Tribological Properties of Fiber Reinforced Polymer Matrix Composites- A review

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***Abstract*— The article provides an overview of the tribological characteristics of several synthetic fibers enhanced polymer composites. FRP's many benefits include its low density, great strength, and ease of production. Several studies have been conducted on choose the FRP composites' tribological characteristics. This study summarizes recent research in this subject and explains how the tribological properties of synthetic fiber reinforced polymer composites are affected by factors such as fiber orientation, rubbing speed, matrix material, filler material, and so on.**

Keywords: : Fiber reinforced polymer composite, glass fiber, carbon fiber, wear loss.

I. INTRODUCTION

Polymers can be defined in the most basic terms as anything composed of repeating units of carbon, hydrogen, oxygen, and/or silicon. Polymers have been around for a long time. Back to prehistoric times, materials like tar and shellac were commonly used. Gears, bearings, bushes, and other items used in modern engineering are made from them after being subjected to high temperatures and pressures.

Natural and synthetic polymers can be manufactured with a wide range of stiffness, strength, heat resistance, crystallinity, density, and even price. Polymers are employed in virtually every industry. Annual polymer consumption is now more than steel's. Polymers are classified as either thermosetting or thermoplastic based on their chemical and technological properties by the American Society for Testing and Materials (ASTM). Composite materials, which are composed of two or more different materials, are used nowadays to improve material performance and reduce the cost of assembly. Varieties of composites, such as metal network composites, are the subject of investigation as their use grows. Multi-matrix composites (MMC), ceramic matrix composites (CMC), polymer matrix composites (PMC), and so on. A wide variety of tribological components, including brakes, grip pivot boxes, cranes, diary bearings, excavators, medical devices, and more, make use of fiber-reinforced polymer composites. Reinforcement in fibre-reinforced polymer composites can come from either synthetic or natural fibre.

II. Literature Review

Amar Patnaik.et.al [1] conducted erosion wear behavior of polyester hybrid composites using Taguchi design. Composite material consisting of polyester, glass fibers and alumina particles. A mathematical model for damage assessment in erosion is developed and validated by a well-designed set of experiments. The study reveals that glass–polyester composite without any filler suffers greater erosion loss than the hybrid composite with alumina filling. Significant control factors and their interactions that influence the wear rate are identified.

Mehmet Bagci.et.al [2] conducted erosion wear behavior of glass fiber reinforced epoxy composite materials. The tests which involved angular aluminum particles with two different sizes were conducted at different conditions of impact velocities, fiber directions and impingement angles. The test specimens were characterized by techniques of X-ray diffraction (XRD) and scanning electron microscope (SEM). In addition, the design of the experiments which utilizes Taguchi's orthogonal arrays approach was used and an optimal parameter combination determined which led to minimization of erosion rate of the composites.

Bernd Wetzela.et.al [3]conducted mechanical and wear behavior of epoxy nanocomposite system by considering calcium silicate CaSiO3, 4–15 mm, alumina Al_2O_3, 13 nm as reinforcing material in an epoxy polymer matrix material. The influence of these particles on the impact energy, flexural strength, dynamic mechanical thermal properties and block-on-ring wear behavior was investigated. Synergistic effects were found in the form of a further increase in wear resistance and stiffness. Several reasons to explain these effects in terms of reinforcing mechanisms were discussed.

Klaus Friedrich.et.al [4]conducted sliding wear behavior of polymer composites with various fillers. fibre reinforced polymer composites are nowadays used in numerous tribological applications. In the present overview further approaches in designing polymeric composites in order to operate under low friction and low wear against steel counterparts are described. A particular emphasis is focused on special filler (including nanoparticle) reinforced thermoplastics and thermosets. Especially, the influence of particle size and filler contents on the wear performance is summarized. Their applications can reach temperatures up to 220 0C, pressures of more than 10 MPa and sliding velocities of about 3 m/s.

