

Tribological Properties of Different Synthetic Fiber Reinforced Polymer Matrix Composites- A review

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Abstract. A review on tribological properties of various synthetic fiber strengthened polymer composite is introduced in the article. FRP has numerous advantages, for example, ease of processing, high strength, low density and so forth. There lots of research has been done to decide tribological properties of FRP composites .It was seen by different specialists that the tribological properties of synthetic fiber reinforced polymer composite relies upon fiber orientation, rubbing speed, matrix material, filler material and so forth, what's more, this paper reviews the work completed in this field by various researchers in recent years.

Keywords: Fiber reinforced polymer composite, tribology, glass fiber, carbon fiber, wear

1. Introduction

These days to enhance the material execution and diminish the cost of assembling composite material are utilized which are made of no less than two particular materials. As the utilization of composites increases, research is being carried out on assortments of composites e.g. metal network composites (MMC), ceramic matrix composites (CMC), polymer matrix composites (PMC) and so forth. [1].Singh et al. [2] found that metal network composites have better tribological property contrasted with metal alloy. Fibre strengthened polymer composite discovers application in numerous tribological parts, for example, brakes, grasp pivot box, cranes, diary bearing, excavators, medical equipment and so on. Both synthetic and natural fibre can be utilized as reinforcement in fibre strengthened polymer composites. Figure 1 demonstrates different arrangements of FRP composites based on matrix and fibre. Minimal effort of manufacturing, high rigidity, high hardness, protection from erosion, capacity to withstand high temperature made synthetic fibre reinforced polymer composite an appropriate material for modern application. Among different manufactured filaments, E-glass fibre is most generally utilized as reinforcement on account of its minimal effort. Be that as it may, for assembling flying machine, marine part S-glass fibre was utilized [3-12, 52].

To improve the tribological property of FRP composite filler material can be presented. CNTs as a filler material improves mechanical and thermal stability of parent material. Hybridization process can likewise be utilized to enhance mechanical and tribological property of base material [13-15]. Fiber volume fraction, connected load, sliding speed, sliding time, surrounding condition, activity temperature, filler material are the elements that for the most part influence the tribological behaviour of synthetic fiber reinforced polymer composite [16-21, 51].



