Tribology of Fiber Reinforced Polymer Composites: Effect of Fiber Length, Fiber Orientation, and Fiber Size

P. S. Sarath, Rakesh Reghunath, Józef T. Haponiuk, Sabu Thomas, and Soney C. George

Abstract This chapter presents a brief account of the current state-of-the-art in the area of the tribology of fiber reinforced polymer composites. The important factors which determine the friction and wear properties of fibers from the surface modification are mentioned here. Tribological trends for fiber reinforced polymer composites, both traditional and nanocomposites, are presented using data currently available in the literature. Variation in fiber length, fiber orientation, type of treatments and physical characteristics are significantly influence the tribological properties. Finally, based on our current understanding of this field, we have speculated upon some future trends and directions in the area of polymer tribology.

Keywords Tribology · Polymer composite · Length · Orientation · Size

P. S. Sarath · S. C. George (✉)
Centre for Nanoscience and Technology, Amal Jyothi College of Engineering, Kanjirappally, Kottayam, Kerala, India
e-mail: soneygeo@gmail.com

P. S. Sarath
e-mail: sarathps005@gmail.com

R. Reghunath
Department of Mechanical Engineering, N.S.S. Engineering College, Palakkad, Kerala, India
e-mail: rreghunath11@gmail.com

J. T. Haponiuk
Department of Polymer Technology, Chemical Faculty, University of Technology, G. Narutowicza Str. 11/12. Gdansk, 80-233 Gdansk, Poland
e-mail: jhp@urethan.chem.pg.gda.pl

S. Thomas
Center for Energy Materials, Mahatma Gandhi University, Kottayam, Kerala, India
e-mail: sabuthomas@mgu.ac.in

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1 Introduction

Today composite materials are considered as the most promising candidates for replacing conventional metals in aerospace industries because of its high strength to weight ratio and low density (Friedrich 1986). Most of the machine parts are exposed to tribological loadings such as adhesive, abrasive etc. in their service. Therefore, tribological studies of materials have an important role in design mechanical parts. Studies confirm that the friction and wear behavior of polymeric materials can be improved by a lower adhesion and a higher stiffness and strength (Czichos and Habig 1992; Friedrich 1997; Reinicke et al. 1998). Application window of these polymer composites can be widened by using different kinds of multifunctional fiber reinforcements. Fibers in these materials are primary load carrying members and provide strength and rigidity while the polymer matrices maintain the alignment of fibers. By reinforcing with these fibers, dramatic improvement in mechanical properties can be achieved, along with more dimensional stability. It is also possible to tailor made the properties according to the end user requirements like enhanced wear resistance, corrosion resistance, moisture absorption etc. by using a variety of fibers in different polymeric matrices (Schwartz and Bahadur 2000; Zhang et al. 2006; Haupert et al. 2004; Werner et al. 2004). During initial stages of research and development in the field of polymer composites, studies were more concentrated on synthetic fibers like Glass, Carbon and Kevlar composites. These composites have high strength, stiffness along with excellent fatigue resistance. These enhanced properties make it a suitable candidate for many aerospace applications. But poor recycling and non-biodegradable properties limits the usage of synthetic fibers. Since the early 1990s researchers are trying to replace synthetic fibers with natural fibers for developing polymeric composites due to increasing demand for eco- friendly materials for sustainability. Beyond the concern of ecological consideration, the properties of natural fibers are quite good, relatively low density which makes its suitable for light weight application. These fibers also offer significant cost advantages over synthetic fibers. Coir, Jute, hemp, sisal and abaca fibers are commonly used natural fibers. But still the properties of natural fibers are inferior to synthetic fiber composites which make it not suitable for many specific applications. For the last few decades amble research work are progressing for improving the mechanical properties of the natural fiber polymeric systems. The sliding wear behavior of polymer composite against a steel counter surface is essential to categorize according to their appearance, performance and other characteristics. Studies have been emphasized that the tribology behavior of natural fiber in composite is not an intrinsic behaviour and it largely depend on many other parameters such as operating parameters, characteristics of polymer material, physical and interfacial adhesion properties of fibers, additives and contact conditions.

This chapter is mainly focusing to give a limelight in the field of different kinds of fiber reinforcement generally used in polymeric systems for enhanced tribological properties. The basic mechanical and tribological properties of fiber reinforced composites, role of fiber length, fiber size and fiber orientation on optimizing the tribological properties will be discussed.