Vinay Kumar Patel.et.al [5]conducted physico-mechanical properties of Luffacylindrica/polyester composites and describes the fabrication and physical, mechanical, three-body abrasive wear and water absorption behavior of Luffa fibre reinforced polyester composites with and without addition of micro fillers of Al_2O_3, $CaCO_3$ and TiO_2.The ranking of the composite materials has been made by using Technique for order preference by similarity to ideal solution (TOPSIS) method without put parameters of their physical, mechanical and abrasive wear and water absorption attributes. The addition of microfillers has enhanced greatly the physical and mechanical properties of Luffa-fibre based composites.

K.Devendra.et.al [6] conducted Thermal Properties of E-Glass/ Epoxy Composites Filled By Different Filler Materials. E-Glass fibre reinforced epoxy composites was fabricated by filling varying concentration of aluminium oxide (Al_2O_3), magnesium hydroxide($Mg(OH)_2$), silicon carbide (SiC), and hematite powder.. Experimental results show that Al_2O_3 and Mg $(OH)_2$ filled composites exhibited low thermal conductivities. Composites filled by SiC particles exhibited low thermal expansion coefficient when compared with other filled composites. Fire test results indicated that increase the loading of Al_2O_3, Mg $(OH)_2$, and hematite powder increase the time to ignition and reduces the flame propagation rate of composites.

Dr. Ibtihal Abdalrazaq.et.al [7]conducted Wear Characteristics Of Glass Fibers-Epoxy Composite with Different Types Of Ceramic Fillers. The influence of three ceramic fillers granite, perlite and calcium carbonate ($CaCO_3$) on the wear of the glass fiber reinforced epoxy composites investigated under dry sliding conditions. The effect of variants in volume fraction, applied load, time and sliding distance on the wear behavior of polymer composites is studied by applied pin – on-disc method. It is observed that the wear resistance increase with the increasing of reinforcement material volume fraction while, the wear rate increases with increasing of applied load, time and sliding distance. The results showed that the filler of granite, perlite and $CaCO_3$ as filler materials in glass epoxy composites will increase the wear resistance of the composite by 76.15%, 73.8%, 71.8% respectively and greatly than glass fiber fillers epoxy composite only and granite filled GE Composite exhibited the maximum wear resistance.

Rudramurthy.et.al [8] conducted wear behavior of glass epoxy composite system by considering coconut shell powder as a filler material for brake pad application and tests were conducted under varying sliding distance conditions to determine Wear loss, Wear Volume and Specific Wear Rate and compared with commercially available brake pad materials. SEM micrographs for the fabricated materials and commercial materials were also considered for the analysis and comparison. Results showed that ER – GF composite material had significantly superior abrasion characteristics and compressive strength in comparison with PF – GF by using CSP.

Shakuntala Ojha.et.al [9] carried out Wear Behavior of Carbon Black Filled Polymer Composites to study characterized by EDS analyzer and uses as filler in polymer composites.Carbon black derived from wood apple shell, was obtained by pyrolysis of wood apple shell particles at 400°C. An experimental study was conducted to compare the erosive wear behavior of both raw and carbon black wood apple shell particles filled epoxy resin matrix composites. The effect of wood apple shell particles concentration with different impingement angles (30°,45°,60°and 90°) at constant impact velocity 48 m/sec on the erosion rate of composite has been analyzed.It is found that the carbon black particulates composite shows minimum wear as compared to raw particulate composite. It also shows semi ductile type failure and maximum erosion rate is observed at 60° impingement angle.

Hanumantharaya R.et.al [10] carried out Friction and Dry Sliding Wear Behavior of Granite - Fly Ash Filled Glass Epoxy Composites. Using a pin-on-disc apparatus, the wear behavior of the composites have been performed at varying abrasive distances viz., 5, 10, 15 20 and25 m at a constant load of 10 N. The experiment has been conducted using two different water proof silicon carbide (SiC) abrasive papers of 320 and 600 grit size at a constant speed of 200 rpm under multi-pass condition. The results show that wear loss of the composites was found increasing with the increase in abrading distances. A Significant reduction in wear loss and specific wear rates were noticed after incorporation of SiC and fly ash filler into GE composite.

