. The Figure 1 shows natural fiber enhancements over synthetic fibers based on the published articles. In the field of tribological applications, a gradual increase can be found in natural fiber research.

![Image](Clutch lining) ![Image](Brake pad) ![Image](Brake lining)

Figure 2. Tribological application of Composites [5]

2. Effect of fiber wt% on tribological behavior of natural fiber composites

The application of the spectrum of natural fiber reinforced polymer composites is growing rapidly in various engineering fields. Using hot compression technique, the different types of natural fibers (i.e. nettle, glewia, optical, and sisal) were incorporated into PLA polymer to fabricate composites laminates. Different operating parameters such as applied load (10-30N), sliding speed (1-3 m/s) and sliding distance (1000-3000 m) under dry contact condition tribological characteristics were analyzed. The results indicates that the incorporation of natural fiber mats into the PLA matrix significantly improves the neat polymer's wear behavior. Compared to neat PLA, there was 10-44% reduction in friction coefficient and more than 70% reduction in specific wear rate reported by pajbai et al [6]. The effects of zeolite particles on the mechanical and tribological properties of the Ultra-high molecular weight polyethylene (UHMWPE) composites. The tribological properties are carried out under various applied loads of 10, 20, and 30 N with various sliding speeds of 0.209 m/s, 0.419 m/s and 0.838 m/s. Using compression molding technique the composites were fabricated. They found that the lowest average COF was also obtained with the 20% zeolite/UHMWPE composite. With increasing applied loads for all samples, the wear volume loss was found to increase[7].

The wear behavior of polyphenylene sulfide composites has been investigated by Besnea [8]. The composites fabricated with 10 wt% carbon fiber, 10 wt% graphite and 10 wt% polytetrafluoroethylene and another composites with 40 wt% glass fiber. Coefficient of friction and wear rate were analyzed using a pin-on-disc device. The polymer composite with polyphenylene sulfide matrix, carbon fibers, graphite, and polytetrafluorethylene exhibits enhanced wear resistance. The wear behavior of jute reinforced polypropylene composites at various loads and varying sliding velocities. The composites were prepared by using an injection molding machine at different fiber weight percentages 5%, 7.5, 10%, 12.5%, and 15%. At different sliding speeds and loads are 50cm / sec, 75cm / sec and 100cm / sec and 4, 6 and 8 kg the composites wear behavior has been studied. The wear and friction coefficient of jute is improved with the increase in normal loads. Decrease in friction coefficient at 50cm / sec and 100cm with the incorporated fillers[9].

Nordin et al. [10] investigated the kenaf polyester composites tribological behavior. The lengthy kenaf fiber is used to fabricate the composite. The epoxy resin and unsaturated polyester were mixed with hardener at weight ratios of 3:1 and 10:1, respectively. The wear test was carried out using an Abrasion Resistance Tester (TR-600) in dry sliding conditions at a constant velocity of 1.4 m/s. With different applied loads ranging from 5 to 30N the test was conducted at room temperature. The results indicates that the wear characteristic of KEC is higher than the KPC composite material. The centre of tribological consideration such as friction and wear of tribo-composites depends on various issues such as the class of polymers, surface characteristics, type (chemical or mechanical), and degree
of adhesion between the transfer layer and counterface material reported by Yousif et al. [11]. Among the various effects, the transfer layer was found to be the critical factor deciding the tribological performance of polymer-based composite materials. Generally, the depletion of soft polymer arising from the wear process may result in the formation of a thin film, which is often referred to as the transfer layer. The existence of the transfer layer is beneficial by maintaining low friction and reduced wear [12].

Yousif et al. investigated the frictional and wear behavior of the composites using a block on disk machine at different applied loads and sliding distances at 2.8 m/s sliding velocity under dry/wet contact conditions. They found that composite polyester reinforced by betelnut fibber (BFRP) had better wear and frictional performance compared to dry under wet contact condition. The wear mechanism of the BFRP composite was predominated in the polyester regions by micro and micro cracks and fiber debonding. They used water to improve BFRP composite wear and friction performance by about 50% and 94% respectively [13].

