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Investigation of heat response, protective layer efficiency and surface characteristics of fiber-based polymer composites: General review

ABSTRACT

This study investigates the influence of thermal characteristics, coating effectiveness, and surface morphology on the performance of polymer matrix composites reinforced with fibers, fillers, and nanofillers. Various factors such as the type and nature of fibers (natural or synthetic), fiber orientation, matrix composition, reinforcement volume, and the presence or absence of surface coatings have been analyzed for their role in governing thermal response. Surface morphological analysis was carried out to understand the mechanisms of wear and the modes of material degradation. The contribution of reinforcement type and its proportion in enhancing wear resistance has also been evaluated. In addition, the role of abrasive parameters, including material type, particle size, and geometry, on the wear behavior of composite systems is examined. The study further explores the selection of coating materials, coating techniques, and their effectiveness in improving thermal and mechanical properties. Finally, a comparative assessment of simulated and experimental results is presented to validate the reliability of computational models in predicting wear and deformation behavior of composite materials.

Keywords: *Fiber orientation, tribological aspect, coating behavior, thermal performance*

1. INTRODUCTION

Tribology is the branch of science that specifically deals with the friction, wear, lubrication and design of interacting surfaces in a relative motion between the pair of surfaces. There are many well documented exist methodology on tribology from early civilizations to till today the developed bearings and other low friction surfaces have been reported so far [1].

Although, the wear and friction understanding has suffered for long time owing to imaginary concepts availability for mechanism explanation. In recent times, tribological behavior related knowledge for composite materials has limitations on basis of prediction capability due to being empirical. However, attempts for generalized determination of degree of governance phenomena for composites tribological performance and consolidation of metal, polymer and ceramic matrix composites interdisciplinary information have been made [2].

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Development of composites is required for superior wear resistance and mechanical strength. Composites comprise of two or more constituents combined together at macroscopic level but are not soluble among each other. Fibers and polymer resin being individual constituents in polymer composites, where fibers carry structural load acting as reinforcing phase, lower thermal stress and result in desired mechanical properties. Polymer sare of tenusedin practical situations where abrasive wear is caused by rubbing of hard particles as counter face against parent material therefore, reducing the amount of wear, obtaining desired mechanical properties is the primarily criteria for designing fiber reinforced polymer matrix composite [1,2]. Fiber reinforced polymer composite are important class of composite material due to the desired mechanical properties and widespread application in materials used in friction and wear. Glass, carbon, aramid and graphite fiber are generally used as fiber reinforcement. Glass and carbon are the most common materials used for the fibers. Fiber reinforced polymers are further classified as randomly oriented chopped fiber reinforced polymer, unidirectional fiber reinforced polymer and woven fiber reinforced polymer [3].

Wear is material loss on account of twin surface dynamic interaction during relative motion. This phenomenon is seen taking place in various mechanical devices and components like piston rings, belts, brakes, rolling mills, cams, dies, tires, liquid and gas seals, sheet products etc., forgings, ore crushers, conveyors, nuclear machinery and erasers [4]. The basic aims of the design engineers are to minimize the amount of wear or totally eliminate it. During operation amongst adhesive, abrasion, fatigue and corrosive wear mode the abrasive wear mode is dominant of all the wear mechanisms. Abrasive wear can be defined as wear in which hard particles penetrate and result in material removal from softer body surface resulting in groove formation. Abrasive wear term does not describe precisely the mechanisms of wear involved [5]. So, mechanisms like fatigue, cutting, grain pull-out, fractureis determined by the stresses developed as well as mating surface characteristics such as surface hardness and finish. However, the second important aspect is the mode of abrasive wear i.e. the way grit passes over the worn surfaces. These are classified as two body and three body abrasive wear. It is the twobody wear which has been most extensively studied, although three body wear is arguably most important industrially.