1.1 Overview of Polymer Composites for Tribological Application

Today in many industries rolling and sliding components such as bearings, rollers, seals gears etc. are manufactured by polymers and its composites. In these applications sustain friction and wear loading in services. When a polymer material comes in contact with any counter surfaces, there are chances of wear and friction. By suitable selection of polymer matrix and fibers, wear resistance can be improved to a greater extent. It was well proved that the friction and wear rate between polymer surfaces depends on roughness of rubbing surfaces, relative motion, temperature, vibration and relative humidity. The parameters that affect the tribological performance of polymer and its composites also include polymer molecular structure, processing and treatment, properties, viscoelastic behavior, and surface texture. There have been also a number of investigations exploring the influence of test conditions, contact geometry and environment on the friction and wear behavior of polymers and composites (Mathew 2007).

Polymer tribology is based on the analysis of abrasion, adhesion, and fatigue of polymer materials in a friction contact. The coefficient of friction (COF) (μ) is largely depend on the mechanical load carrying capacity and the wear rate (Ws) that determine their acceptability in industrial applications. The wear of material is not a simple material property, it largely depends on the two surfaces which comes in contact. The structural features of polymers provide a variety of tribological applications of basic polymers mostly as matrices and fillers of composite materials. Friction is greatly influenced by the class of polymers viz. elastomers, thermosets and thermoplastics (semi-crystalline and amorphous). Semi-crystalline linear thermoplastic would give lowest coefficient of friction whereas elastomers and rubbers show large values. This is because of the molecular architecture of the linear polymers that helps molecules stretch easily in the direction of shear giving least frictional resistance. Table 1 provides some typical values of the coefficient of friction for pristine or virgin polymers (Fig. 1).

1.2 Fiber Reinforcements—Synthetic and Natural Fibers

Scientists and engineers have been actively exploring to find the materials that will be used as replacement of conventional materials and this leads to the development of features of new design units and innovations. It is very important to select proper fibers based on the application of composite materials because of laminate density,

Table 1 Friction coefficient of few polymers when slide against a steel disk counter face (surface roughness, Ra = 1.34 μm). Corresponding specific wear rates and the pressure (P) × velocity (V) values are also presented

Polymer	Coefficient of friction	Specific wear rate (× 10^{-6} mm^3/Nm)
PMMA	0.48	1315.90
PEEK	0.32	31.72
UHMWPE	0.19	15.54
POM	0.32	168.24
Epoxy	0.45	3506.65

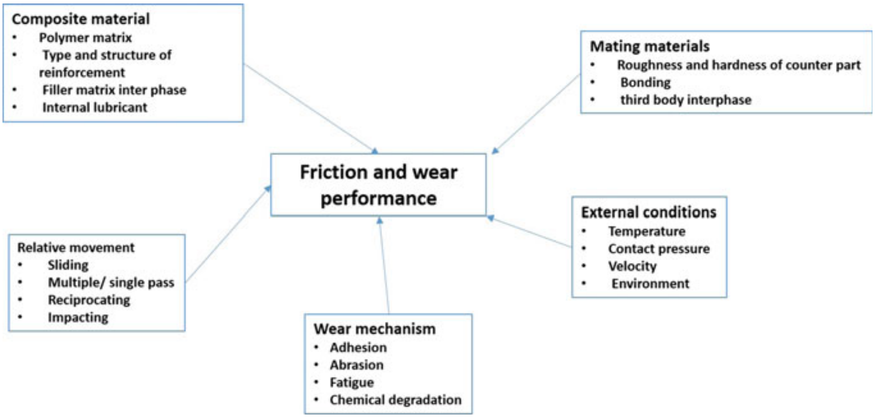

Fig. 1 Areas of influence on the tribological performance of composite materials. Ref -Friedrich et al. (1993)

tensile and compressive strength, conductivity and fatigue strength which depends on the properties of fibers. Fiber reinforced composite material consist of major volume fraction and takes up the major portion load acting on the composite structure (Fig. 2).

Fibers can generally be categorized into three types: synthetic fibers, natural fibers and mineral fibers. Synthetic fibers are made from raw materials such as petroleum, based on chemicals or petrochemicals. These materials are polymerized into a long, linear chemical with different chemical compounds and are used to produce various types of fibers. There are several methods of manufacturing synthetic fibers, but the most common is the melt-spinning process. It involves heating the fiber until it begins to melt, then fiber must be drawn out of the melt with tweezers as quickly as possible. The next step would be to align the molecules in a parallel arrangement. This brings the fibers closer together, and allows them to crystallize and orient. Synthetic fibers are more durable than most natural fibers, and will readily pick up different dyes. In addition, many synthetic fibers offer consumer-friendly functions, such as stretching, waterproofing, and stain resistance. Glass fibers are the most commonly used synthetic fibers for reinforcing polymer matrices because of its low cost, high