Sandhyarani Biswas.ej.al [11] carried out a comparative study on erosion characteristics of red mud filled bamboo–epoxy and glass–epoxy composites. The solid particle erosion characteristics of the bamboo–epoxy composites have been studied and the experimental results are compared with those for glass–epoxy composites under similar test conditions. For this, an air jet type erosion test rig and Taguchi orthogonal arrays have been used. The methodology based on Taguchi's experimental design approach is employed to make a parametric analysis of erosion wear process. The comparative study indicates that although the bamboo based composites exhibit relatively inferior mechanical properties, their erosion wear performance is better than that of the glass fiber reinforced composites. It further indicates that the incorporation of red mud particulates results in improvement of erosion wear resistance of both the bamboo and glass fiber composites.

Niharika Mohanta.et.al [12] conducted wear behavior of glass epoxy composite system by considering Red mud as a filler material. The erosive wear of red mud filled composites is evaluated at different impingement angles from 300 to 900and at three different velocities of 48, 70 and 82 m/s. The erodent used is silica sand with the size range 150–250µm of irregular shapes. The result shows semi-ductile erosion behavior with maximum erosion rate at 600 impingement angle. The erosion rate (R) displays a strong dependence on impact velocity (V), which follows and the power law Rα Vn for all the materials. Erosive wears of GFRP composite with 25%red mud as filler is the lowest. This filler restricts fiber–matrix deboning. Pure glass epoxy without any filler shows the highest erosion rate due to weak bonding strength.

M.S. Senthil Kumar.et.al [13] conducted wear behavior of glass epoxy composite system by considering nano clay (Cloisite 25A). Test was carried out with the assistance of pin-on-disk machine and Taguchi's technique.L25 orthogonal array was constructed to evaluate the tribological property with four control variables such as filler content, normal load, sliding velocity and sliding distance at each level. The results indicated that the combination of factors greatly influenced the process to achieve the minimum wear and coefficient of friction. Appreciable wear and friction coefficient was noted for without fiber laminates. Additionally, the SN ratio results too exhibited the similar trend. Moreover, ANOVA analysis revealed that the fiber inclusion on laminates has lesser contribution on coefficient of friction and wear when compared to without fiber laminates. At last, the microstructure behavior of the test samples was investigated with an assistance of Scanning Electron Microscope (SEM) to analyses the surface morphology.

K.Srinivasa.et.al [14] conducted Wear Behaviour of Epoxy Hybrid Particulate Composites. The RT cured epoxy composites subjected to post cure cycle containing particulate Gr, SiC and Gr-SiC of length 25mm and diameter 10mm were the pin specimens and EN31 steel was the disc of the computerized pin on disc wear tester. The results show that the synergic effect of hybrid filler Gr-SiC is to improve the wear resistance when compared with that of Gr/SiC. The improvement in wear resistance for the composite containing 5%SiC 35%Graphite is 85% when compared with epoxy, 25% over composite containing 40%Gr and 36% over 40%SiC. The composites containing 5% Gr and 35% SiC exhibits highest wear resistance.

M. Sudheera.et.al [15] conducted Mechanical and Wear Performance of Epoxy/glass Composites with PTW/Graphite Hybrid Fillers. The effect of ceramic whisker (7.5 wt%) and solid lubricant filler (2.5 wt%) on mechanical and dry sliding wear behavior of epoxy/glass composites was studied. Experimental results indicated that single incorporation of ceramic whisker can improve stiffness, friction coefficient and antiwear abilities of epoxy/glass composites significantly. The strength properties of composites were slightly reduced after whisker addition. However, incorporation of solid lubricant as secondary filler resulted in improvement of both mechanical and tribological properties of composites.

K.M. Subbaya.et.al [16] conducted wear behaviour of carbon epoxy composite system by considering SiC as filler material. The experiments were designed according to Taguchi's (L9)orthogonal array to optimize experimental runs. In order to assess the wear behavior of composites satisfying multiple performance measure, grey-based Taguchi approach has been adopted. Two-body abrasive wear tests were carried out using pin-on-disc apparatus with four process parameters, filler content, grit size, load and abrading distance. Analysis of variance was applied to determine the significant parameters that affect abrasive wear. The results indicated that, addition SiC particles into C–E composite increased the wear resistance considerably. Highest wear resistance of C–E composite was achieved by incorporation of 10 wt.% of SiC. Observation showed that filler content and abrasive grit size have the most significant influence on abrasive behavior of C–E composite.