Design and manufacturing of fiber reinforced polymercomposites

Advanced composites require synthesis and characterization based on material design underlying their usefulness. Based on reinforcement material and matrix spectrum, optimization of properties for specific application can be done. Design of advanced composite requiring no thermal expansion coefficient can be done as an example. Reinforcement with various other fibers and geometries resulting in hybrid polymer matrix composites may be done for cost minimization and performance maximization. Realization of polymer matrix composite materials design opportunities are beginning [6]. Broad combination of various matrix and fiber material can be used for making polymer matrix composites. Apart from any one area, development of technology for manufacturing low cost advanced composites is required for wide their wide usage. Advanced Polymer composites techniques of production are shown in Table 1. Basic steps are:

1) Resin impregnation in fiber

2) Structure formation

3) Thermoset matrix curing process or thermoplastic matrix thermal processing

4) Surface Finishing

Effect of fiber/filler on abrasive wear of polymercomposites

Resin is impregnated with fillers and fibers for improving electrical properties, stiffness, ultraviolet radiation resistance, shrinkage reduction along with resin usage reduction for applications involving low cost. Presence of continuous fibers in form of yarns, rovings, tows and strands results in fabrication of advanced composites. Discontinuous fiber based composites are called long or short fiber reinforced composites. Determination of addition effects of particulate fillers/fibers on abrasive wear and mechanical behavior of nano-clay filled polyamide 66/ blend of polypropylene/ polypropylene nanocomposites/ polypropylene and polyamide 66 with reinforcement of short carbon fiber was made by authors and analyzed that lower wear rate exhibited by polypropylene/polyamide 66 nano-clay filled composites compared to polypropylene/ polyamide 66 filled with short carbon fiber composites [7].

Two-body abrasion test investigation against abrasive papers on polythylene terephthalate with filled and unfilled glass fiber have shown increase of wear rate with abrasive grain size increase as per Friedrich and Cyffka [8]. Abrasive particles increase hardness is seen to increase events of cracking of elements of rigid filler per unit time, thereby leading towards improved wear rate and wear amount being a linear function of density of abrasive grain per unit area [9]. Investigation was done by Indumathi et al. [10], on cryo treatment influence on performance of wear of thermoplastic polymer series like poyethermide, polycarbonate, polyimide, polyurethane and poly tetra fluoro ethylene, experimental results revealed that Sample wear rate for both treated and untreated case under varying loads show potential of increased wear resistance of some of the composites or polymers till a fiber loading of 20%. However, wear resistance deterioration is seen beyond fiber loading of 20%. Reinforcement of fiber and fillers increase polymer's stiffness and strength thereby being effective in wear reduction in conditions of dry sliding with involvement of fatigue or adhesion transfer. In case of abrasive wear, however less effect is seen in such reinforcements for polythylene terephthalate with bronze fillers but increase wear rate for graphite, carbon, and polythylene terephthalate [11]. Investigation of polymer composite materials with reinforcement of graphite fiber for abrasive wear was done with the analysis that lowest wear was seen for single directional graphite polyamide with normal oriented fibers to the abrading surface [12].

Effect of filler/fiber addition on polymer matrix composites wear rate is shown clearly in Figure-1.

Composites were developed with matrix of polyetheretherketone and carbon fiber with polyethersulphone. Enhancement in performance due to treatment with carbon fiber was quantified by wear resistance and mechanical property improvement [13,14].

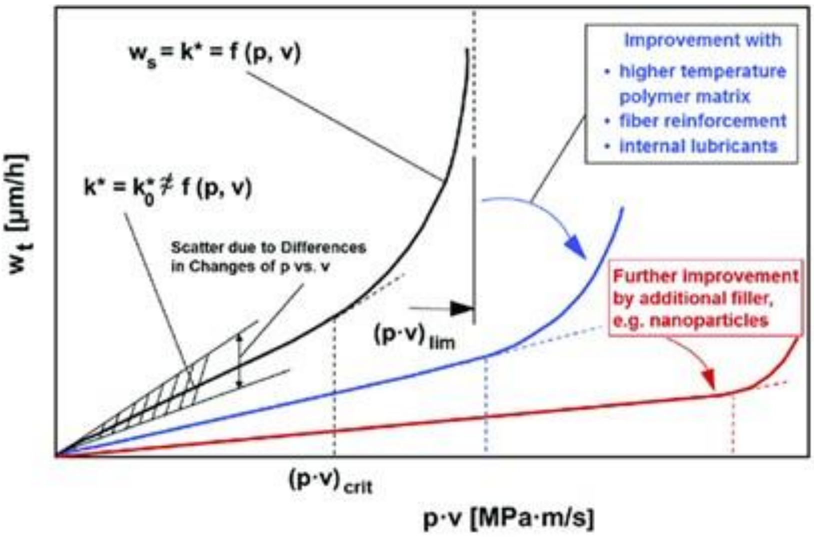

Figure-1. Effect of addition of fiber filler on the wear rate of Polymer matrix composites [15]

