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Experimental Investigation on Sliding Wear of E-Glass Composite Material

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ABSTRACT

Fibre reinforced polymer (FRPs) composites are becoming more popular and have a wider range of applications due to their multiple advantages, which include a higher strength-to-weight ratio, a lighter weight, and a lower production cost. They are employed in the aerospace, automotive, and civil industries because of these advantages. E-glass fibre was utilized as a reinforcing agent in this study, both with and without alumina filler. The purpose of this study was to investigate the behaviour of E-glass fibre reinforced epoxy based composites with and without coatings, as well as the effects of fibre loading and filler quantity on the mechanical properties of the composite materials. In this study, a Taguchi approach, a sophisticated design tool, was utilized to establish the ideal condition for a certain wear rate of composites by taking into account various characteristics. ANOVA was used to investigate the sliding behaviour of these composites as a result of the effects of various parameters. Finally, the surface morphology of composites is examined using an optical microscope.

Keywords: Fibre reinforced polymer, Taguchi method, ANOVA

1. INTRODUCTION

A mixture of two or more materials having diverse properties, or a system made up of two or more physically distinct phases separated by a distinct interface, whose combined properties are superior to their individual constituents in many ways. A novel material made up of two or more materials can have increased qualities that work together to provide a synergetic effect.

There are two types of elements in composite materials: matrix and reinforcement. Matrix refers to the parts that are continuous and present in greater quantities. The matrix's primary roles are to keep or bind the fibres together, equally distribute load amongst the fibres, protect the fibre from mechanical and environmental degradation, and carry interlaminar shear. The other component is reinforcement, which has the primary goal of improving mechanical qualities such as stiffness and strength. The mechanical property is determined by the reinforcement's shape and dimensions. Composites are divided into three categories based on the type of matrix material used polymer, metallic, and ceramic.

1.1 Classification Of Composites

The following are the detailed classification of composites

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1.1.1 *Classification based on matrix constituent*

- Organic Matrix Composites
- Metal Matrix Composites
- Ceramic Matrix Composites

1.1.2 *Classification based on reinforcement*

- Fibre reinforced composites
- laminar composites
- particulate composites

Fibre Reinforced Composites (FRP) are classified as either discontinuous or continuous fibre composites.

1.2 Fibre Reinforced Polymer (FRP)

Fibre-reinforced polymer (FRP), often known as fibre-reinforced plastic is a composite material made up of a polymer matrix and fibres. Glass, carbon, or aramid fibres are commonly employed, but other fibres such as paper, wood, or asbestos have also been used. Epoxy, vinylester, or polyester thermosetting plastics are commonly used, however phenol formaldehyde resins are still used. The aerospace, automotive, marine, and construction industries all use FRPs. While the classification of composites based on reinforcement is illustrated in Figure below:

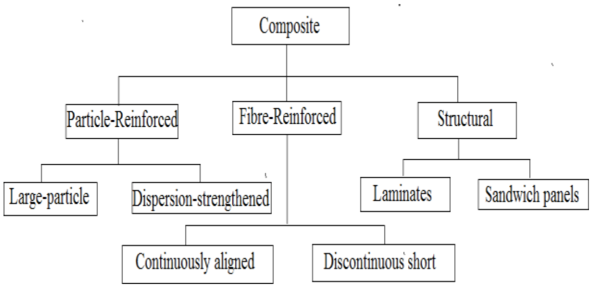


Fig1.1: classification of composites based on reinforcement

Fibers are an important class of reinforcements because they meet the required requirements and transfer strength to the matrix constituent, affecting and increasing the desired qualities. The oldest known fibres used to strengthen materials are glass fibres. Ceramic and metal fibres were later discovered and widely used to make composites stiffer and more heat resistant. Fibers fall short of ideal performance for a variety of reasons. The length, shape, orientation, and composition of the fibres, as well as the mechanical properties of the matrix, determine the performance of a fibre composite.

The strength of the composite is determined by the orientation of the fibre in the matrix, and the strength is greatest along the longitudinal axis of the fibre. This does not imply that longitudinal fibres can take the same amount of load regardless of the direction of application. Longitudinal fibres work best when the load is delivered in the same direction as the fibres. The composite's strength can be substantially reduced by even the tiniest change in loading angle.