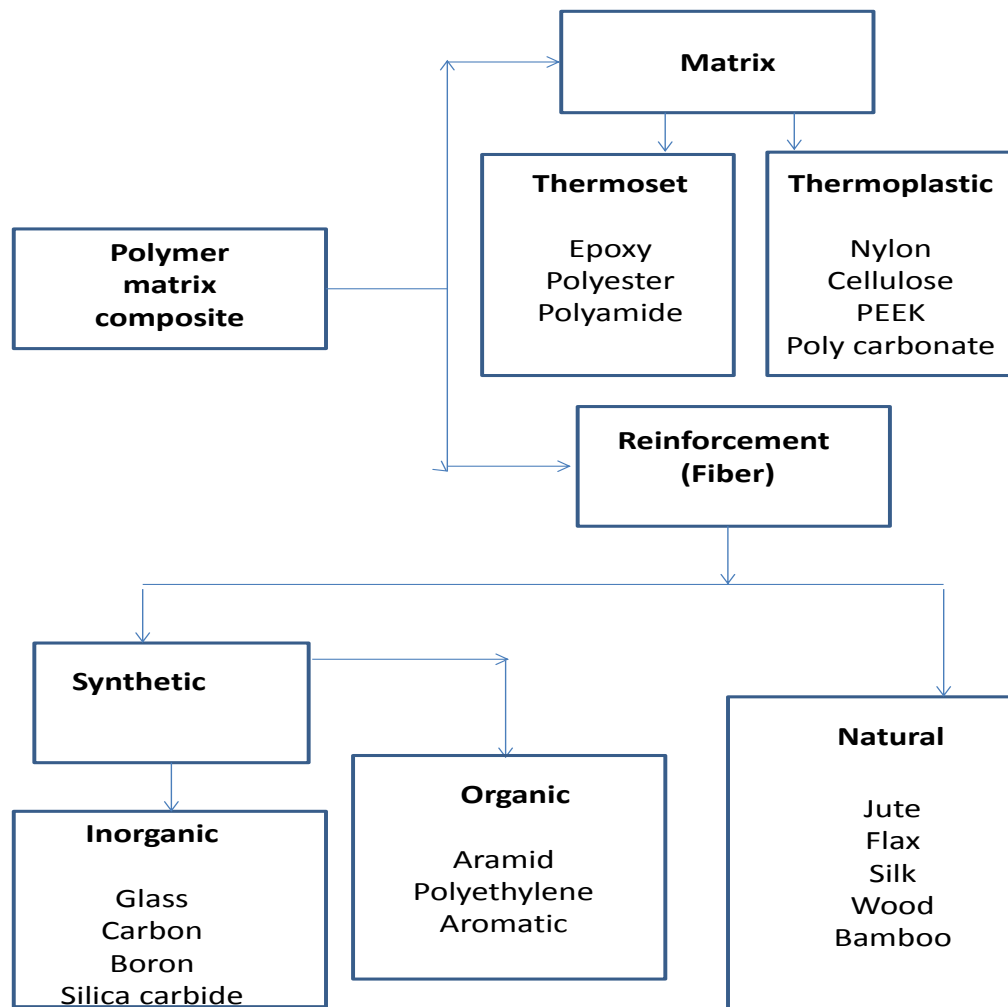


Figure 1. Matrix and reinforcement in polymer matrix composites

There are lots of research done by numerous scientists to comprehend the tribological properties of synthetic fiber reinforced polymer composites and this paper exhibits a concise review on worked did in this field lately.

2. Literature review

2.1. Effect of various sliding parameters(Load, sliding velocity, rubbing distance) on tribological property of synthetic fiber reinforced polymer matrix composites:

Arun and Singh[24] in their paper examined the impact of increment in load and sliding velocity in GFRP composite. Pin-on-disc tribometer was utilized to play out the test. Tests were performed under three unique loads (40N to 120N) and two distinctive sliding speeds (2.51m/sec and 3.14m/sec). It was seen in the examination that with increment in both speed and load weight loss (mg) , rubbing coefficient and wear rate increments. The fundamental explanation behind increment in wear rate is matrix wear and fiber debonding. Guermazi et al. [22] researched physical, mechanical and thermal properties of carbon/epoxy, glass/epoxy and hybrid laminates in terms of dampness assimilation, thermal dependability, elastic modulus and abrasive wear protection. The effect of hygrothermal aging on the mechanical properties has likewise been researched. It was presumed that with increment in

abrading distance wear rate additionally increments however wear rate in hybrid composite is less contrasted with glass/epoxy composite. Hygrothermal aging likewise influence wear rate, it was observed that wear rate of aged composite more than unaged composite. Srinivas and Bhagayshekhhar [23] utilized diverse filler on epoxy based composite and its impact in light of tribological properties. The samples used in the experiment are in the (diameter 10mm and length 25mm) form of pins.. The test were conducted under dry sliding condition. By shifting level of graphite (Gr) and silicon carbide (SiC) a sum of fourteen different kinds of samples were readied. The comparison of tribological property was done based on coefficient of friction and particular wear rate. The samples were tested under three different loads (10N, 20N and 30N) and six diverse sliding velocity. Results demonstrated that with increment in sliding distance for a specific load wear rate diminishes. It was seen from the experiment that SiC/Gr epoxy hybrid composite have most reduced particular wear rate or we can state have great wear protection property contrasted with other tested materials amid the examination. The material having 5 wt.% SiC and 35wt.% graphite displays least wear rate. Friction coefficient demonstrates an exceptional conduct, with increment in load there is a diminishing in the estimation of rubbing coefficient and consistent estimation of friction coefficient with increment in sliding distance. It can likewise be seen from the outcomes that with decrease in SiC substance and increment in graphite content gives a lower estimation of friction coefficient, this is because of self-greasing up limit of graphite that structures a tribofilm on the steel counter surface. This is the reason erosion coefficient decreases with increments in graphite content in epoxy hybrid composites. SEM pictures of the examples approved the outcome got amid the experiment .