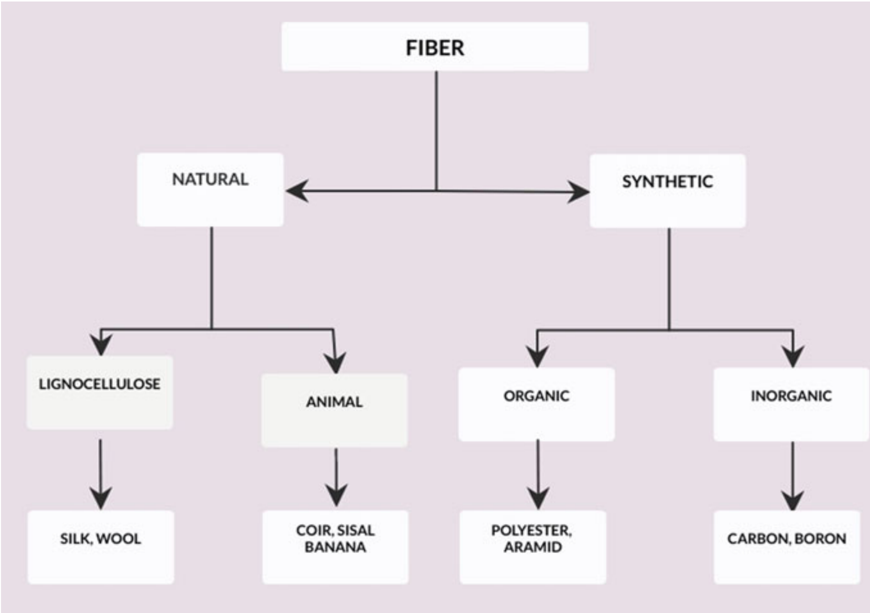

Fig. 2 General classification of fibers

tensile strength and chemical resistance. Two types of glass fibers are quite popular E-glass and S Glass fibers. Glass fibers (GFs) have been employed in various forms such as longitudinal, woven mat, chopped fiber (distinct) and chopped mats to enhance the mechanical and tribological properties of the fiber reinforced composites. Figure 3 shows that properties of such composites were however dependent on the nature and orientation of the fibers laid during composite preparation (Alam et al. 2010). The mechanical behavior of a fiber-reinforced composite basically depends on the fiber strength and modulus, the chemical stability, matrix strength and the interface bonding between the fiber/matrix to enable stress transfer.

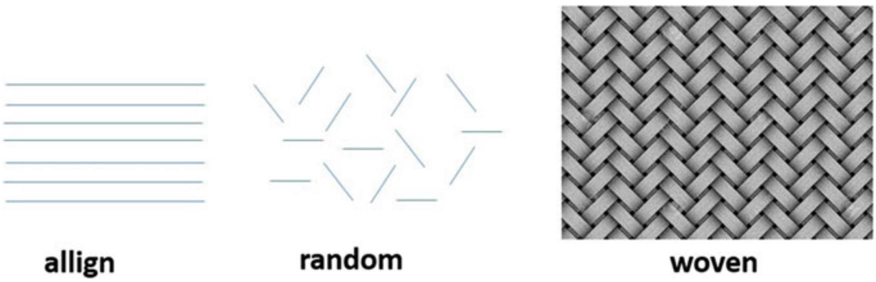

Fig. 3 Different types of fiber alignment

2 General Characteristics of Fiber Reinforced Composites

Fiber-reinforced composites exhibit high specific strength and high specific modulus. The strength is obtained by the better interfacial interaction between fiber and matrix. Fiber geometry also plays an important role in the reinforcement of composite materials. Composite materials with aligned fiber reinforce geometry which exhibit highly anisotropic nature. Random (or chopped) fibers exhibit much lower strength compared to aligned fibers, however, they exhibit istropic character and are cheaper. The fabric made up of woven fibers are layered in the matrix material forms a laminated structure.

Carbon fibers are commercially available with a variety of tensile modulus. It offers the highest specific modulus and strength. Additionally, carbon fibers have the ability to retain its tensile strength even at high temperatures and are independent of moisture. Carbon fibers do not necessarily break under stress in contrast to glass and other organic polymer fibers. Carbon fibers also offer high electrical and thermal conductivities with relatively low coefficient of thermal expansion. This property of carbon fibers makes them ideal for applications in aerospace, electronics and automobile sectors. Poly-acrylonitrile (PAN) is one of the most common precursors employed in carbon fiber production, which offers high tensile strength and higher elastic modulus, extensively applied for structural material composites in aerospace and sporting/recreational goods. Depending on the final curing temperature, different classes of carbon fibers namely high tenacity (HT) fibers, intermediate modulus (IM) fibers, high modulus (HM) fibers and ultra-high modulus (UHM) fibers are formed with PAN precursors (Prashanth et al. 2017).