Feng-Hua Su.et.al [17] conducted Tribological and mechanical properties of Nomex fabric composites filled with polyfluo 150 wax and nano-SiO2.The friction and wear behaviors of the pure and filled-Nomex fabric composites sliding against AISI-1045 steel in a pin-on-disk configuration were evaluated on a Xuanwu-III high temperature friction and wear tester. The structure of the composites, and the morphologies of the worn surfaces and of the counterpart steel pins were analyzed by means of scanning electron microscopy. The adhesion and tensile strength of the unfilled, PFW or nano-SiO2 filled Nomex fabric composites were evaluated with a DY35 universal material tester. The results showed that the addition of PFW and nano-SiO2 significantly improved the wear resistance and decreased the friction coefficient, moreover thePFW as a filler is better than nano-SiO2.

X.F. Yao a.et.al [18] conducted Macro/microscopic fracture characterizations of SiO2/epoxy nanocomposites. Characterizations of fracture surface in nanocomposites are analyzed using the scanning electron microscope (SEM).Distribution of displacement field at the initial edge crack tip in nanocomposites is obtained by digital speckle correlation method. Crack propagation characterizations of nanocomposites are described using field emission scanning electron microscope (FE-SEM). The influence of nanoparticle contents on fracture behavior of nanometer composites is analyzed.

G. Zhang.et.al [19] conducted tribologicalbehavior of short carbon fiber reinforced PEEK with filler material as nano-SiO2 particles. Tribological tests were carried out at room temperature in extremely wide pressure and sliding velocity ranges,i.e. from 1 MPa to 7 MPa and from 1 m/s to 2 m/s, respectively. The nanopartilces remarkably reduce the friction coefficients. With respect to the wear rates, however, the roles of the nanoparticles show a strong dependence on the sliding conditions. Under 1 MPa, the abrasiveness exerted by possible nano-SiO2 agglomerates seems to accelerate SCF destructions. Under pressures higher than 2 MPa, however, the nanoparticles remarkably reduce the wear rate. This effect is more pronounced under high pressures and especially at high sliding velocities. The protection of SCF/matrix interface byte nanoparticles is supposed to be the main reason for the enhancement of the wear resistance.

Qing Bing Guo.et.al [20] conducted Sliding wear performance of nano-SiO2/short carbon fiber/epoxy hybrid composites. By evaluating sliding wear properties of the composites as a function of the components concentrations, positive synergetic effect was found. That is, both wear rate and friction coefficient of the hybrid composites were significantly lower than those of the composites containing individual nano-SiO2 or short carbon fiber. The composite with 4 wt.% nano-SiO2and 6 wt.% carbon fiber offered the greatest improvement of the tribological performance. Compared to the results of hybrid composites reported so far, the above composite is characterized by relatively lower filler content, which would facilitate processing in practice. Increased surface hardness, lubricating effect of the sheet-like wear debris reinforced by nano-SiO2 and rapidly formed transfer film were believed to be the key issues accounting for the remarkable wear resisting and friction reducing behaviors.

Qing Bing Guoa.et.al [21] conducted tribological and mechanical properties of epoxy through hybrid filling. The lowest specific wear rate and friction coefficient of the composite can be 9.8×10−7mm3/Nm and 0.12, respectively, much lower than those of unfilled epoxy, i.e. 1.3×10−4mm3/Nm and 0.56. In addition, mechanical properties, especially the maximal loading ability, of the quaternary composite were evidently higher than those of the binary composite with oil-loaded microcapsules. The oil released from the broken microcapsules during sliding wear mainly accounted for the lubrication, while nano-SiO2and carbon fibers serve as both solid lubricant and reinforcement. As a result, positive synergetic effect appeared and the proposed quaternary composites might be applicable in practice.