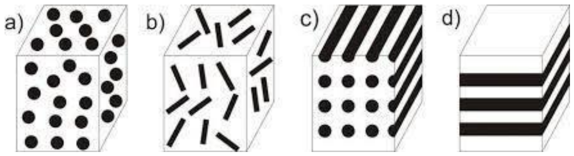


Fig1.2: Reinforcement of fibers

There are wide verity of reinforcement like Natural fibres (e.g. hemp, kenaf, sisal, coir, jute, etc.), synthetic fibres (e.g. glass fibres, ceramics, etc.), and organic fibres (e.g. aramid). Natural fibres are inexpensive, readily available, and biodegradable, but these benefits are insufficient to overcome substantial disadvantages such as moisture absorption, chemical resistance, and low strength when compared to synthetic fibres.

1.4 Manmade Fibres

2 Synthetic fibre
3 Organic fibre

Nylon, acrylic, polyester, glass fibres, and other synthetic fibres are only a few examples. Glass fibres are the most regularly used synthetic fibre nowadays. There are also several types of glass fibres, such as A-glass, C-glass, D-glass, E-CR glass, E-glass, and S-glass, among which E-glass and S-glass are the most frequently and commonly utilised, accounting for over 90% of the reinforcements used in numerous industries. Commercially available glass fibres are mostly made up of woven roving (cloth), chopped strands, and long continuous threads. Continuous roving, which is a fabric woven in two mutually perpendicular directions, makes up woven roving. Continuous fibres are cut to a short length and placed in the form of a bundle in chopped strand. S-glass, on the other hand, has a higher tensile strength, greater modulus, and greater elongation at failure than E-glass, and it is primarily used in applications where strength and weight are important, such as aeroplane fuselages, tail wings, pipes for carrying aqueous liquid, ship hulls, helicopter blades, tanks, and vessels. However, its high cost prevents it from being utilised in everyday products such as domestic appliances such as fibre glass doors, window frames, and bath tubs, as well as sporting equipment such as hockey sticks, fishing rods, and archery arrows. Table 1.1 shows the many types of glass fibres available.

Table 1.1 Types of glass fibres

Fibre	Composition
A-glass	Alkali-lime + boron oxide (less amount)
C-glass	Alkali lime + boron oxide content (more amount)
D-glass	Borosilicate
E-glass	Alumino-borosilicate + alkali oxides (< 1%)
E-CR- glass	Alumino-lime silicate +alkali oxides (<1%)
S-glass	Alumino silicate + MgO

1.5 E-Glass Fibre

The letter "E" stands for electric in E-glass fibre, which is made of alumino-borosilicate glass with alkali oxides of less than 1% by weight, whereas C-glass has a high boron oxide content and S-glass has a high magnesium oxide concentration with silica and aluminium oxide. The composition of several glass fibres was explained below.

E-Glass : SiO_2 52.3% +(Al_2O_3 + Fe_2O_3)14.4% + CaO 17% + MgO 4.6% + (Na_2O + K_2O) 0.7% + B_2O_3 10.7%

C-Glass: SiO_2 64.5% +(Al_2O_3 + Fe_2O_3) 4.08% + CaO 13.28 % + MgO 3.2% + (Na_2O + K_2O) 9.5% + B_2O_3 4.7% + BaO 0.8%

S-Glass: SiO_2 64.3% +(Al_2O_3 + Fe_2O_3) 25.0% + MgO 10.2% + (Na_2O + K_2O) 0.5%

Table 1.2: Properties of Glass fibres

Property	**E-Glass**	**C-Glass**	**S-Glass**
Density (gm/cm^3)	2.61	2.48	2.74
Thermal Conductivity (W/mK)	13	13	13
Coefficient of Thermal Expansion (10^{-6} K^{-1})	4.8	7.3	5.7
Tensile stress(GPa)	3.43	3.28	4.59
Elastic modulus (GPa)	75	70	85.4

1.6 Industrial Applications Of Fiber Glass

For industrial gaskets, materials with high-temperature insulation provide an effective thermal barrier. Fiberglass is one of the most extensively used materials in industrial gaskets because it is long-lasting, safe, and provides excellent thermal insulation. They help to preserve machines, conserve energy, and secure the safety of the professional staff in addition to providing superior insulation. This is maybe why fibreglass is commonly utilised in Automobiles, Aerospace, defence, manufacturing industries, beverages, chemical industries.