2.1 Natural Fibers

During the last few years, research has been conducted to replace the conventional synthetic fibers with natural fibers (Mahir et al. 2019). For instance, fibers of sisal, jute, coir, oil palm, bamboo, wheat and banana have been found to be an effective reinforcement in the polymer matrices. The advantages of natural fibers over traditional reinforcing materials such as glass and carbon fiber are their strength, toughness, corrosion resistance, thermal properties, wear resistance etc. Natural fibers reinforcement, have attracted the attention of researchers because they are: (a) environmentally friendly, (b) fully biodegradable, (c) abundantly available, (d) renewable, (e) inexpensive, and (f) lightweight. Fibers in general play a crucial role in deciding the end property of the fiber reinforced composite systems. Thus, appropriate selection of fiber material and their relative orientation can lead to composite to composites with tailor made properties to suit specific application requirements. But the growth in environmental consciousness, community interest, the new environmental regulations and unsustainable consumption of man-made materials, led to thinking of the use of environmentally friendly materials. Owing that view natural

Table 2 Properties of a few natural fibers

Fiber	Density	Young's Modulus (GPa)	Tensile strength (MPa)	Elongation at break (%)
Coconut	1.15	4–6	131–175	15–40
Cotton	1.5–1.6	5.5–12.6	287–587	7–8
Bamboo	0.6–1.1	11–17	140–230	–
Jute	1.44	10–30	393–773	1.5–1.8
Hemp	1.47	17–70	368–800	1.6

fiber is considered as one of the best environmentally friendly materials which have good properties compared to synthetic fiber (Chandramohan and Marimuthu 2011). Table 2 shows the properties of natural fibers. Production of natural fibers causes less severe environmental impacts as compared to that of synthetic fibers. The applicability of tribological testing setup in various natural fibers reinforced polymer composites and its tribological applications have been summarized and illustrated in Table 3.

2.2 *Tribology of Fiber Reinforced Composites*

Tribology is the science that deals with design, friction, wear and lubrication of interacting surfaces in relative motion. Composites have diverse range of mechanical and tribological properties that can be obtained using different types of reinforcements in different orientations with different volume fractions. Today conventional metals have been replaced by composite materials in most of structural applications in aerospace and automotive industries. Comparing with conventional metals composites have high strength to weight ratio and low density and even it can with stand high temperature, high load, high fatigue resistance, high corrosion resistance and less noisy operating condition. Frictional properties of polymer composites are different from that of metals. Like metals polymers deform with higher loads. Adhesion and deformation are characteristic of the friction on the matting surfaces. As a result, the coefficient of friction decreases as the load increases. Among the different classes of composite materials such as polymer matrix composites (PMCs), metal matrix composites, ceramic matrix composites and carbon–carbon composites, PMCs are quite popular in tribological applications because of its self-lubrication capacity.

Today natural fiber composites are gaining a lot of attraction comparing with synthetic fiber mainly due to ease of accessibility, renewability, lower weight, less price low density and biodegradability (El-Tayeb 2008). Reinforcement is a process by which tribological properties of fibers or polymers are altered (positively or negatively) (El-Tayeb et al. 2006). Chin and Yousif (2009) used kenaf fibers reinforced with epoxy composite for a kind of bearing application in which they reported 85 percent increase in wear efficiency and standard composite orientation. Friction and wear rate of the composites depend on the materials selected for reinforcement

Table 3 Role of various natural fiber reinforced polymer composites in tribological applications

Fiber	Matrix	Conditions	Test conducted	Manufacturing Method	Tribological application	References
Rice straw dust/Rise husk	Phenolic	Untreated	Wear test	Hot pressing	Brake pad	El-Sayed et al. (1995)
Sisal	Phenolic	Silane coupling	Adhesive friction and wear	Hot compression	Brake pad	Mutlu (2009)
Betelnut	Polyester	Untreated	Constant speedtester	Hand lay-up		El-Tayeb (2008)
Sugarcane/Glass	Polyester	Untreated	Friction assessment	Hand lay-up	Bearing	Srivastava et al. (2015)
Sea shell nano Powder	Poly - Methyl methacrylate	Untreated	Wear	Micro-hardness Mold	Dental	Xin et al. (2007)
Banana and Kenaf	Polyester	NaOH	Mechanical	Hand lay-up	Clutch	Franklin and de Kraker (2003)
Grewiaoptiva fibers	PLA	Untreated	Wear test	Hot compression		Sabeel Ahmed et al. (2012)

and resin, manufacturing process, operating parameters, fiber volume fraction, fiber orientation, fiber length, and surface treatments. No material is perfect for all types of wear modes. Tribo properties of composites can be predicted only by evaluating them in the laboratory under the different operating conditions. Tribological and mechanical characteristics of fiber reinforced composite material not only depend on the properties of fiber but it also depends on the interfacial interactions of fiber and counter surface. In the case of fiber reinforced composite material there is some critical fiber length is necessary for effective load transfer in addition to the strengthening and stiffening of the composites. Critical fiber length dependence on fiber strength and diameter, and fiber-matrix bond strength/matrix shear yield strength of the composite material.

