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A Study on Mechanical and Sliding Wear Behaviour of E-Glass Fibre Reinforced Epoxy Composites

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Abstract

Due to increasing demand and widespread application of Fibre reinforced polymer (FRPs) composites, they have been used in a variety of application like aerospace, automotive, sports, ships and constructional work. Because of their several advantages such as relatively low cost of production light weight, easy to fabricate and superior strength to weight ratio. In the present work E-glass fibre is used as reinforcing agent with and without alumina filler. The objective of the present research work is to study the mechanical and abrasive wear behaviour of coated and uncoated E-glass fibre reinforced epoxy based composites. The effect of fibre loading and filler content on mechanical properties like hardness, tensile strength, flexural strength and impact strength of composites are studied. A robust design technique called Taguchi method is also used to determine the optimal condition for specific wear rate of the composites by considering different parameters. ANOVA study is also performed to study the effect of various factors on the sliding wear behaviour of the composites. Surface morphology of composites was studied by optical microscope.

INTRODUCTION

Back ground and Motivation

A combination of two or more materials with different properties, or a system composed of two or more physically distinct phases separated by a distinct interface whose combination produces aggregate properties that are superior in many ways, to its individual constituents. Anew material with combination of two or more material can provide enhanced properties that produce a synergetic effect [1].

In composite materials there are two constituents one is matrix and other is reinforcement. The constituents which is continuous and present in greater quantity is called matrix. The main functions of the matrix is to holds or bind the fibre together, distribute the load evenly between the fibres, protect the fibre from mechanical and environmental damage and also carry inter laminar shear. While the other constituent is reinforcement; its primary objective is to enhance the mechanical properties e.g. stiffness, strength etc. The mechanical property depends upon the shape and dimensions of reinforcement [1]. On the basis of type matrix material, composites can be grouped into three main categories, polymer, metallic and ceramic.

The main elements of polymer matrix composite are resin (matrix), reinforcement (e.g. fibre, particulate, whiskers), and the interface between them. The present work deals with the fibre reinforced polymer. FRP's offers significant advantages, like combination of light weight and high strength to weight ratio and it is way easy to fabricate which is better than many metallic components [1].

The matrix of FRPs is further classified into-

I. Thermosetting resin
II. Thermoplastic resin

Thermo set resin (e.g. polyester, vinyl esters and epoxy) undergo chemical reaction that cross link the polymer chain and thus connect the entire matrix into three dimensional network due to this they possesses high dimensional stability, resistance to chemical solvent, and high temperature resistance. On the other hand unlike thermo set, curing process of thermoplastic resin (e.g. polyamide, polypropylene, and polyether-ether-ketone) is reversible. Their strength and stiffness depends on the molecular weight. They are generally inferior to thermo set in case of high temperature, strength, and chemical stability but are more resistant to cracking and impact damage [2].

As far we concerned about the reinforcement, there are wide variety of it, like natural fibre (e.g. hemp, kenaf, sisal, coir, jute etc), synthetic fibre (e.g. glass fibres, ceramic etc) and organic fibre (e.g. aramid). Natural fibres are cheap, easily available, and bio- degradable but these advantages are not sufficient to overcome their major drawbacks like moisture absorption, It can be easily attacked by chemicals and has low strength compared to synthetic fibres. Now, in manmade fibres there are two types of fibres,

1. Synthetic fibre
2. Organic fibre

There are numerous types of synthetic fibres such as nylon, acrylic, polyester, glass fibres etc. Now a day most commonly used synthetic fibre is glass fibres. There are also varieties of glass fibres e.g. A-glass, C-glass, D-glass, E-CR glass, E- glass and S-glass, among them E-glass and S-glass are most widely and commonly used, in many industry they represent over 90% of reinforcements used. Glass fibres which are available commercially are mainly manufacture in the form of woven roving (cloth), chopped strands, long continuous fibres, Woven roving's consist of continuous roving, which is a fabric are woven in two mutually perpendicular directions. In chopped strand, continuous fibres are cut to the short length and fibres are arranged in the form of bundle [3]. On the other side S-glass has higher tensile strength, greater modulus and higher elongation at failure compared to the E- glass, and S-glass is mainly used where strength is a primary concern along with weight e.g. airplane fuselage, tail wings of airplane, pipes for carrying aqueous liquid, ship hulls, helicopter blades, tanks and vessels. But its cost is primary issue which restrict its application in commonly used items like house hold appliances e.g. fibre glass doors, window frame, bath tub etc. and sports items e.g. hockey sticks, fishing rod, arrow of archery etc. [5].

Organic fibre- The commonly used organic fibre derived from aromatic polyamides possesses high modulus, are called aramid fibres. They were first developed by Du Pont with the trade name "***Kevlar***". They derived from the polymer molecules those have high degree of aromaticity (containing benzene rings in their structure) which possesses crystalline behaviour in liquid solution. They are usually produced from spinning and extrusion process [1]. Its common application are in rail carriage, for temperature resistance environment like hoses, tyres, brake pads and belts, ball is tichel mets in military applications. Due to its property like high tensile strength, light weight and dielectric property it is also used in wide variety of optical fibre applications.