The Sugarcane fiber/polyester (SCRP) and glass fiber/polyester (GRP) composites (i.e. with chopped fibers of 1, 5, 10mm length randomly distributed and unidirectional mat fibers) using compression mold and hand-lay-up techniques. The friction coefficients and wear rates of the composites SCRP and GRP were determined by applying the load at 2.8 m/s in the range between 5 -30N sliding speed. They found the composite of SCRP that can compete with the composite of GRP. When tested in AP-O and tested in P-O, the U-SCRP composite displayed the lowest friction coefficient [14] Nomex fabric/phenolic composite, and its tribological properties and evaluated under dry and water-bathed sliding conditions by a pin-on-disc tribometer. The Nomex fabric was cleaned by a Soxhlet extractor in petroleum ether and ethanol in turn, and then dried in the oven. It was found that the penetration of distilled water/sea water induces damage to the mechanical properties. Owing to the NaCl, Mg (OH)₂ and CaCO₃ deposited on the pin surface, the wear results show that Nomex fabric /phenolic composite was much higher in a water-borne sliding condition than in a distilled water-borne sliding condition. [15]. The tribological behavior of novolac phenolic resin matrix composites reinforced with three kinds of carbonaceous fibers in sliding contact against cast iron. Samples with different type and volume fraction of carbonaceous fibers were prepared and tested in sliding contact against cast iron in a pin-on-disc wear testing machine. The worn surfaces and the debris were analyzed by SEM analogy. They found a reduction in wear rate of composites was observed with the increase in carbonaceous fiber volume fraction. Friction coefficient also showed a trend to reduce with the increase of fiber volume fraction [16]. Natural fibers are used in varied applications of wear and friction. The advantage of natural fibers over ancient reinforcing materials includes low cost, low density, Biodegradability, and recycyclability. Abrasive wear rate is tested by employing a two-body abrasion wear tester and also the bagasse fiber reinforced epoxy composite powerfully depends upon load and abrasive grit size. With a rise of load and grit size, the wear and tear rate will increase. The orientation of fiber in composites contains an important influence on the wear and tear rate of composite reported by Punyapriya et al. [17]. The importance of natural fiber with the initiation of sustainable development is narrated, and also the composite materials have currently become a lot of prominent in several applications. Several natural fibers reinforced hybrid composites are being introduced in the aviation business, construction, industrial applications, automotive components, bearing and plenty of others, creating tribo testing a lot of demanding reported by Nirmal et al. [18].

The wear behavior of lantana fiber reinforced polymer epoxy matrix composites. The composites were prepared using hand layup method then the respective size of wear specimens has been prepared. The tribological test was carried out on a pin on disc machine against the 400 grit size abrasive paper with a load of 5,10,15,20 and 25N and a test speed of 0.314m/s. The composites having 40% of fiber content indicates the optimum wear reduction also it is observed with increase in normal load the wear losses are increased. [19]. Tribological behavior of short glass fiber reinforced thermosetting polyester composite. The wear rate of polyester is much lesser than the unreinforced polyester. At 10 wt% of glass fiber content, the wear rate and coefficient of friction are minimal. Further increasing the proportion of glass fiber, wear rate and coefficient of friction is increased. The wear rate is increased...
while increasing the sliding speed and load but there is no significant change in the coefficient of friction. [20] Glass fiber based epoxy composite using hand layup method by varying their weight percentage of fiber such as 40%, 60%, and 80%. The fillers are added with and without 10wt%. The wear rate is decreased by increasing the fiber content. The filled composites exhibit superior wear performances and mechanical behavior than the unfilled composites. [21], the tribological performances of short PALF reinforced Bisphenol-A composites. The composites have been fabricated by changing their fiber length such as 2, 4, 6, 8, 12,14mm. Using pin on disc machine the wear behavior of the composite is tested by varying a load of 5N, 10N and 15N at constant sliding speed, velocity, and speed. They have reported, when increasing the load the wear rate is increased due to the less adhesive bond between fiber and matrix. [22] Nirmal et al. made a review on tribological performances of natural fiber reinforced polymeric composites. Various operating input parameters were considered such as load, speed, sliding distance for different natural fibers and concluded, significant improvement of wear and friction is attained in polymeric composites reinforced with natural fibers. The cellulose content of natural fibers mainly attributing to reduce or less abrasive damage i.e fibers generally soft by nature. Due to the well adhesive of natural fibers its tends to reduce the impact of thermo mechanical loading and the formation of transfer film or back film protect the surfaces from severe wearing or improve the resistance of wear rate and friction. Fiber treatments and fiber loading and nano fillers can further enhance the tribological properties. [23]. The wear properties of jute fiber reinforced polypropylene composites and reported that the wear resistance is increased while addition of woven jute fabric into polypropylene matrix and the coefficient of friction is reduced to 45% and the specific wear rate also decreased by 65% for further addition of Jute fiber.[24] The effect of unidirectional cotton fiber reinforcement on friction and wear characteristics of polyester. They established that the friction coefficient increases and the wear rate decreases with increasing fiber volume fraction up to 40%. [25]