Bijwe et al. studied the friction and wear analyses under varying fiber percentage, of polyetherimide glass fiber composites were conducted (Bijwe et al. 2001). The authors have revealed that rate of wear resistance of composites is different for different types of wear modes and fiber percentage.

In the case of phenolic compounds it is proved that irrespective of graphite filler size and loading condition, with increasing temperature, friction and wear rate were increased (Kolluri et al. 2018). It was also well proved that nano particles like clay and silicon carbide when mixed with polymer matrices improves the tribological performance of composites (Nguong et al. 2013). Rubber dust was identified as suitable filler for improving anti wear performance. Study was conducted by varying the volume fraction of rubber and it was found that corresponding to 10% of rubber tribological performance was optimum (Mishra 2012). Basavarajappa and Ellangovan (2012) has done studies on glass fiber reinforced epoxy composites with SiO_2 fillers, all these studies indicates that fiber contributes to a key role in controlling the wear rate of the composites.

Friction is the opposing force which is generated when a surface is slide across another surface. Wear on the other hand is the progressive loss of material on a surface, caused by rubbing by another surface. In tribology, friction and wear depend on factors such as rubbing surface roughness, relative motion, and type of material, temperature, normal force, stick slip, relative humidity, lubrication and vibration (Ravikumar and Murali 2018). Abrasive wear of polymer matrix composite is a serious issue because repeated abrasion between two layers of polymer composites (two-body abrasion) or when loose particles are embedded in between two layers (three-body abrasion) causes loss of material. For effective working of fiber-reinforced polymer composites (FRPC's), abrasion wear is to be minimized (Taylor et al. 2014). It was well proved that incorporation of micro and nano-ceramic fillers into fiber reinforced polymer composites have improved their tribo-performance (Friedrich et al. 2005). Studies were conducted to analyze the effect of various fillers like graphite and SiC and it was found that by adding 5 wt% of these fillers wear resistance was improved. It was found that there exist an optimum wt% of these fillers for optimum performance. Normal load was found to have great influence on wear rate of epoxy/glass/SiC/Gr composites followed by sliding velocity and sliding distance were of least significance. Adding 3 wt% graphite into epoxy glass multilayered laminates has led to enhancement of both mechanical and dry sliding performance

Table 4 Tribological properties of different fiber reinforced polymer composites

Materials	Specific wear rate (mm^3/Nm)	Coefficient of friction	References
Polyester	16–22	0.9–0.95	Yousif (2009)
Chopped glass/polyester	2–3.7	0.23-0.7	Yousif and El-Tayeb (2007)
Coir/polyester	1.4–2	0.57–0.8	Hashmi et al. (2007)
Sisal/polyester	0.84–1.12	0.6–0.65	(Yousif et al. 2010)
Cotton/polyester	1.5–3.5	<1	Chin and Yousif (2009)
Un treated oil palm/polyester	4.2–5.5	0.2–0.65	Nirmal et al. (2012)
Betel nut/polyester	2–2.2	0.22–0.55	Prasad et al. (2014)
Kenaf/epoxy	1–1.9	0.36–0.42	Callister (2007)
Bamboo/epoxy	5.5-7.5	0.57–0.64	Rasheva et al. (2010)

of laminates. By adding beyond 3 wt%, it was interesting to note that agglomeration of these fillers took place which adversely affect the wear performance (Shivamurthy et al. 2013).

From Table 4 it is clear that natural fiber reinforced polymer material obtained tribological properties similar to that of synthetic fibers. The table also provides details of the conditioning of natural fibers and their corresponding consequence on friction and wear characteristics.

2.2.1 Effect of Fiber Length

The mechanical characteristics of fiber reinforced polymer composites not only depends on the properties of fiber but also the degree to which load is transmitted to the fiber by the matrix phase. The extent of this load transmittance is the magnitude of the interfacial bond between the fiber and matrix phases. Under an applied stress, this fiber–matrix bond ceases at the fiber ends, yielding a matrix deformation pattern as shown schematically in Fig. 4.

Some critical fiber length is necessary for effective strengthening and stiffening of the composite material. This critical length is dependent on the fiber diameter d and its ultimate or tensile) strength σ_f and on the fiber–matrix bond strength (or the shear yield strength of the matrix, whichever is smaller) τ_c according to

$$l_c = \frac{\sigma \sigma_f d}{\tau c} \quad (1)$$

- When the fiber length $l < l_c$; the reinforcement is particulate in nature.
- When the fiber length $l >$ lc but $l < 1.5l_c$ the reinforcement is short fiber types
- When the fiber length $l > 15l_c$; the reinforcement is continuous in nature.