In the present work randomly oriented short E-glass fibre is used as reinforcing agent because of its good strength, light weight, chemical resistance and more importantly its low cost. Aluminium oxide (Al_2O_3) also called as alumina is used as a filler material. The addition of filler to the composites enhances the mechanical as well as physical properties[6]. The properties of Al_2O_3like chemical inertness, high hardness, good strength and less expensive made it fit for the use where friction and wear conditions are predominant e.g. for low cost automotive brake linings [7]. Pure aluminium is chosen as coating material because of its wear and corrosion resistance property due to its passivation effect (it is the property of material to form thin coating film of its oxide and prevents its surface from foreign factors e.g. air and moisture)[8].And also filler material is compound of aluminium.

Thesis Outline

The rest of the thesis work is summarized as follows:

Chapter 2: This chapter includes literature review related to present research work is detailed in this chapter.
Chapter 3:This chapter provides detail description of material, their fabrication techniques and description of composites for different tests were investigated and robust design method called Taguchi experimental design is explained.
Chapter4: This chapter deals with analysis of experimental result of physical and mechanical properties of composites.
Chapter 5: In this chapter experimental result of wear rate are analysed and selection of optimizing parameter is done by Taguchi method.
Chapter6:This chapter presents the conclusions and scope of future work.

LITERATURE SURVEY

This chapter reveals the upbringing information on the topic to be considered in present research work and focuses on the importance of current study. The objective is to analyse the effect of various parameters influencing the mechanical and wear behaviour of FRPs composite. The literature survey is based on the following aspects:

On mechanical properties of E-glass reinforced epoxy composites

Rout et al. [9] investigated the mechanical properties and erosion wear of glass fibre reinforced epoxy composite with filled and unfilled rice husk particulates. Experimental design was also done using Taguchi optimization technique to determine the optimal parameters, which minimizes the wear rate. They concluded that factors like filler content, impact velocity, impingement angle and erodent size has more significant effect on wear rate, and at 15 wt% of rice husk shows maximum wear resistance. Tensile modulus, hardness and impact energy improves with addition of filler content. Decline in flexural and tensile properties of the composites were noticed. Al-Hasani [10] studied the tensile strength and hardness of glass fibre reinforced epoxy composite at different volume fraction as layers. Three types of composite samples were prepared, woven roving, randomly oriented and sandwich which consists of (woven roving and Random oriented). It was found that sandwich composite exhibits higher value of tensile strength 254 N/mm^2 whereas, nine layered glass fibre woven roving composites exhibited higher hardness of 62.1 BHN.

Koricho et al. [11] studied the bending fatigue behaviour of twill E-glass epoxy composite. Bending fatigue behaviour of composites specimens were analysed by displacement controlled bending fatigue test. Samples were subjected to different fatigue loadings with maximum level up to 0.75 times the ultimate flexural strength of the material, After 1 million cycles residual properties of selected specimen were measured. They found experimentally that tensile stresses are damaging while compressive stresses are beneficial.

Denget al.[12] experimentally investigated the influence of different types of E-glass fibre cross-section (round, oval and peanut-shaped) aspect ratio on inter laminar shear strength, inter laminar fracture toughness, and charpy impact test. They reported that delamination resistance of composites is lower for the composites having larger fibre cross- section compared to the composites reinforced with round cross-section, because of the fibre overlapping. Same trend were observed for different tests like double-cantilever beam(DCB), short-beam-shear (SBS), and end-notched flexure (ENF) and however larger aspect ratio fibre reinforced composite shows better energy absorbing capacity than composites reinforced with conventional round fibres.

Alvarez et al. [13] conducted three point bending test with Perkin Elmer DMA-7 equipment to determine loss modulus, storage modulus ,and loss factor of unidirectional glass fibre reinforced epoxy resin. Two different types of epoxy resin were used to coat the fibres and their viscoelastic properties were determined. Span to thickness ratio L/h should be higher than 15 for good results, because modulus is constant for all settings.

On Sliding Wear Behavior of Fibre Reinforced Polymer Composites

El-Tayeb et al. [14] had carried out experimental study on frictional and wear behaviour of a unidirectional E-glass reinforced epoxy composite. Wear rate and friction coefficient was calculated under different sliding velocities, normal applied load for various surface conditions (e.g. dry, wet, lubricated conditions) using pin on disc apparatus while load is applied normal to the fibre orientation. The wear and frictional behaviour of composite is dominated by surface conditions of counter face, e.g. wet and clean surfaces improves the friction coefficient and wear rate. It was also observed that minimum value of friction coefficient and wear rate was obtained in case of water lubricated conditions which depend on applied normal load and speeds. Friction coefficient and wear rate was decreased in all cases when either the load or speed decreases.