Agarwal et al. [25] in their paper observed the wear behaviour of two distinct sorts of glass/epoxy composite (short and long fiber). Abrasive tests were performed with the assistance of TR-50 (DUCOM) tribometer. Size of rough molecule, connected load and rubbing speed assumes fundamental part in deciding wear behaviour. The wear behaviour were looked at by (a) varying sliding speeds (b) varying connected load. It can be finished up from the outcomes acquired from the experiment that with increment in connected load ,size of molecule(grating) wear rate of both the composites increments. Yet, with increment in sliding speed there is diminish in wear rate up to 40% fiber loading and afterward it increments. Tosun and Pihtili [27] investigated the behaviour of glass fiber reinforced polymer composite and plain polyester resin at various sliding distances and different applied loads. The correlation is done based on weight loss. It was found in the examination that with increment in rubbing distance the weight reduction in case of GFRP composite is less in contrast with polyester composite. It was likewise observed that for a specific sliding distance with increment in applied load weight reduction additionally increments for both the material. Deshpande et al. [28] contemplated the tribological behavior of bone fiber filled HFRP composite. Glass fiber was utilized as reinforcement and jute fiber as filler material. Three materials were set up by hand lay up technique, by fluctuating the concentration of filler material (0%, 10% and 15%). Taguchi technique was employed to decide the impact of different factors on wear rate e.g. applied load , sliding speed and filler content. Among every one of the parameters impact of sliding speed on wear rate is predominant Sudheer et al. [29] examined mechanical and wear properties epoxy/glass polymer hybrid composite with PTW was utilized as filler material and graphite was utilized as solid lubricant. Three unique sorts of material (a) epoxy/glass without filler (b) epoxy/glass/PTW without internal lubricant (c) epoxy/glass/PTW with internal lubricant were set up by hand layup strategy took after by vacuum bagging process. The tribological behavior of the composites were analyzed based on wear rate and rubbing coefficient. The test were performed under steady sliding distance. The wear rate and fiction coefficient were compared by changing load and sliding speed. It was seen amid the test that with increment in load rubbing coefficient diminishes for all the three materials and epoxy/glass/PTW composite with filler material shows better tribological behavior among the three materials. Again it was observed that with increment the rubbing speed friction coefficient increments for every one of the materials. Epoxy/glass/PTW composite with filler material has minimum wear rate. Specific

wearrate has inverse relation with increments in load and direct relation with sliding speed for all the three materials.

2.2. Effect of surrounding environment, fiber orientation and fiber fraction on tribological property of synthetic fiber reinforced PMCs:

Agrawal et al. [30] researched the friction and wear characteristics of glass fiber reinforced composites under three distinctive load, three speed and three diverse surrounding condition (dry, oil and inert). The materials required for the examination was prepared by vacuum bagging process. The examination was performed on a pin on disc type tribometer. Epoxy was utilized as matrix material for the investigation. The outcome demonstrated that among all the three condition the estimations of tribological properties is greatest in inert gas (argon) condition and least under oil greased up condition. Because of self-greasing up property of tribo film under oil greased up condition prompts improvement of tribological property. Chen et al. [31] examined the erosion and wear behaviour of Polytetrafluoroethylene composite. Ocean water, carbon fiber and polyimide were utilized as surrounding condition, reinforcement and filler material separately. By changing the volume portion of polyimide and carbon fiber five distinct sorts of composites were prepared. Ring on block type tribometer was utilized to assess tribological property. During the test applied load was shifted from 100N to 400N and sliding time is made steady of 120 min. Results demonstrated that impact of ocean water has negligible impact on tribological property of PTFE composite. It was likewise seen amid the experiment that addition of PI and CF improves tribological property and PTFE–5%PI–15%CF composite show minimum erosion coefficient and particular wear rate among all the material tested amid the experiment. Jain et al. [57] in their paper studied the effect of addition of MWCNTs on tribological behaviour of GFRP composites. By varying the concentration of MWCNTs three different types of material was prepared (neat, 0.5wt.% and 1wt.%). The composites were fabricated with the help of vacuum bagging process. It was observed that with increase in sliding velocity frictional force, wear in micrometer increases. The results also showed that with increase in concentration of MWCNTs wear rate and friction force decreases.

Basavarajappa et al. [32] studied the impact of graphite (Gr) addition on wear behavior of composite. Pin on disc type mechanical assembly was utilized to decide the tribological properties of the composite. Epoxy and glass fiber was utilized as matrix material and reinforcement respectively. Amid the test filler volume% was fluctuated from 0% to 10%. It was observed that addition of filler material decreases wear and rubbing coefficient and best outcome was acquired in for GE/10%Gr composite. Gandhi et al. [33] examined the impact of CNTs and its uses for the upgrade of tribological property of polypropylene composite. Five unique sorts of material were studied (a). Neat polypropylene (PP) (b) PP + 1% CNTs (c). PP + 3% CNTs (d). PP + 5% CNTs (e). PP + 7% CNTs. It was obvious from the outcomes that with increment in load and sliding speed weight loss (gram) increments. With increment in %CNTs wear resistance behavior also increases. It was additionally observed from the outcomes that with increment in load friction coefficient increments and after that it achieve a constant value. Among the all materials PP+ 7% CNTs composite show best tribological behavior. Hanumantharaya et al. [34] in their paper investigated the friction characteristics of boron carbide, MoS₂, fly ash reinforced epoxy polymer composites. By shifting sliding speeds, distance and load all tests are performed. To figure out which parameter impacts the most ANOVA was carried out for all experiments. Results depict that load and speed plays an essential role in wear behaviour. Among the tested materials pure epoxy composite shows most noticeably bad tribological behaviour. Gao et al [35] in their paper considered the impact of various filler materials (short glass fiber, short carbon fiber, silicon oxide and graphite) on friction and wear conduct. Water was utilized as surrounding condition. Results showed that addition of filler material has a positive effect on wear characteristics and Epoxy/SCF/Gr/Si shows least friction coefficient among various materials utilized as a part of the test.