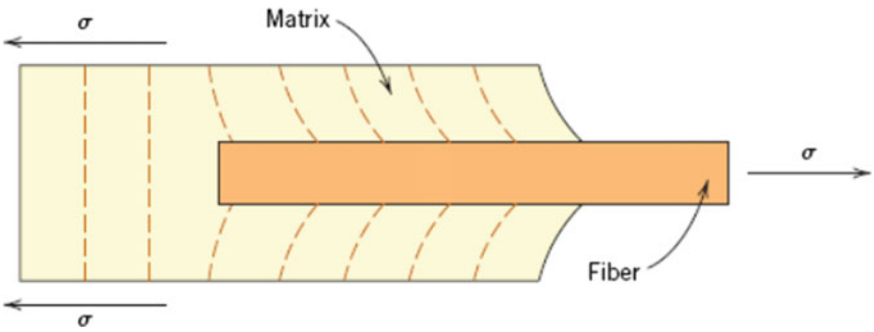

Fig. 4 Deformation pattern in the matrix surrounding a fiber that is subjected to an applied tensile load (Callister et al. 2012)

Compared to continuous fiber composites, short fiber reinforced polymers (SFRP) combine easier process ability with low manufacturing cost. Therefore, in recent years the use of SFRP composites grows rapidly in many engineering applications, in particular in automobile and mechanical engineering industry (Callister 2007). For the last few years numerous amounts of research work has been progressing to find the effect of fiber length in determining the mechanical properties of the composites. All these investigations indicate that the fiber length is a crucial parameter in determining the mechanical performance of SFRP. It is known fact that fiber length plays a main role to create interfacial bonding between fiber and the matrix. In the theoretical sense too, short length reduces the load carrying capacity of fiber and responsible for high wear rate and excessive length results in easy pull out of the fibers and produces more wear rate.

2.2.2 Effect of Fiber Orientation

There are various parameters which influence the performance of composites such as amount of matrix and fibers, their alignment with respect to loading direction, fiber–matrix interface, processing technique etc. Different orientation of the fiber with respect to the sliding direction of the counter face was considered; fiber orientations classified as normal, parallel, anti-parallel and random. From the literature it is very clear that the orientation of fiber is a very important critical parameter in composite design. Fiber reinforced composites generally behave in different way for different modes of loading conditions, for example fibers aligned in parallel direction to load gives excellent tensile properties, but in tribological loading it can lead to fiber pullouts. Therefore, at each loading conditions, the orientation of the fibers should be comprehensively studied about the performance of the composites. Friction and wear behaviour of unidirectional carbon fiber-reinforced epoxy composites containing various unidirectional carbon fibers was investigated on a pin-on-flat plate configuration (Zhang and Friedrich 2007). The carbon fiber improved the tribological properties of thermoset epoxy by reducing wear rate. The wear rate decreased with decreasing load while friction coefficient increased with decreasing load. Pineapple leaf fibers were identified as potential fillers for bisphenol-A composites. Experimental study was conducted to find the effect of fiber orientation, namely, unidirectional, bidirectional and 45° orientations on specific wear rate and frictional coefficient of PALF reinforced Bisphenol-A (BPA) composite by using a pin-on-disc wear and frictional testing machine (Prasad et al. 2014). It is found that the wear resistance of pure Bisphenol-A resin is improved after PALF reinforcement. Among three types of fiber orientation in composite, bidirectional composite shows least specific wear rate and coefficient of friction. Three different set of composites were prepared perpendicular, anisotropic and isotropic orientation were taken for the study. It was found the polyester/kenaf sandwich composite with kenaf fiber in anisotropic orientation design will form a strong bridge over the cracks, thus increasing the breakage resistance of the kenaf fiber. Polyester/kenaf composite with kenaf fiber in anisotropic arrangement achieved the highest tensile, flexural, and impact properties. This was followed by a sandwich composite with kenaf fiber in isotropic and perpendicular orientations (Chin and Yousif 2009). PTFE and graphite powder filled SCF reinforced PEEK composites were prepared and effect of fiber orientation on the tribological properties were studied and a correlation between mechanical and tribological properties with fiber orientation was developed (Rasheva et al. 2010) (Table 5).

Test results shows that the tribological performance of the composite MA (a total of 20 vol.% solid lubricants and 10 vol.% SCFs) is significantly dependent on the fiber orientation with an advantage for the perpendicular fiber orientation. Furthermore, a low solid lubricants content and high SCF-content (MC—a total of 10 vol.% solid lubricants and 15 vol.% SCFs) lead to a tendency for higher wear rates, especially for the perpendicular fiber orientation, since a transfer film is hard to be built. The worn surfaces of this material combination is very rough with a lot of grooves and wear debris. The composite MC presents low wear resistance. The composition MB (a total of 20 vol.% solid lubricants and 15 vol.% SCFs), presents the most stable wear behavior with a stable worn surface, independent from the fiber orientation and the applied load (Table 6).