Lu et al. [15] investigated the wear and frictional behaviour of blends of PEEK with poly tetra fluoro ethylene (PTFE), polyether-ether ketone and carbon fibre reinforced PEEK composites using a pin on disc apparatus. The experiment was performed by sliding specimens against hard steel under dry sliding conditions. The study shows that wear rate of higher molecular PEEK was better than lower molecular PEEK and also this effect was more significant at higher values of load and rpm. But the friction coefficient had not clear variation with combination of load and rpm. Addition of PTFE to PEEK lowered the friction coefficient, which is minimum at 15%and wear rate is minimum when5%ofPTFEaddedup to PEEK. Wear rate and friction coefficient were also affected by variation of temperature and it is observed that at 10% volume of carbon fibre the wear rate is minimum. The further increase in fibrevolume caused stick slip phenomenon to occur at higher testing temperature.

Ramesh et al. [16] had studied the tribological behaviour and microstructure of nickel coated silicon nitride (Si_3N_4) particles under dry sliding condition. Friction and wear test were conducted on pin on disc apparatus over a range of load varies from 20-100N and sliding velocities in the range from 0.31-0.157 m/s. Results shows that, distribution of nickel coatedSi_3N_4particles was uniform in the entire matrix. The friction coefficient for composite was decreased when load increased up to 80N, but further increase in load raised the friction coefficient. Wear rate of composite depend both on sliding velocity and load applied, i.e. its rate increased with continuous increase in load and velocity. However, friction coefficient of composite was increased only with increasing sliding velocity.

Basavarajappa et al. [17] studied the sliding wear behaviour of glass-epoxy laminate composite made by hand lay-up technique filled with both silicon carbide and graphite under dry sliding condition, by pin on disc apparatus. The volume fraction of filler was varied in the rangeof5-10%forSiC and kept constant for graph it eat 5%.The transfer film was formedon the counter surface improves wear resistance of glass-epoxy composite. Impact of applied load on wear rate was more prominent compared to other constraint like sliding velocity and sliding distance. In premature stage the wear rate of composite was significantly affected by presence of filler. The abrasive wear depends on composition of filler as well as nature of formation of transfer film against counter surface. SEM images were used to observed fibre breakage, fibre debonding from matrix and debris formation.

Soussia et al. [18] investigated the dry cutting of glass-epoxy composite for different variety of coating. The experiments were done with different orientation of glass fibre at 0^0, 45^0, and 90^0on three different samples in the cutting direction. Three different inserts e.g. CVD diamond coated, uncoated tungsten carbide, and multi-layer titanium coated were used to perform cutting test. They found that wear resistance depends upon type of orientation and coating type. CVD diamond coated had better wear resistance at 0^0orientations but at $45^0$and 90^0fibre orientation it leads to the catastrophic failure. Uncoated WC had lowest flank wear. The adhesive property of the epoxy increased the thermal conductivity of the matrix. Multi layered coated tool showed better dissipation of thermo-mechanical energy due to good adhesion between coating layer and substrate.

Basavarajappa et al. [19] studied the wear behaviour of glass-epoxy composite filled with graphite under dry sliding conditions. Experiment investigation using a pin-on-disc apparatus was done under different load, sliding distance and sliding velocity to understand the comparative performance of glass-epoxy composites with the influence of graphite filler. They found that lower weight loss of the composite on increasing the graphite percentage in the composites. The wear rate of unfilled glass-epoxy was higher compared to graphite filled, because graphite serves as lubricant and it forms thin film which transferred on the counter surface and moderate the effect of three body abrasion. SEM micrographs revealed the formation of debris, fibre breakage, debonding between fibre and matrix under varying load, sliding velocity and sliding distance.

Sampathkumaran et al. [20] analysed the SEM topographies of glass-epoxy laminate composite under dry sliding condition for varying distances in the range from 500m to 6000m. Authors found different changes in worn surfaces at different sliding distances. For the shorter distances wear debris was formed and also sometimes fragmentation of glass fibre were seen. While for longer distances separation of interface occurred. They concluded that on subjecting the specimens to wear conditions, particularly in the sliding distance range of 0.5 km–6 km features like increased matrix debris formation, fibre breakage and exposed transverse and longitudinal fibres were observed.

Andrich et al. [21] had investigated the wear and frictional behaviour of glass fibre reinforced polypropylene composite and carbon fibre reinforced epoxy composite against coated and uncoated 100Cr 6 steel.They used diamond like carbon(DLC) as coating material. Tribological properties were improved by using suitable fibre reinforcement. They mainly focus on the development of the new materials those are loaded in their tribological applications. The carbon fibre reinforced composite showed remarkable improvement in wear rate against DLC coated steel counter surface and shows its potential application for sliding bearing material.

Kishore et al. [22] studied the sliding wear behaviour of glass/epoxy composite filled with different types of filler like rubber and oxide particles for bearing application, using back on roller arrangement. They calculated weight loss as a function of sliding distance for different sliding velocity ranges from 0.5 to 1.5 m/s at three different loading settings 42,140, and 190N respectively. SEM was used to observe worn surfaces morphology. They found that, oxide filled composites had lower wear at low load but for rubber filled composite wear rate was lower at higher load. They also reported inclined fibres fracture, interface separation and loss of matrix as well as the presence of debris with two different fillers at higher sliding velocity and load conditions of wear. The work shows the dependency of wear system on type of filler used and their pattern.