Effect of fiber orientation on abrasive wear of polymercomposite

The fiber distribution known as pattern of fiber lay in 2D/3D space describe orientation of fiber in polymer matrix composites. For analyzing fiber orientation effect on polymer matrix composite wear rate, pattern of fiber layout should be properly understood. with the fiber orientation being either parallel, normal or anti-parallel towards direction of abrasive wear. Reinforcements which are unidirectional are seen to have edge over bidirectional ones in some aspects in spite of some difficulty in their processing. Problems faced during bidirectional composite development on account of fiber strands improper wetting in points of cross-over being not applicable in unidirectional composites. It was analyzed that for unidirectional long fiber in carbon fiber polyether amide composites mechanical properties deteriorate with the increase in fiber orientation angle from 0° to 90°; lowest specific wear rate is observed at 0° whereas highest specific wear rate is observed at 90° [16]. The unidirectional carbon fiber polyetheramide composites, composites with fiber in 0°(parallel to the loading direction) proved best in almost all the properties (Table 2).

Table-1. Production techniques for polymer composites

Technique	Characteristics	Applications
Sheet Moulding	Flexible 5-8mm short fiber	Automotive body panels
Injection Moulding	High volume, short fibers thermoplastic products	Gears, Fan Blades
Filament Winding	Moderate speed, Complex Geometries	Aircraft Fuselage, pipes, driveshafts
Resin Transfer Moulding	Referred orientation of fibers, complex shape parts	Automotive structural parts
Prepeg tape winding	Comparatively slower, expensive,accurate process	Aerospace structures
Pultrusion	Cylindrical parts, continuous winding	Columns, cylindrical parts

Table-2. Effect of fiber orientation on specific wear rate of artificial fibers [13,16]

Specific wear rate of material	Orientation of fibers with reference to loading direction			
	0°	30°	60°	90°
Carbon Fiber	Lowest	Moderate	Higher	Highest
Kevlar Fiber	Lowest	Moderate	Higher	Highest
Glass Fiber	Lowest	Moderate	Higher	Highest

Table-2 shows the effect of fiber placement on the specific wear rate of artificial fibers. Effect of fiber placement with reference of loading direction is investigated and observed that lowest wear rate is observed when the fibers are placed at 0˚ with reference to loading direction whereas if we increase the angle of fiber placement further the wear rate in turn increases [18]. Highest wear rate is observed when the placement of fibers with respect to loading direction is at 90˚. It has been investigated through several investigations that three normal orientations is the best preferred orientation and least wear rate is observed in such orientation and the friction and wear was least observed when the placement of fibers are normal to the direction in sliding [19]. The best wear resistance for unidirectional oriented carbon fiber reinforced plastics being for high modulus carbon fibers in comparison to that of high strength carbon fibers.

Effect of volume fraction on abrasive wear aspect of polymercomposites

Volume fractions are the dominating factor on which the abrasive wear aspect of polymer composites depends on. With the change in volume fraction a proportional change in abrasive wear of polymer composites is noticed. Abrasive wear resistance behaves in a rational manner with the change in fabric reinforcement of Polyethersulfone approximately 1.35-9.46 times and for highest resistance to abrasive wear 83 wt% kelvar 29 fabrics is most suitable. On reinforcement of fabric material namely E-glass fibers, high strength carbon fiber and Kevlar-49 fiber with poly(vinyl butyral) phenolic resin matrix, the wear behavior of glass fabric exhibits poor and low grade properties in comparison to that of Kevlar fabric reinforced composite [20]. On the other hand, if we check the abrasive wear performance of carbon fabric reinforced polyetherimide composites, the former exhibits best tensile strength. This in turn interpret that the 65wt% volume faction is best followed by 75 wt% volume fraction during loading in carbon fabric composites [21, 22].