Table 5 The composition and specific wear rate parallel and perpendicular to the fiber direction

Material code PEEK/PTFE/Graphite/SCF	Apparent pressure	Specific wear rate parallel	Relative error %	Specific wear rate perpendicular	Relative error
MA 70/10/10/10	1	0.554	8.68	0.410	5.85
	4	0.494	6.88	0.367	2.39
MB 65/10/10/15	1	0.413	15.74	0.424	17.68
	4	0.420	5.00	0.468	8.33
MC 75/05/05/15	1	0.501	13.77	0.397	10.30
	4	0.454	11.23	0.525	15.12

Table 6 Effect of sliding parameter on synthetic fiber reinforced Polymer composites

Polymer	Reinforcement	Load (N)	Sliding speed (m/s)	Environment	Observation	References
Epoxy	Glass fiber	40–120	2.51–3.14	Oil	Weight loss, wear rate, and COF increases with increase in load and sliding speed	Sarkar et al. (2017)
UHMWP	Glass fiber		0.2–1	Dry Water	Friction coefficient decreases	Vadivel et al. (2018)
Polyetheri-mide	Glass fiber MoS_2 Graphite PTFE	70–100			Addition of filler material improve performance of composite	Bijwe et al. (2001)
Polypropylene	MWCNTs (0 wt% to 7 wt%)	10–50	1–5	Dry	Increase in weight % of CNTs reduces weight loss and friction coefficient	Gandhi et al. (2013)

Friedrich et al. studied tribological anisotropy of different fiber orientations in continuous carbon fibers (CCF) reinforced polymers. Study shows that tribological sliding in direction parallel to the fibers axis leads to a higher wear resistance than in perpendicular direction. Effect of fiber orientation on Lyocell reinforced polypropylene composites show that mechanical properties are strongly depending on the fiber orientation (Cordin et al. 2018).

3 Surface Modification of Fibers—Physical and Chemical Methods

Now a days, there has been several attempts to replace the synthetic fibers with natural fibers for reinforcing the composite materials due to increasing environmental awareness. There are some limitations for using natural fibers as a reinforcing material such as poor compatibility with different matrices, high moisture absorption, swelling property etc. These limitations can be successfully overcome by modifying the surface of natural fibers using various techniques. Interfacial adhesion between fiber and matrix play a significant role in controlling the tribological properties of polymeric composite.

3.1 Physical Techniques

3.1.1 Plasma Treatment

Plasma treatment can be successfully utilized to improve surface properties of fibers in many applications. The process can be utilized to introduce new functional groups into the surface of natural fibers, which can form strong covalent bond with matrix leads to strong fiber/matrix interaction. This process also can be used for surface etching which improve in surface roughness and results in better interfacial interactions. Sarkar et al. (2017) studied the tribological behavior of PEEK reinforced with and without plasma treated carbon fiber. The mean friction coefficient dropped from 0.42 to 0.23 and the mean specific wear rate 5% dropped from 10^{-5} to 10^{-6} ($mm^3\ N^{-1}\ m^{-1}$). The improvement of tribological behaviour of PEEK and its composites after plasma surface treatment is due to cross-linking of PEEK and improvement of the interface strength of carbon fiber reinforced PEEK composites. They also studied the effect of different ratios of carbon fiber (CF) reinforcing polyimide (PI) and surface treatment of CF on the microstructure and wear resistance of surface layers. The friction coefficients of the composite increased with the increase of CF content. The reason may be the improvement of the microhardness and wear resistance of the CF/PI composite aroused by the addition of CF in the composite. Basalt woven fabric was surface-treated by atmospheric oxygen plasma to improve adhesive force at the fiber/matrix interface and the wear volume of the basalt/epoxy woven composite was reduced from 2.95 to 0.65 mm^3 (Kim et al. 2011). The surface treatment improves the interfacial adhesion between the fiber and resin, thus reducing the debonding of basalt fibers on the wear surface.

3.1.2 Laser Method

Laser treatment method modifies the polymersurface without any changes in its bulk properties. This method creates morphological changes on the smooth surface of synthetic fibers, that further changes its physical (roughness) and chemical properties (water absorption, dyeing. Advantage of laser treatment is that the small area can be treated and depending on the level of power chosen, chemical and physical changes can occur (Abdolahifard et al. 2011).