3. Effect of Nano fillers on tribological behavior of natural fiber composites

Wang et al. [26-28] have reported filled PEEK with various weight fractions of nano fillers such as ZrO₂, SiC, SiO₂, Si₃N₄ and MWCNT. The wear resistance is improved and the friction coefficient is reduced by the addition of nano fillers less than 10wt% infractions. Two factors attribute enhanced wear and friction coefficient are transfer film formation and steel counterface smoothing. Investigated the effect of varying weight percentages of sustainable kenaf particles as specific fillers and reinforcement in epoxy thermoset matrix on the wear and friction properties. They demonstrated that the connotation of slight wear occurs at advanced loading condition with mild plastic deformation. There was more substantial origination of transfer films at higher loads, which would defend the composite from additional wear and thus dip the wear rate. [29]

Due to their superior qualities such as large aspect ratio, good mechanical strength, thermal conductivity and a higher thermal degradation limit, the MWCNTs are established among the numerous types of nano materials available. In the case of modified MWCNTs at high temperature, hybrid composites of PTFE / cotton fabrics in the phenolic matrix with the addition of MWCNTs show better wear resistance. The well-dispersed MWCNTs in a matrix and the transfer layer adhesion can be credited to enhance wear resistance and it is shown that adding MWCNTs shows improved COF wear performance. The well-distributed MWCNTs in a matrix can be ascribed to better wear resistance due to the thermal insulation behavior and rolling effect of MWCNT reported by Zhang et al. [30] The wear behavior of PEEK composites under dry sliding conditions. The presence of constantly decreasing coefficient of friction due to counter face transfer layer formation. Even in the case of higher loading due to the disintegration of agglomeration and improved interfacial adhesion between filler and matrix, the superior friction properties were found.[31] Prepared the short carbon fiber reinforced polyimide (PI) composites filled with particulates of graphite by a heat molding technique. The friction and wear behaviours of PI composites sliding against GCr15 steel rings were evaluated on an M-2000 model ring-on-block test rig. The anti-wear and friction-reducing abilities of the short carbon fiber reinforced PI composites are significantly improved by incorporation
The differences in the friction coefficient and wear properties of the short carbon fiber reinforced PI composites filled with a solid lubricant are closely related with the sliding condition such as sliding rate and the applied load. [32]

Various types of nano- filling materials, such as Al₂O₃, TiO₂, ZrO₂, ZnO, Si₃N₄, CaCO₃, SiC, SiO₂, and nano-CuO, were used in different types of polymers like Epoxy, Polysters, PMMA, PEEK and PTFE. Nano scale fillers are exhibiting good tribological properties rather than micro scale fillers. The wear resistance and friction coefficient of nano scale filled composites show an increase in values while increasing the filler concentration. Wear behavior of alumina (Al₂O₃) filled glass fabric reinforced epoxy (G-E) composites. Alumina filled G-E composites containing 0, 5, 7.5 and 10 wt% were prepared using the hand lay-up technique by compression molding. Studies of two-body abrasive wear against waterproof silicon carbide abrasive paper were conducted. It was found that the loading of the filler increases the volume of wear and increases as the abrading distance increases. For Al₂O₃ filled G-E composites, excellent wear resistance was obtained. In addition, filler loading of 10wt% resulted in a much lower wear loss. [33]