Effect of fiber length on specific wear rate of polymercomposites

Effects on specific wear rates on length of fiber in test specimen in the direction of sliding including dominant aspects were taken into consideration; A slight variation in fiber length may in turn result in significant variation in wear rate. Large grit sizes, significantly removes more amount of material in the “long” direction and in turn gives higher wear in comparison to that of grit with small abrasive diameters. Figure-2 shows the behavioral aspect of fiber length with specific wear rate of pineapple leaf fiber. In case of long fiber reinforced unidirectional and bidirectional polymer matrix composites, specimen length and fiber length are both same and as the specimen length increase, fiber length automatically increases and in turn wear rate decreases. The fiber/fabric is linearly distributed inside the specimen and the presence of fiber/fabric throughout the wear length increases the wearresistance.

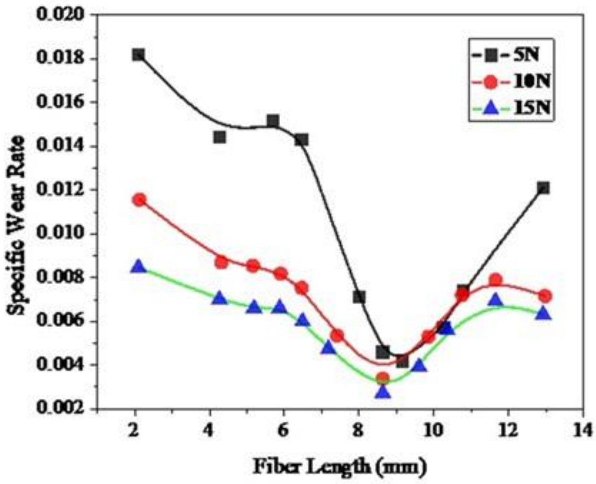

Figure 2. Effect of fiber length on specific wear rate of PALF composites [17]

The Voss and Friedrich [23] investigated thebehavioral aspects of poly ethyl ether ketone, during investigated it was noticed that short length fiber proves to be beneficial in reducing the wear rate. Thermal treatment is also an important aspect with is taken into consideration because it enhances the fiber – matrix bonding and in turn reduces the wear rate up to significant extent.

Effect of temperature on tribo engineering materials for abrasive wear of polymer composites

Polymer and their composite form a important class of tribo engineering materials. The term ‘tribo’ comes from “tribology” which means the science of friction and wear between interacting surfaces in relative motion. Due to friction and wear in between common surfaces the temperature of the contact surface increases, therefore ‘tribo’ engineering products are surface modified, low friction and high temperature polymer composites which are used for heavy duty application such as seals, bearing etc. Number of researches has been devoted to find the increasing demand of abrasive wear of thermoplastic matrix for high temperature resistant materials. By improving the surface properties and reducing the sliding friction in between the surfaces, significant reduction in friction and wear in between the surfaces were noticed. The same can also be enhanced by providing suitable lubricants such as polytetrafloroethylenein between the surfaces. Proper and effective use of lubricants in turn reduces the adhesion of molecules between contacting surfaces, better handling of extreme pressures due to compressive effect is best handled by the effective use of lubricants. Lubricants such as polytetrafloroethylene form a molecular thin film in between the surfaces which can provide a slight lift to the contacting surfaces and in turn wear between the contacting surfaces reduces significantly [24].

Effect of coating on abrasive wear of polymercomposites

Coatings are being used to suppress the effect of moisture on polymer matrix composites. The effectiveness of the coating is decided by the quality and thickness as well as moisture absorbing capability i.e. protection from mechanical damage during inspection and maintenance, impact damage and corrosion. Polymeric coatings on the surface of water injector tubing resist not only water corrosion but also mechanical damage from maintenance and inspection. Such applications require filled epoxy coatings as filled epoxy coatings outperform traditional coating methods [25]. Further investigations were carried out by Xu and Mellor [26] to determine wear resistance caused by impact damage and inspection tools. Afluoropolymer with 2% calcium fluoride filler was used as a coating material to enhance the surface properties. It was observed that the significant use of surface coating enhances the surface performance during extreme weather conditions by reducing moisture absorption, anti bacterial applications etc. Engineering applications such as erosive resistance, wear resistance also get enhanced by applying suitable coating thickness on required surface [27]. Coating hardness plays an important role in deciding the wear resistance of polymer matrix composites. Excellent correlation is obtained between coating hardness and abrasion resistance in Micro-scale abrasive wear testing of PVD coatings on curved substrates, as the coating hardness increases wear resistance automatically increases [28]. Mohan et al. [29] based on various investigations concluded that abrasive wear increases with increase in sliding distance and applied load. Abrasive wear is less when hard particle are added in the matrix material in comparison to that when particles are not added. At mild pv condition Carbon/Epoxy shows superior wear behavior with the wear rate an average factor of 22 lower than the Glass/Epoxy rates whereas at roughest *pv*-conditions Carbon/Epoxy shows complete failure with respect to Glass/Epoxy [30].