3.1.3 Electron-Beam Modification

Electron beam is a way of radiation that can produce polymer free radicals. These free radicals combine with each other to form cross links resulting in the formation of a three-dimensional network structure. Polypropylene fabric showed improved wet ability and dye ability due to formation of (O–H) and (C=O) groups on the surface of samples after electron beam irradiation (Ibrahim et al. 2005)

3.2 Chemical Techniques

In chemical techniques the natural fibers have been treated with different chemicals such as silane, alkali, permanganates, peroxides etc. It has been found that some of these chemical treatments successfully improve the properties of natural fibers. This type of modifications removes the weak components of lignin from fibers and modifying their crystalline structure. Main objectives of this treatment to improve the fiber strength and adhesion between fiber surface and polymer matrix.

3.2.1 Enzymatic Modification

The use of enzyme in the field of textile and natural fiber modification is rapidly increasing. Enzymatic treatment is ecofriendly method of fiber surface modification as it do not discharge harsh effluents to the environment and use milder conditions (Ibrahim et al. 2005). Other benefits of this treatment are cost reduction, energy and water saving, improved product quality and potential process integration.

Ozone gas treatment

Ozone is excellent oxidizing agent and is used for fiber modification. In this treatment hydrophilic groups are incorporated on fiber surface which results in change in fiber surface chemistry.

Oxidation of wool fiber by ozone gas leads to increase in polymer adsorption by increasing the polarity (Bradley et al. 1993).

3.2.2 Sol-Gel Technique

The sol-gel technique is of particular importance for textile materials. The principles of the sol-gel process include hydrolyzation, application and curing (Textor 2009). The deposition of coating on fibre surface in the form of sol gel is applied to improve some fiber properties such as abrasion resistance, UV protection and attains water repellency.

Adhesion between the fiber and the matrix can be improved by various surface treatment methods viz. electrochemical, chemical, thermal, discharge plasma etc. It is improved by various means such as,

(a) Wettability of the fiber surface improved by using the matrix resin.
(b) Removing the weak boundary layer on the fiber surface. This would provide a more intimate contact between the fiber and the polymer.
(c) Promoting mechanical interlocking between the fiber and the matrix by which creating surface porosity, and resin molecules can penetrate into porosity of fiber.
(d) Chemical bonding between the fiber and unreacted species in the matrix resin can be improved by increasing the number of active sites on the fiber surface.

4 Tribology—Future Aspects in Fiber Reinforced Composites

Now a days polymer composite materials replace metals from almost all area and their usage increases steadily. Matrix materials and wide variety of different fiber permits the design of composites with unique properties for different kinds of application. Polyether ether ketone (PEEK) is reinforced with carbon fiber can be used for the development of an artificial hip joint. In thermoplastics matrix short fibers can be used to process complex geometries. There is remarkable improvement in tribological properties observed with combination of SCF (short carbon fibers) with micro- and nano-filler combination. Nano fillers get freely movable in the contact region between the mating surfaces, nano rolling effect which smoothen the topographies and reduce the coefficient of friction and temperature of the contact region. Load bearing capacity of the thermosetting polymers improved by the addition of fiber, now a days these materials are used in automobile for composite break materials. In future, definitely there is a high demand for high performance materials. i.e., materials which can operate high pressure, velocity and temperature conditions. In this aspect, functionalized fiber reinforced composite material and new emerging area of polymer nanocomposites could be a great promise. The main advantage of certain fiber (carbon) reinforced polymer composites over traditional composites is its ability to improve both strength and tribological properties simultaneously. Polymers reinforced with fibers possess low specific wear rates and significant improvement in mechanical properties. Synthetic fibers such as glass, carbon, graphite and aramid are all commonly used fibers in thermosets as well as thermoplastics. Among all these fibers, continuous carbon fibers reinforced polymer exhibits excellent tribological properties. Studies of tribological properties of nano-fiber reinforced composites are still at a relatively early stage. There are lot of innovative research work that will happen in this area for coming years. There are some research papers available in the farea of high performance polymeric material mixed with nanoparticle that enhance the tribological property to a great extent. Hence this could be another major area of growth that occur in polymer tribology field.

5 Conclusions

A detailed study of different types of fiber reinforcements generally used for developing polymer composites was discussed in this chapter. The physical and mechanical properties of both natural and synthetic fibers were compared. It was found that fiber length and fiber orientation are a critical factor that effects the mechanical and tribological properties of the composites. Surfaces of the fiber can be easily modified using different techniques it will enhance the interaction between fiber and the matrix. Fiber orientation has very significant influence of the wear and frictional performance of fiber reinforced materials. Studies of tribological properties of polymer nanocomposites are still in the early stage. In future, there is a great demand for polymer composite material prepared with nano fibers which can be easily moulded in any shape and high strength and toughness properties simultaneously and isotopically.

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