Table 1: Effect of sliding parameter on synthetic fiber reinforced PMCs

Polymer	Reinforcement	Filler material	Load	Sliding Speed	Surrounding environment	Observation	Ref.
Epoxy	Glass fiber	—	40N to 120N	2.51m/sec to 3.14m/sec	Dry Oil Inert	Weight loss , wear rate, friction coefficient increases with increase in load and sliding speed.	[6]
UHMWP	Glass fiber Class fiber	—	—	0.2m/sec to 1 m/sec	Dry Water	Friction coefficient decreases in water lubricated condition and increases in dry condition.	[44]
Polyeterimide	Glass fiber	MoS ₂ Graphite PTFE	70N-100N	—	—	Addition of filler material improve performance of composite.	[45]
Epoxy	Short Glass fiber Long Glass fiber	—	20N to 100N	0.48m/sec to 1.44m/sec	—	Specific wear rate increases with increase in load	[25]
Epoxy	Glass fiber	MWCNTs	30N to 90N	3.14m/sec	Dry Oil	Addition of CNTs reduces wear rate and weight loss. Tribological property show better behavior in dry lubricated condition.	[46]
Polypropylene	-	MWCNTs (0wt. % to 7wt. %)	10N to 50N	1m/sec to 5m/sec	Dry	Increase in weight % of CNTs reduces weight loss and friction coefficient.	[33]

Polyether imide	Short glass fiber	MoS ₂ Graphite	70N to 100N		Dry	Addition of solid lubricant improve wear resistance.	[47]
UHMWPE	–	1.Graphene oxide(GO) 2.Nano diamond(ND) 3.Short carbon fiber(SCF)	–	–	Water	Unfilled UHMWPE has poor wear resistance characteristics. Addition of filler material improve tribological property	[48]
PTFE	Carbon fiber	–	–	0.54 to 5400cm/sec	–	Addition of carbon fiber enhances wear resistance property.	[49]
Epoxy	Glass fiber	–	5N to 50N	0.5m/sec to 3 m/sec	Dry	With increase in load for a particular sliding speed friction coefficient decreases.	[50]
Vinyl ester	Glass fiber Carbonfiber		42N to 142N	.5m/sec to 2m/sec.	Dry	With increase in sliding speed for a particular load wear rate increases	[53]

Ojha et al. [36] inferred that with increment in level of carbon black as filler material diminishes the reduces the erosion wear in polymer composite at a specified impact velocity.

Wang et al. [37] contemplated the impact of variation of orientation of aligned carbon nanotubes on the wear protection property of epoxy based composites. Three distinctive orientation of epoxy/ACNTs taken amid the analysis (a) ACNTs parallel to direction of sliding (b) ACNTs normal to direction of sliding (c) ACNTs antiparallel to direction of sliding. It was observed that normal direction shows better tribological behavior among the all other orientation with increase in load and sliding velocity. Wang et al. [38] studied the effect of variation in fiber orientation on tribological behavior of carbon fiber reinforced composite. Copper was used as filler material during the experiment. During the test tribological behavior was studied under the influence of electric current. Ring on block type tribotester was used to perform the experiment. Three different types of orientation were taken (a) vertical (b) parallel (c) normal. Speed during the tests was varied from 10 m/sec to 60m/sec. it was observed that at high speed(above 30 m/sec) normal orientation of the composite show better wear resistance behavior but under low speed it show less wear resistance. It was observed that wear rate occurs mainly due to erosion at high speed and matrix removal at low speed. El-Tayeb [39] studied the friction and wear behaviour of effect of varying fiber orientation with