Suresha et al. [23] studied the two-body abrasive wear and mechanical behaviour of glass and carbon reinforced vinyl ester composite. They observed a rise in wear weight loss with increase in particle size of abrasive and abrading distance. But specific wear rate shows opposite outcome to wear volume loss, it decreases with abrasive particle size and abrading distance. The study reveals the higher wear loss of glass/vinyl composite in comparison to carbon/vinyl composite with increasing abrading distance. Because of the higher specific strength and self-lubricating property of carbon fibre, it exhibits superior abrasion resistance than glass fibre under different loading and sliding distance conditions. The result shows that higher wear rate for the glass fibre composite was $10.89\times10^{-11}m^3/N\text{-}m$, whereas for carbon fibre composite its value was4.02×10^{-11} $m^3/N\text{-}m$.

Effect of coating on wear behavior of fibre reinforced polymer composite

Kim et al. [24] Studied the effect of coating material like epoxy and polyethylene mixed with self-lubricating powder molybdenum disulphide and PTFE powders on the tribology of carbon reinforced epoxy prepreg composites with many grooves on its surfaces, under dry sliding and water loosened conditions. When the surface was coated with self-lubricating powder it significantly improve the wear resistance by blocking water to enter into the grooves of composite and coating also reduces the formation of blister for water loosened conditions. When either of the epoxy or polyethylene mixed with MoS_2, friction coefficient was reduced by 9% compared to the epoxy or polyethylene containing PTFE powder. The mixture of polyethylene and MoS_2 has imparted excellent wear resistance by arresting hard particles into coating layer. Pan et al. [25] analysed the effect of two phase composite coating on graphite-epoxy composite. The surface resistance decreased with the addition of graphite after seepage critical value (SCV) and conductivity increases. They observed that when the graphite content exceeds to 40% the conductivity of the graphite-epoxy composite increased and surface resistance decreases because of that. But, on the other hand adhesion of coating decreases due to higher graphite content. Similar graph were obtained for wear rate vs. graphite content and friction vs. graphite content both model shows the two valleys. They found that at graphite content less than 40%, epoxy appeared as a continuous phase and graphite as dispersed phase whereas, reverse of this happened when graphite content was greater than 40%.

Bakshi et al. [26] studied the wear and microstructure of the composites with coating of aluminium andAl-11.6wt% silicon eutectic alloy phases of varying composition prepared by cold spraying. The micro hardness of coatings was enhanced with increase in volume fraction of Al-Si coating. They observed similar volumetric wear loss for both Al and Al-Si coated composites in spite of increased micro hardness of Al-Si composite. This may be due to inter-splat delamination mechanism.

Conradi et al. [27] investigated anti-corrosion and mechanical behaviour of Nano- silica filled particle epoxy resin composite coating. For this study composites with two different coatings were prepared. Epoxy coating of 50 µm thickness and another coating of epoxy which contained 2 wt% of silica Nano particle of 130 nm size were applied over the surface of austenitic stainless steel. Vickers hardness tester and Profilo meter were used to understand the mechanical properties and surface morphology, respectively.

The effects of addition of silica particle on corrosion resistance and surface characteristics were determined by measuring contact angle as well as by potential dynamic polarization and electrochemical impedance spectroscopy in a 3.5 wt% sodium chloride solution. They observed that addition of silica particle considerably advanced the micro structure of coating matrix. This leads to the increase in surface roughness, hardness and prompted hydrophobicity. It was reported that Nano-silica coating act as barrier in chloride rich environment which resulted in better anticorrosion performance. The surface energy was lowered by adding Nano-silica to epoxy matrix.

OBJECTIVE OF THE PRESENT RESEARCH WORK

Keeping in view of the current status of research the following objectives are set for the scope of the present research work.

1. Fabrication of glass fibre reinforced epoxy composites with and without Al_2O_3filler and evaluation of their mechanical and sliding wear properties.
2. To study the influence of fibre loading and filler content on mechanical and sliding wear behaviour of glass-epoxy composites.
3. To understand the effect of aluminium coating on the sliding wears behaviour of glass-epoxy composites.
4. Parametric analysis of sliding wear process using Taguchi experimental design and to study the effect of various parameters on specific wear rate.
5. To study the surface morphology of the fractured sample susing optical microscope.

MATERIALS AND METHODS

This section deals with different material and processing technique used for the fabrication of composite under this present work. It provides the details of tests and characterization which are conducted on composite samples.

Materials

Matrix

Polymer matrices are most common and widely used matrix material, because of its availability, easiness to fabrication, light weight and low cost compared to others.

The matrix material used in the present work is epoxy resin which belongs to the class of thermoset material that contains epoxide group as its functional element in which one oxygen atom is bonded to two carbon atoms.

Among all thermo set resin, epoxy resin is widely used as matrix material. It forms three dimensional cross-link structures after undergoing irreversible chemical reaction. It possesses several benefits over other thermo set resin like superior mechanical strength, good bonding with various type of fibres, low shrinkage upon curing and resistant to chemicals.