Lancaster [31], studied abrasive wear of polymers involved in the variations in the mechanical properties of polymers**.** Various tests have been done to notice the effect of degrading parameters on the performance of polymers. Various tests have been done to notice the performance of polymers in life time applications and real time applications [32]. The effect of various type polymers, variation in reinforcement and type of loading on different sliding speed and abrasive grades were done in the past. Based on several experiments by varying several parameters it has been observed that highest wear rate is for polyoxymethylene fiber preceded by Polyethylene fiber with 30% glass fiber loading and lowest wear rate is observed for Ultra high molecular weight poly ethylene [33-34].

An in-depthinvestigation into the thermal transport characteristics of FRP systems, emphasizing the influence of fiber geometry on heat transfer efficiency. Their findings showed that non-circular fiber arrangements enhance inter-fiber connectivity which contribute an improvement in transverse thermal conductivity as well apredictive framework using machine learning to estimate various thermal and mechanical properties of polymer composites [35,36]. This data-driven approach facilitates rapid screening and design of composites with tailored thermal behavior. A remarkable work demonstrated significant improvement in adhesive bonding with carbon fiber panels, as well as surface uniformity and mechanical durability with exploring micro/nano-scale aramid pulp–epoxy coatings applied on laser-engraved titanium alloy surfaces. The results were analyzed for the application of Al/FeCoNiCrMo coatings via plasma spraying, which indicate that optimal spray currents improve coating adhesion, reduce porosity, and enhance thermal resistance—making them suitable for thermal barrier applications in CFRP systems.

In a broader context, the summarized challenges and future prospective of coated FRP composites were reviewed that reveal the importance of advanced surface treatment technologies, such as cold spray and chemical functionalization, for improving interface stability and environmental resistance [37]. Meanwhile, the comprehensive insights into long-term durability, highlighting degradation mechanisms due to temperature cycling, moisture ingress, and micro structural aging have been reviewed and emphasized the evolving role of surface morphology in influencing both short-term performance and long-term reliability of FRPs [38,39]. Preliminary investigation on abrasive wear analysis of polymer composites

2. MATERIAL PREPARATION

Woven glass, aramid, carbon fabric and short glass, aramid fiber and carbon fiber are taken for experimentation. 10% of hardener is mixed along with epoxy. By adding 10% hardener along with epoxy it has been observed that the hardener increases the chemical reaction of epoxy. By mixing of reinforcement, epoxy and hardener inappropriate quantities the composition was left for solidification and further processing. The simple and most popular technique that is the hand lay-up technique was selected for the preparation of composite slabs. Variation in reinforcement, epoxy and hardener was done by weighing the content in specified proportion of the trio. Once the composite slabs of various desired composition were prepared they are then marked as per ASTM standards and sectioning and physical testing were then done based on various requirement of research.

3. EXPERIMENTALDETAILS

A standard test (ASTM G65) was performed on dry sand/rubber using wheel abrasive test machine.The sample to be tested was forced against the rubber wheel and uniform flow of dry sand/abrasive particles was insured so that the dry sand particles comes in between, when the rubber wheel moves and abraded the surface of the specimen. Due to the movement of rubber wheel and material pull out by abrasive particles against the surface of specimen, some removal of material from the surface of test specimen takes place and due to that material removal loss in the weight of the test specimen occurs. As the weight loss of the sample during abrasion reduces, the wear rate automatically reduces. Sample having minimum wear rate determines the variables and fiber loading at which the wear rate is minimum.

SurfaceMorphology

Above hypothesis is verified by SEM micrographs taken to notice the effect of abraded surface during three body abrasion of glass, kevlar and carbon fiber reinforced epoxy composites when subjected to three body abrasion.