C.M. Manjunatha.et.al [22] conducted fatigue behavior of a glass fiber reinforced hybrid particles modified epoxy nanocomposite. Two types of glass fiber reinforced plastic (GFRP) composites were fabricated viz., GFRP with neat epoxy matrix (GFRP-neat) and GFRP with hybrid modified epoxy matrix (GFRP-hybrid) containing 9 wt.% of rubber microparticles and 10 wt.% of silica nanoparticles. Fatigue tests were conducted on both the composites under WISPERX load sequence. The fatigue life of the GFRP-hybrid composite was about 4–5 times higher than that of GFRP-neat composite.

C.P.Gao.et.al [23]conducted Tribological behaviors of epoxy composites underwater lubrication conditions at both varying and constant sliding speeds with filler like carbon and glass fibers, solidlubricantsandSiO2 nanoparticles. It is demonstrated that both there in forcing fibers significantly enhance the wear resistance of EP. Under mixed and boundary lubrication conditions, the addition of SiO2 nanoparticles into EP conventional composite filled with carbon fibers and graphite reduces the friction and wear. It is revealed that the tribological performance of the fiber-reinforced EP composites is mainly attributed to the high abrasion resistance of the fibers and the tribo film formation. Alessio Caverzan.et.al [24] conducted tensile behavior of high performance fibre-reinforced cementitious composite sat high strain rates. The material behavior was investigated at four strain rates(0.1, 1, 150 and 300 s_1) and the tests results were compared with their static behavior. Tests at intermediate strain rates (0.1e1 s_1) were carried out by means of a hydro-pneumatic machine (HPM).High strain rates (150e300 s_1) were investigated by exploiting a Modified Hopkinson bar (MHB).Comparison between static and dynamic tests highlighted several relevant aspects. First, with the change in the strain rate, the Dynamic Increase Factor (DIF) of the material appears well predicted by some models proposed in the literature up to a value of 0.1 s_1, while at higher strain rates it increases less than expected from models. The post-peak behavior showed a stress plateau influenced by theirs and dependent on the strain rate.

N. Vijaya Kumar.et.al [25] conducted wear properties of industrial waste (slag) reinforced polypropylene composites. Wear resistance of material is an important requirement for many of the industries like automotive, aircraft and aerospace. The effects of variation in sliding velocity and applied load on the wear behavior of polymer composites are studied in the present work. Composite specimens are prepared by injection molding machine with varying particulate weight percentage of 0%, 10%, 20%, 30% & 45%. The pin-on disc wear testing machine has been used to study the friction and wear behavior of the polymer composites. The wear loss and coefficient of friction are plotted against the normal loads and sliding velocities.

Sandhyarani Biswas.et.al [26] conducted Erosion Wear Behavior of Copper Slag Filled Short Bamboo Fiber Reinforced Epoxy Composites. New ways of utilizing various metal industry slags are being explored in order to safeguard the environment and to provide useful ways for their utilization and disposal. Copper slag is such an industrial waste which is produced as a by-product during smelting and refining of copper. Rich in various metal oxides, it has tremendous potential to be utilized as a filler material in polymer composites. Therefore, this work is focused on the erosion wear behavior of copper slag filled short bamboo fiber reinforced epoxy composites. It further outlines a methodology based on Taguchi's experimental design approach to make a parametric analysis of erosion characteristics. It is found that for the current study the factors like impact velocity, impingement angle, stand-off distance and fiber loading have greater effect on erosion rate. This study reveals the semi-ductile response for all composites irrespective of copper slag content. The peak erosion rate is found to be occurring at 60° impingement angle. Also, the erosion rate of all these composites is also affected by the erodent temperature.

VII. CONCLUSION

Throughout the past few decades, FRPCs have garnered substantial interest. PP is an inexpensive thermoplastic polymer with outstanding characteristics. PP is used to strengthen various fibres to create composites. Glass fibres are the synthetic fibres most commonly used to reinforce PP. The injection molding process parameters do not have a significant effect on fiber volume fraction.

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