Because of several advantages over other types of resin, epoxy resin LY-556 is picked as matrix material.
Commonly used epoxyis Diglycidyl Ether of Bisphenol-A. The chemical structure of epoxy is shown below.

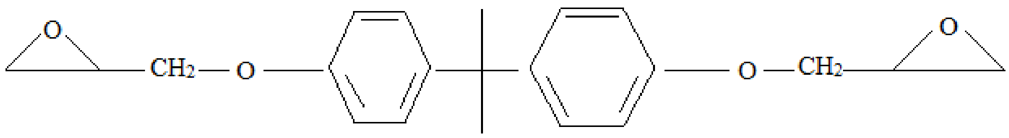

Figure 3.1 Chemical structure of diglycidyl ether of bisphenol-A [2]

Fibre Material

Glass fibres are most common reinforcing agent among various composite materials. Glass fibres areavailable in the form of woven fabric, chopped strands, long continuous fibre and short discontinuous fibre. In present research work randomly oriented short E-glass fibre is usedas reinforcing agent. The average length of E- glass fibreis about 6mm. it is basically an ordinary borosilicate glass containing less than 1% of alkali oxides.

Filler Material

Various types of particulate filler are used as reinforcement in polymer based composite. Among them silicon carbide (SiC), alumina (Al_2O_3) and Titania (TiO_2) are most widely used as conventional filler. In the present work alumina (Al_2O_3) is used as filler material. The properties of Al_2O_3like chemical inertness, high hardness, good strength and less expensive made it fit for the use where friction and wear conditions are predominant.

Coating Material

In the present work material aluminium is used as coating material due to its wear and corrosion resistance property due to its passivation effect (it is the property of material to form thin coating film of its oxide and prevents its surface from foreign factors e.g. air and moisture) [8]. And also filler material is compound of aluminium

COMPOSITE FABRICATION

Mechanical Testing

In the present work short glass fibre is taken as reinforcing agent. The epoxy resin (LY-556)and hardener(HY-951)were supplied by CibaGeigy India Ltd. Alumina(Al_2O_3)is used as a filler material, having particle size in the range of 80-100 µm. The short E-glass fibre mixed with epoxy resin and hardener in the ratio of10:1 by weight with and without use of alumina filler. Then combined mixture is carefully mechanically stirred and poured into different moulds using hand lay-up technique.

A mould releasing sheet is used for the easy removal of composites from the mould. The cast is allowed to cure under a load of 20 kg at room temperature 27^0C for 24 h. By varying weight percentage of E-glass fibre different composite samples are made (EG-1 to EG-4) with no use of filler material. Other composite samples with varying fibre loading and 5% of alumina (EGA-1 to EGA-3) are also prepared. After curing, samples were cut to the desired dimensions for different mechanical test. The composition and description of composite used in this study are listed in Table 3.1

Wear Test

In case of wear test, the samples are prepared using syringe needle of 2.5 ml volume, of circular cross-section having diameter of 10 mm and 50 mm length. The fibre and filler percentage of the composites, curing temperature and duration remains same as before. Coating of Composite

Thermal evaporation technique is used for coating of composites. The target material (aluminium) is heated in an evacuated chamber so that it attains a gaseous state. Vapour of this aluminium traverse the space from the source to the substrate [28].The typical deposition rate for aluminium is (~8nm/s). But in present work aluminium is chosen as coating material because it has low melting point, low cost and easily available. When temperature is high enough, the gas impingement rate $\Phi = \Phi\ (P_e)$ can cause deposition of material (thin-film) ona substrate (Ts<<T).

Where,

Ts=Substrate temperature and T = Source temperature

Mechanical testing of composites

The tensile test is conducted on all the samples as per ASTM D3039-76 test standards. Specimens are positioned in the grips of universal testing machine and a uniaxial load is applied through both the ends until it gets failure. During the test, the crosshead speed istakenas2mm/minas perASTMstandards, specimen sof rectangular cross-section shaving length and width of 100 mm and 15 mm respectively are used. Figure 3.5 shows the experimental setup for the tensile test.

Figure 3.5 Experimentalsetup for Tensile Test

To determine the flexural strength of composites a three point bending test is performed using (Tinius Olsen H10KS). Before testing width and thickness of specimens measured at different point and mean value is taken.

Samples were placed horizontally upon two points and midpoint is perpendicular to loading nose. The crosshead speed for test is maintained at 2 mm/min. Flexural strength in terms of MPa is determined using the equation

$$F = 3PL/2wt^2 \quad (3.3)$$

Where,
P=Load applied on centre of specimen(N) L = Span length of specimen (m)
w=Width of specimen(m)
t=Thickness of specimen (m)

Sliding wear test of composite

Wear behaviour of composites is studied using a pin-on-disc apparatus under dry sliding condition. Figure 3.8 and 3.9 shows the schematic diagram and pictorial view of pin- on-disc setup, respectively. Wear monitoring setup was supplied by DUCOM and the sliding wear test is performed according to ASTM G99 test standards (standard test method for wear testing with a pin-on-disk apparatus). The specimen is held stationary in pin assembly and counter disc is rotated while the normal load is applied through a lever arm mechanism. Optical microscope

Zeiss optical microscope is used to the view the surface of the composites. It works on Axiom imager microscopy. In bright field microscopy, light from an incandescent source concentrated on lens called condenser which is used to focused the light on the specimen through an opening stage, after that light passes through objective lenses and finally to eyepiece lenses through second magnifying lenses.