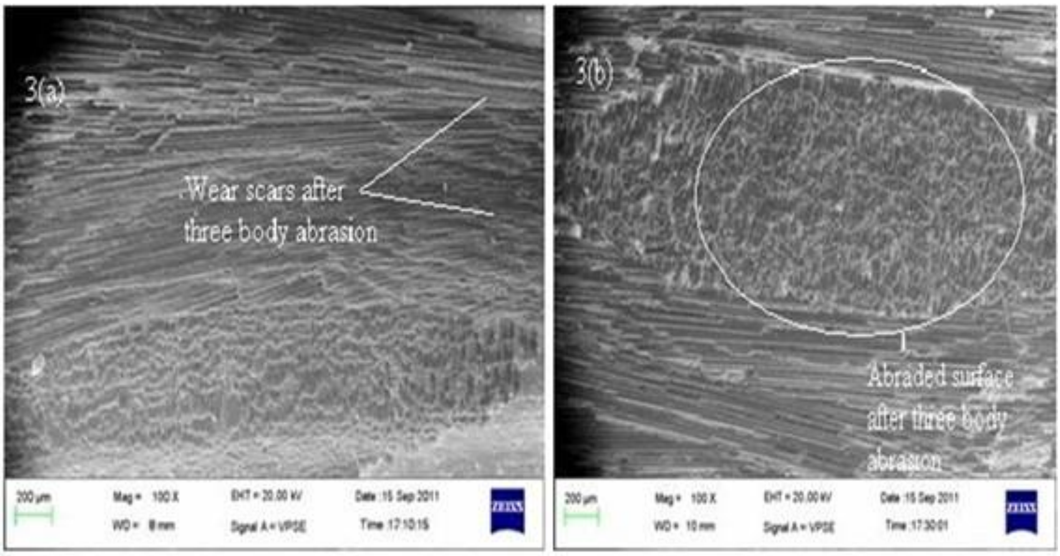

Figure 3. SEM of long glass fiber reinforced epoxy composites

Fig. 3(a) and Fig. 3(b) shows the surface details of woven glass fiber reinforced epoxy composites. In Fig. 3(a) (normal load 100N, silica sand abrasive particle size500μm and sliding speed72cm/sec) presences loose particles on the surface of the specimen which results in loss of material (fibers or resin) during three body abrasion. Due to higher load acting normal to the surface of the specimen, abrasive particles penetrate inside the surface of the specimen and remove material in the form of resin and fibers The more the normal load, higher the abrasive particles (hard particles) present in between the surface of the specimen and the rubber wheel enters the surface of the specimen resulting in highermaterialremoval rate. Wear scars and abraded surface details clearly represent the uneven removal of material as the loose particles present in between the rubber wheel and specimen may penetrate, roll or slide and in turn produce uneven surface. Wear of matrix material is faster than that of fiber resulting in some broken or left out parts of fibers which are not totally detached or removed and exposed to the surface during abrasion. Fig. 3(b) shows the surface details of the abraded sample (sliding velocity 144cm/sec), since the sliding velocity and abrasive particle size is more than normal load, tendency of the abrasive particles to roll or slide on the mating surface of test specimen increases and hencelooseparticles, pulls out fibers, wear scars and material removal from the surface of the specimen are dominant observations. Uniform distribution of fiber and binding material on the mating surface of the specimen resulting in better surface finish and reduces the chances of air entrapment between two layers of fibers which in turn produced lower void fraction.

For kevlar fiber reinforced epoxy composite, reduction in loss of material and improved surface finish are the dominant mechanisms. In Fig. 4(a) presence of pores and voids are due to air entrapment during uniform mixing of resin and fibers using hand lay-up technique. Test specifications taken for short KFRE at 10wt% fiber loading, normal load 100N, sliding velocity 144cm/sec and abrasive particle size 375μm. Improper and uneven compression also results in air entrapment and hence creates pores and voids. Mixing of fibers and resin is uneven in the composite lamina, creates more surface irregularities and even surface during three body abrasions. In Fig. 4(b) SEM micrographs taken at abrasive size 125μm, normal load 80N and sliding velocity 72 cm/sec revealed that cracking / removal of binding material takes place due to continuous abrasion of sand particles (SiC) against parent material resulting in loss of binding material from abraded surface.