respect to sliding direction on tribological property of glass fiber reinforced polyester composite. Wear resistance and friction coefficient were compared for three different orientations (a) cross laminar (b) normal (c) parallel, under different load and sliding velocity. Experiment was conducted under varying load (4N to 22N) and varying sliding speed (0.05m/sec to 1.2m/sec). It was observed that friction coefficient is lowest in cross laminate orientation and highest in parallel orientation. This is due to rapid exposure of new fiber on the counter surface with variation of load and sliding speed in case of parallel orientation. Ho Sung and P Suh [40] examined the wear property of FRP composites by changing orientation of fiber in regard to rubbing direction. Three unique sorts of material were looked at (Graphite-epoxy, Kevlar-epoxy, Glass fiber-MoS₂-PTFE). Experimental results showed that values of tribological properties were least in Gr/epoxy composite and rubbing direction was normal to direction of fibers.

Babu et al. [41] studied the mechanical and specific wear properties glass/carbon fiber reinforced hybrid composite. It was observed that tribological parameters depends on stacking sequence, operating parameters and material. The stacking sequence used during the experiment was [CG₃C]_s. Wear tests were conducted on a wear testing tribometer (TR-50). To perform abrasive test dry sand was used as abrasive material, rpm of the wheel is maintained constant during the experiment. In order to know the effect of input factors (hardness of the composite, sliding distance, applied load) on specific wear rate ANOVA was performed. Among these parameters sliding distance plays a vital role in wear rate. Harsha and Jha [42] studied the erosive wear behavior of epoxy based composites reinforced with glass fiber and carbon fiber. Four types of composites were prepared (a) neat epoxy (b) uni-directional glass fiber epoxy composites (c) Bi directional glass fiber epoxy composites (d) uni-directional carbon fiber epoxy composite. Results from the experiment showed that uni-directional glass fiber composite has poor erosive wear resistance characteristics compare to bi directional glass fiber composites. Wear due to erosion increase with increase in velocity of impact. Again microscopic study of the samples revealed that fiber matrix debonding, fiber pull out, crack propagation are the main mechanism responsible for increase in wear rate. David et al. [54] carried out study on glass fiber reinforced polymer composites. They have studied the effect of fiber volume fraction and length of fiber on tribological properties. During the experiment the glass fiber content was varied from 2 wt.% to 7.6wt.% and fiber length from 1.5mm to 3mm. It was observed from the experiment that in case of longer fiber wear rate was minimum compared to shorter fiber. It was also observed that 5.7wt.% specimen show better tribological behavior under varying sliding distance and load. B.C.Ray [43] explored the temperature impact on shear strength of glass and carbon fiber strengthened composites. Epoxy was utilized as matrix material. The materials were set up by utilizing vacuum bagging technique. Experimental result demonstrated that as temperature expands dampness take-up rate likewise increases. The interfacial region of glass fiber epoxy and carbon fiber epoxy exceedingly affected by hygrothermal ageing at higher molding temperature and for more exposure time.

Bijwe et al. [55] in their paper contemplated the impact of variation in carbon fiber (CF) content and fiber orientation on tribological conduct of polyetherimide (PEI) based composites. By varying (40% to 85%) the volume % of CF five unique sorts of composites were set up by utilizing impregnation strategy. Applied load was differed from 10N to 40N amid the test. It was seen from the trial result that with increment in carbon fiber content above (65vol. %), composite begins to demonstrate poor tribological conduct. Keeping in mind the end goal to comprehend the impact of fiber orientation on tribological conduct, 40% vol of CF composite was taken and six distinct kinds of orientation of fiber regarding rubbing plane and rubbing direction was tested. It was observed that normal orientation of fiber to sliding plane show better wear protection qualities contrasted with other tested fiber orientations. Qianqian et al. [56] investigated the impact of surface treatment on rubbing and wear behavior of CF/PTFE composite and observed that surface treated composite show better wear and friction attributes contrasted with untreated composite under differing sliding parameters.

3. Conclusion:

Excellent mechanical and tribological properties like unprecedented rigidity, modulus, great erosion and corrosion protection and dynamic soundness have empowered the utilization of FRP composites in an assortment of uses. Scarcely any research papers are accessible on deciding the impact of encompassing environment on tribological property of synthetic fiber reinforcement polymer composite. There are a less research papers on hybrid fiber strengthened polymer composite. Epoxy was for the most part utilized as reinforcement material. This review paper will enable the individuals who to need to complete research in this field of study.

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