This technique is usually employed for thin section material. Samples are cleaned thoroughly and air dried for better illumination. Working parameters like voltage, magnification and contrast depends upon type of view of specimens.

Taguchi method

Taguchi method is the technique based on performing experiments to test the sensitivity of a test of response variables to a set of control factors (or independent variables) by designing experiments in "*orthogonal array"* with an objective to attain the finest set of control. An array indicates the number of rows and columns and also number of level in each column. The important tools for robust design is Taguchi method, design of experiment (DOE), and regression analysis. For instance L_4 (2^3) has four rows and three "2 level" columns. The no. of rows of orthogonal array represents required number of experiments.

The no. of rows must be at least equal to degree of freedom associated with control variables. In present study, four parameters is, sliding velocity, sliding distance, normal load, and fibre loading are set at three levels while filler content and coating thickness set at two levels. Mixed level type L_{36} (2^11 3^12) orthogonal array design is used. Table 3.2 shows the experimental details of control factors and their level.

There are three types of S/N ratios available according to the type of response. For minimum specific wear rate, S/N ratio falls under the category of smaller is better. Mathematically it can be expressed as

$$S/N=-10\log\frac{1}{n}\left(\sum y^2\right) \qquad (3.7)$$

Where, n = number of observations andy=observed data

Table 3.2 Experimental Details of Control Factors And Their Level

Control factors	Levels I	II	III	Units
Filler Content	0	5	-	%
Coating Thickness	0	0.25	-	µm
Sliding Velocity	0.523	0.7854	1.1	m/s
Sliding Distance	314.16	471.3	659.73	m
Normal Load	5	10	15	N
Fibre Loading	10	15	20	%

PHYSICAL AND MECHANICAL CHARECTERISTICS OF COMPOSITES: RESULT AND DISCUSSIONS

This section presents the results of physical and mechanical properties of short E- glass fibre reinforced epoxy composites with and without alumina filler.

Physical Property of Composites

The theoretical and measured density of composite samples with their void volume fraction is presented in Table 4.1. The differences in theoretical and measured densities are the measure of voids present in composite samples. It is difficult to avoid the formation of voids in the composites fabricated by hand layup technique but maximum possible measures were taken to minimize the formation of these voids during the fabrication of the composites. It is necessary to determine the void content of the composites as it effects the property of the material.

Table 4.1 Theoretical and measured densities with void fractions in composites

Sample name	Filler content (%)	Theoretical density(gm/cc)	Measured density(gm/cc)	Void Fraction (%)
EG-1	0	1.15	1.032	10.2
EG-2	0	1.216	1.133	6.8
EG-3	0	1.2532	1.183	5.6
EG-4	0	1.292	1.195	7.48
EGA-1	5	1.2643	1.215	3.9
EGA-2	5	1.3035	1.246	4.41
EGA-3	5	1.345	1.317	2.08

Part-1Mechanical properties of composites without filler at different fibre loading

Hardness is one of the most important factors that affect the wear property of materials. The E-glass fibre epoxy composites with different fibre loading, with and without filler is shown in Table 4.2.From the Table it is clear that, with the increase of fibre loading, micro-hardness of the glass epoxy composites increases from 0 to 10 wt% of fibre loading then it shows very little increment in hardness with further increase in fibre loading. This is attributed to the fact that hardness is a function of the relative fibre volume and modulus[34]. The flexural strength of unfilled composites increases with increase in fibre loading up to 15 wt% and then decreases on further increasing the fibre loading. The decrease in flexural strength at 20 wt% fibre loading may be due to insufficient wetting between fibre and matrix because of which stress doesn't transfer properly to the fibres. Impact strength of composites without filler increases with fibre loading from 0wt%to 10wt%, after that it decreases irrespective of fibre loading. At higher fibre loading poor distribution and dispersion of fibre may occur due to which the impact strength of the composites decreases [9].

Part-2 Mechanical properties of composites with filler at different fibre loading

The mechanical properties of the short E-glass fibre reinforced epoxy composites at different fibre loading withfillerarepresentedinTable4.3. Itis observedfromTable4.1that composites with 10wt% of fibre loading with 5 wt% of alumina content i.e. EGA-1 display better flexural and impact strength as compared to others composites. On the other hand EGA-3 and EGA-2 composites exhibit higher hardness and tensile strength values.

The hardness of Al_2O_3 filled composite increases from 21.26 to 37.28 Hv. This implies 75% increment in hardness value compared to unfilled composites. During hardness test filler phase and matrix phase pressed together and interface can transfer load more effectively although interfacial bond strength may be poor which results in improved hardness [30].