Tribological and mechanical properties of silicon carbide filled a hybrid glass and basalt fiber reinforced composites. The composites were prepared using a compression molding technique. Increased flexural strength and modulus while increasing silicon carbide’s wt%. The specific wear rate of the composite is decreased when the sliding distance is increased. The optimum wear resistance obtained in 6% of silicon carbide filled hybrid composites. [34] The friction and wear behavior Cu-Ni-TiC composites at four different normal loads of 5, 10, 15, and 20 N. A constant sliding speed of 1.25 m/s was maintained while sliding against a hardened counter face made of EN31 steel (HRC 60) under ambient conditions using a pin-on-disc test rig. The addition of 4 wt% TiC was showed the optimum friction and wear performance due to its higher hardness and ability to hold a transfer layer. The composite wear rate and the Cu4Ni matrix alloy increased with the load linearly. [35]

4. Effect of fiber treatment on tribological behavior of natural fiber composites

Treated and untreated carbon fiber reinforced composites and investigated wear behavior of the developed composites sliding against GCr15 steel rings using on an M-2000 model ring on a block test rig. Following the rare earth treatment, the treated carbon fiber enhanced composite surfaces become rougher and form many active groups. In the treated carbon fiber reinforced composites, the wear rate and friction coefficient were reduced compared to the untreated carbon fiber reinforced composites. The optimum content of composites enhanced by 15wt% carbon fiber produces the continuous film transfer in the counterpart surfaces. [36] The tribological properties of rice husk (RH) reinforced composites. They have prepared composites laminates in two different sets such as modified rice husk and unmodified rice husk with polymer epoxy matrix. Due to the unique properties of natural fibers, it has been used by increasing their strength through surface treatments. The better tribological properties were obtained in modified RH composites than the unmodified RH composites. [37] The wear behavior of coir fiber reinforced composites under the condition such as treated and untreated, changing the filler loading and sliding distance. From the results, wear volume increases as the sliding distance increases. The composites reinforced with untreated coir fiber show the higher specific wear rate than the composites treated with alkali and silane. [38] The wear performances of natural fiber hybrid composites. The result reveals that the behavior of wear and friction on normal oriented fibers exhibited better than the fibers treated. The best orientation against the direction of sliding that affects wear and friction is identified. Here is the fibers orientation that dominates the one being treated. Performance varies depending on fiber volume fraction or weight fraction, applied load selection and fiber matrix selection. Normally the wear rate will be increased while the applied rate increases. [39] BF Yousif et al analyzed the wear behavior of untreated oil palm fibre-reinforced polyester and treated oil palm fibre-reinforced polyester composites. The results revealed that, the treated oil palm fiber reinforced composites are enhancing the wear properties [40]. The wear behavior of the composites are determined by the film generated on the counter surface of the composites. Generally the composites are having the frictional characteristic like, the high coefficient of friction at
the running stage then followed by steady state. It shows the stability of the rubbed surface. On the other hand the friction coefficient is decreased in the steady state than the running in condition. This is due to the smooth film transfer is generated on the counter surface and its more stability [41-43].

5. Conclusion

In this article, the tribological characteristics of natural fiber reinforced composites in associated with various polymers and improvements have been discussed. In addition to that the factors like weight %of fibers, addition of nano fillers and treatment of fibers are effecting on the wear behaviour of the composites such as specific wear rate and coefficient of friction also been reviewed. The various input parameters like load, sliding speed, time, temperature and fibers are effecting on the wear behaviour have also been reviewed. Still many types of natural fiber and plants which have not been discovered. More opportunities in the new research, especially tribological behaviour of natural fiber reinforced composites would lead to new discoveries that would bring green environment.

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