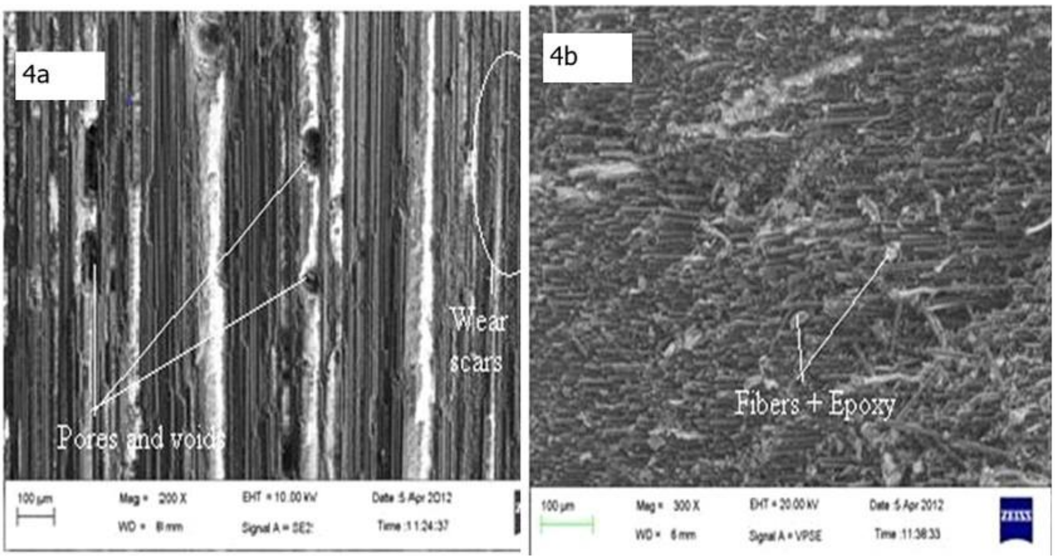

Figure 4. SEM of long Kevlar fiber reinforced epoxy composites

For smaller particle size and higher normal load epoxy resin chips off faster from the composite than the fibers. Proper adhesion between the binding and reinforcing material and higher load and stresses developed on common mating surface results in better mechanical properties in comparison to that ofglass fiber reinforced matrix composites.

Fig. 5(a) and 5(b) represent that CFRE composite shows better surface properties and reduced wear rate in comparison to GFRE composites. Fig. 5(a) (F.L – 20wt%, normal load 80N, sliding velocity 96cm/sec and abrasive particle size 375μm) micrograph shows the removal of top layer of fibers from the surface during the abrasion. At higher normal load particles embedded at the mating surface of specimen because due to medium sliding and higher normal load the particles come in between thet wos ur facesem bed dedinside the softer surface (specimen) and hence material removal occurs. Also it is observed that the edge and some part of the fibers are removed during abrasion and only few parts are left. Fig. 5(b) clearly shows the remaining parts of the fibers attached to the composite specimen and few broken parts of the fiber detached from the specimen after three body abrasion. Fig. 5(b) shows the SEM images of CFRE composite at constant fiber loading 30 wt%, normal load 40N, sliding velocity 144cm/sec and abrasive particle size 625μm respectively. Due to lower normal load abrasive particles may not penetrate easily in the exposed layer of the test specimen and hence reduction in wear.