The flexural strength of filler content composites reduces when fibre loading increases from 10 wt% to 15 wt% this may be due to poor dispersion of particulate and possibility of existence of voids [9, 31]. It is clearly observed from the Table 4.1 that Al_2O_3 filled composite with 15wt% of fibre has more void percentage as compared to Al_2O_3 filled composite with 10wt% of fibre loading. However, the strength increases for Al_2O_3 filled composite with 20wt% of fibre loading as it has low void content.

Surface Morphology of Composites Before And After Tensile Test

Figure 4.6 (a) shows the glass fibre reinforced epoxy composites before tensile test. It shows the even fibre distribution in matrix, presence of voids and small patches that indicates the presence of filler in matrix. After applying uniaxial tensile load, layer breakage of matrix takes place, crack propagates through matrix where fibre distribution is uneven i.e. from weakest section of composite which causes localized yielding. Presence of fibres prevents crack formation, but when applied load reached above yield point of material then fibre- Matrix bonding was not sufficient to stand the applied load and it finally breaks down .

Sliding Wear Behaviour of E-Glass Fibre Reinforce Depoxy Composites

The sliding behaviour of uncoated fibre reinforced, fibre and filler reinforced, and aluminium coated fibre reinforced has been studied. The chapter deals with parametric analysis of sliding wear process using Taguchi experimental design. Results of ANOVA study is also reported to understand the effect of various parameters.

SLIDING WEAR BEHAVIOR OF E-GLASS-EPOXY COMPOSITES

Effect of Fibre Loading On Sliding Wear Behaviour Of Uncoated And Unfilled Composites

The variation of wear rate with respect to fibre loading at different testing conditions is shown in Figure 5.1. Specific wear rate of the composites decreases with increase in fibre loading, at C1 testing condition. The hardness plays an important role in the wear resistance of the material. As fibres are harder phase in the composite more energy is required for the failure of the fibres.

Thus, the wear failure is less in case of composites with higher fibre loading. At C2 testing condition (sliding velocity 250 rpm, sliding distance 471.23 m and normal load 10 N) minimum specific wear rate is observed in case of composite with 20 wt% fibre loading. Among all the testing conditions (i.e. C1, C2 and C3) composites with 15 wt% fibre loading exhibit minimum specific wear rate [32].

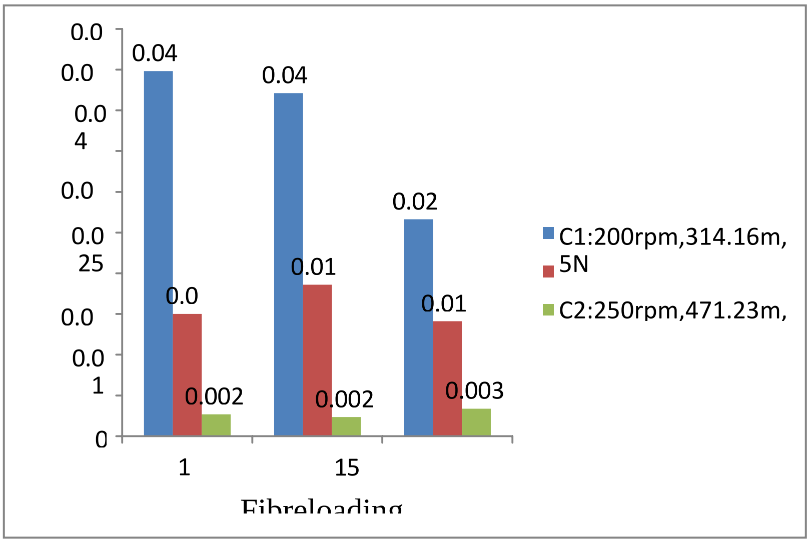

Figure 5.1 Wear rate of uncoated and unfilled composite at different fibre loading and test conditions

Effect of fibre loading on sliding wear behavior of uncoated and filled composites

The specific wear rate of Al_2O_3filled composites are shown in Figure 5.2. The filler content is same for all samples. Wear resistance of polymer composites depends on the bonding between filler and matrix, distribution of filler material, fibre loading and also the presence of voids in composite samples. At sliding velocity 200 rpm, sliding distance 314.16 m and normal load 5 N, wear rate increases from 0.0263 to 0.0321 cm^3/Nm with the increase in fibre loading up to 15 wt% beyond which specific wear rate decrease. However, at sliding velocity 250 rpm, sliding distance 471.23 m and normal load 10 N, wear rate gradually decreases with increase in fibre loading [33]. This may due to less voids and uniform distribution of filler and fibre throughout the matrix. But at sliding velocity 300 rpm, sliding distance 659.73 m and normal load 15 N, specific wear rate of specimens is lesser than the those specimens subjected to C2 and C3 test conditions, as observed from Figure 5.2.This may be due to the less contact time during the wear test.

Effect of fibre loading on sliding wear behaviour of coated and unfilled composites

Figure 5.3 shows the specific wear rate of the coated samples at different testing conditions. The maximum wear is observed in case of coated sample with 15 wt% fibre loading which was subjected to test condition of 200 rpm, 314.16 m and 5 N. Minimum specific wear rate of 0.0155 cm^3/Nm is observed in case of composite have 20 wt% fibre loading. The samples at C3 testing condition depict the minimum specific wear rate.