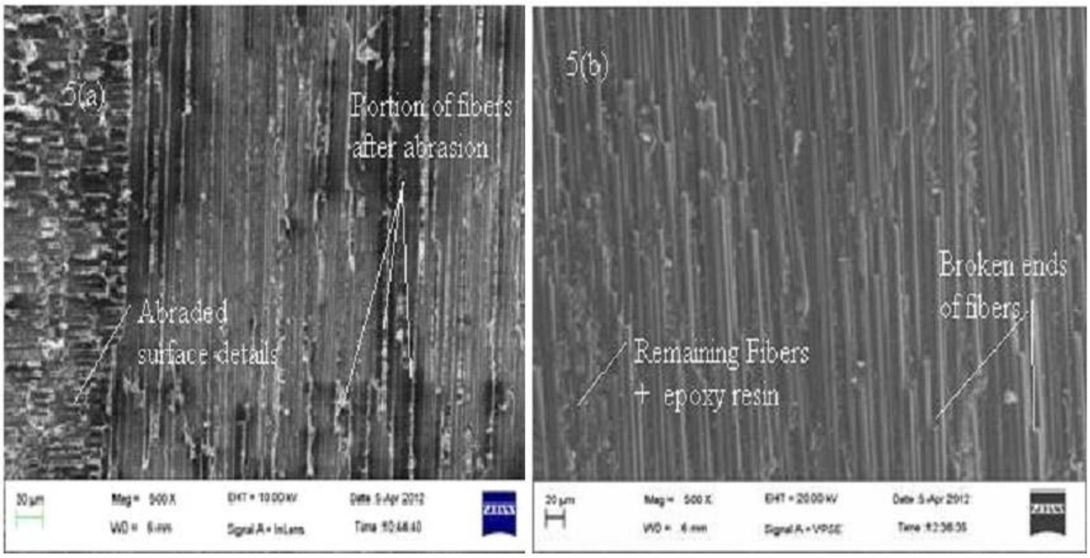

Figure 5. SEM of long carbon fiber reinforced epoxy composites

From Fig. 5(a) it was noticed that the material removal was less in comparison to that of Fig. 3(b), this may be due to smaller abrasive size particles (250μm). Surface micrograph clearly represents the wear scars as a result of rubbing of rubber wheel against the common surface of the test specimen since the size of sand particles was larger 500μm uneven removal of material occurs. Pores and voids are clearly visible from the micrograph, this due to entrapment of air bubbles during solidification. Also due to higher sliding velocity fibers detached faster than the matrix material this is also clearly represented by the micrograph.

4. CONCLUSIONS

Based on the analysis done on the abrasive wear of polymer matrix composite it has been revealed that the reinforcement of fiber /fabric in polymer matrix could provide an improvement in wear resistance and overall properties of composite.

The type of fiber weight percent of fiber and the orientation in which they are reinforced inside the composite was dominant factor in deciding the wear behavior of composite. Since the studies carried out so far on the abrasive behavior are experimental and simulation based therefore selection of proper equipment, filler/fiber material for particular matrix is very important. Results obtained during abrading of test specimens in three body abrasion is far - far better in comparison to similar testing during two body abrasion. The introduction of third medium i.e. abrasive particles reduces the overall wear rate in the former one. The best wear resistance for fiber reinforced plastics has been obtained when sliding at 90° to that of placement of fibers whereas worst wear resistance was obtained when sliding at 0° to the placement of fibers. Besides suppressing the effect of moisture coatings are also used in reducing the wear rate and enhancing the properties of composites. Excellent correlation is obtained between coating hardness and abrasion resistance i.e. as the coating hardness increases wear resistance automatically increases. Key parameters such as speed of sliding, distance of sliding, load/pressure, grit size and hardness/type of abrasive particle are used to help in deciding the amount of wear rate.

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IZVOD

ISTRAŽIVANJE TOPLOTNOG ODZIVA, EFIKASNOSTI ZAŠTITNOG SLOJA I POVRŠINSKIH KARAKTERISTIKA POLIMERNIH KOMPOZITA NA BAZI VLAKANA: OPŠTI PREGLED

Ova studija istražuje uticaj termičkih karakteristika, efikasnosti premaza i morfologije površine na performanse polimernih matričnih kompozita ojačanih vlaknima, punilima i nanopunilima. Različiti faktori kao što su vrsta i priroda vlakana (prirodna ili sintetička), orijentacija vlakana, sastav matrice, zapremina armature i prisustvo ili odsustvo površinskih premaza analizirani su zbog njihove uloge u upravljanju termičkim odzivom. Analiza površinske morfologije sprovedena je kako bi se razumeli mehanizmi habanja i načini degradacije materijala. Takođe je procenjen doprinos tipa armature i njegov udeo u povećanju otpornosti na habanje. Pored toga, ispitana je uloga abrazivnih parametara, uključujući vrstu materijala, veličinu čestica i geometriju, na ponašanje habanja kompozitnih sistema. Studija dalje istražuje izbor materijala za premaze, tehnika premazivanja i njihovu efikasnost u poboljšanju termičkih i mehaničkih svojstava. Konačno, predstavljena je uporedna procena simuliranih i eksperimentalnih rezultata kako bi se potvrdila pouzdanost računarskih modela u predviđanju ponašanja habanja i deformacije kompozitnih materijala.

Ključne reči: *Orijentacija vlakana, tribološki aspekt, ponašanje premaza, termičke performanse*

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