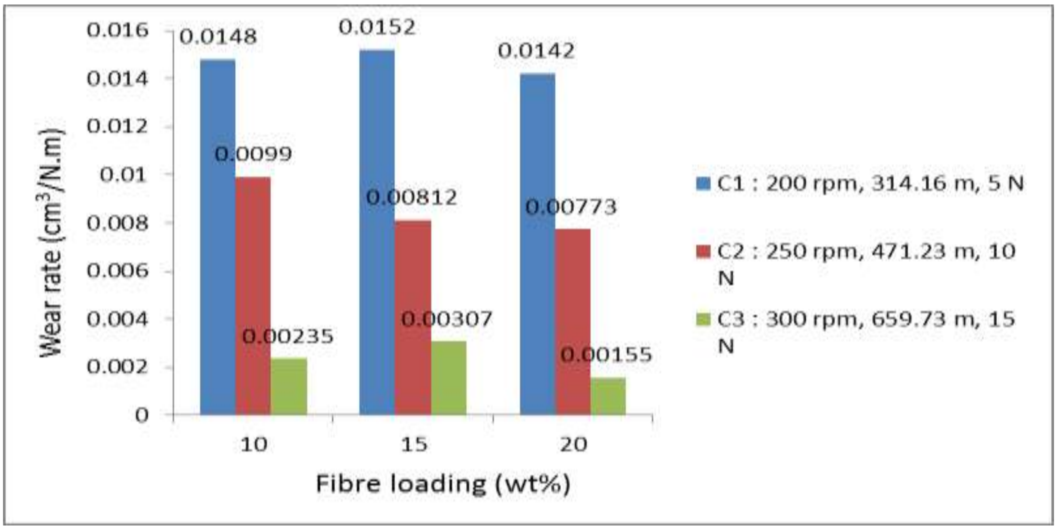

Figure 5.3 Wear rate of coated and unfilled composite at different fibre loading and test conditions

On comparing Figure 5.1, 5.2 and 5.3 it has been found that maximum wear occurs in case of uncoated and unfilled composites. The addition of Al_2O_3 filler in the uncoated composites results in improved wear resistance. The hard Al_2O_3 particles fill the space between the matrix and fibre thus making the composite more brittle and results in low wear. The aluminium coating on the surface of unfilled composites further enhanced the wear resistance of the composites. When the aluminium coated samples comes in contact with the environment formation of oxides layer takes place and during the sliding wear this oxide film breaks and provide the lubricating effect which in turn reduces the wear of the composites.

Taguchi experimental result

Table shows the Taguchi orthogonal array used for the present study. Column 2, 3 4, 5, 6 and 7 shows various factors (i.e. filler content, coating thickness, sliding velocity, sliding distance, normal load and fibre loading) and there levels. Each row shows the experimental condition i.e. combination of various parameters and levels under which the composites were subjected to sliding wear test. The overall mean value for the S/N ratio of specific wear rate for 36 different iterations is found to be 41.23 db. From the Figure 5.4 it is observed that factor combination of filler content of 5 %, coating thickness of 0.25 %, sliding speed of 0.6280m/s, sliding distance of 659.73 m, normal load of 10 N and fibre loading of 20 wt% gives minimum specific wear rate.

CONCLUSIONS

The experimental work done on the effect of fibre loading, filler content on mechanical and also the effect of coating on sliding wear behaviour of E-glass reinforced epoxy composite leads to obtained the following conclusions from the present study as follows:

1. Fabrication of E- glass fibre reinforced epoxy composites with and without filler composites is done using simple hand lay-up technique.
2. Thin film coating of aluminium on glass-fibre reinforced epoxy composites is done by using thermal evaporation technique. The coating thickness of 0.25 µm is achieved over the surface of fabricated composites.
3. The addition of glass fibre in the composites improves the mechanical property of polymer resin. The hardness and tensile strength of the composite increases with the increase in fibre loading. Flexural strength and impact strength of the fibre reinforced composites increased up to an optimum level of fibre loading.
4. Hardness, flexural and tensile properties of the glass epoxy composites are enhanced with addition of Al_2O_3 filler in the glass-epoxy composites.
5. The addition of filler in to the glass-epoxy composites results in improved sliding wear resistance of the glass-epoxy composites. However, the aluminium coated glass- epoxy composites shows minimum specific wear rate on comparing with glass-epoxy composites and Al_2O_3 filled glass-epoxy composites.
6. The factor combination of filler content of 5 %, coating thickness of 0.25 %, sliding speed of 0.6280 m/s, sliding distance of 659.73 m, normal load of 10 N and fibre loading of 20 wt% gives minimum specific wear rate.
7. ANOVA study reveals that filler content, coating thickness, sliding distance and fibre loading has significant effect on specific wear rate of glass-epoxy composites.

Scope for Future Work

There is wide scope for the future researchers to explore this field of research. This work can be further extended to investigate the other aspects of coated composites like use of other potential coating materials for the development of hybrid composites and evaluation of their wear and mechanical properties.

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