Randomly oriented short E-glass fibre is used as a reinforcing agent in this study because to its high strength, light weight, chemical resistance, and, most importantly, low cost.

Aluminum oxide (Al2O3), often known as alumina, is used as a filler. The addition of filler to composites improves their mechanical and physical qualities. The chemical inertness, high hardness, high strength, and low cost of Al2O3 made it excellent for applications involving friction and wear, such as low-cost automotive brake linings. Because of its wear and corrosion resistance, pure aluminium was chosen as a coating material due to its passivation effect (the property of a material to create a thin coating film of its oxide that protects its surface from outside influences such as air and moisture). Aluminium can also be used as filler.

2. LITERARURE SURVEY

Rout et al. investigated the mechanical properties of filled and unfilled rice husk particles in a glass fibre reinforced epoxy composite, as well as erosion wear. In the experimental design, the Taguchi optimization technique was also applied to determine the appropriate parameters for decreasing the wear rate. Filler content, impact velocity, impingement angle, and erodent size all have a significant impact on wear rate, with 15 wt percent rice husk demonstrating the best wear resistance. Tensile modulus, hardness, and impact energy are all improved by adding filler material. The flexural and tensile properties of the composites have worsened.

Koricho et al. examined the bending fatigue behaviour of a twill E-glass epoxy composite. The displacement controlled bending fatigue test was used to explore composite material bending fatigue behaviour. The samples were subjected to various levels of tiredness. The residual properties of selected specimens were examined at maximum levels up to 0.75 times the material's ultimate flexural strength after 1 million cycles. According to the researchers, tensile stressors are damaging, but compressive stresses are beneficial.

On many types of E-glass fibre cross-sections, Deng et al. investigated the influence of varying aspect ratios on interlaminar shear strength, interlaminar fracture toughness, and charpy impact test (round, oval, and peanut-shaped). Due to fibre overlapping, they discovered that composites reinforced with larger fibre cross-sections have lower delamination resistance than composites reinforced with round cross-sections. The same trend was seen in different tests, such as the double-cantilever beam (DCB), short-beam-shear (SBS), and end-notched flexure (ENF), but composites reinforced with larger aspect ratio fibre reinforced composites have better energy absorbing capacity than composites reinforced with conventional round fibres.

To determine loss modulus, storage modulus, and loss factor, Alvarez et al. employed Perkin Elmer DMA-7 equipment to perform three point bending tests on unidirectional glass fibre reinforced epoxy resin. The viscoelastic properties of two different types of epoxy resin that were utilised to coat the fibres were studied. Because all parameters have the same modulus, the Span to Thickness Ratio L/h should be greater than 15 to get the optimum results.

In an experimental study, El-Tayeb et al. studied the frictional and wear characteristics of a unidirectional E-glass reinforced epoxy composite. Under various sliding velocities and normal applied loads for various surface conditions (e.g. dry, wet, lubricated conditions), wear rate and friction coefficient were calculated using a pin on disc apparatus (e.g. dry, wet, lubricated conditions). The wear and frictional behaviour of composite is determined by the surface conditions of the counter face, such as damp and clean surfaces. The wear rate and friction coefficient have both improved. It was also revealed that in water-lubricated conditions, the lowest friction coefficient and wear rate were achieved, which were dependent on the applied normal load and speeds.

2.1 Objective of the Present Work

The following objectives for the scope of the current research endeavour are set in light of the existing state of research.

1. To investigate sliding wear characteristics and mechanical characteristics epoxy composites with and without Al_2O_3 filler.
2. To investigate the effects of fibre loading and filler content on the mechanical and sliding wear of glass-epoxy

composites.
3. To determine effect of aluminium coating on sliding wear of glass-epoxy composites.
4. To determine the effect of various factors on a certain wear rate, a parametric analysis of the sliding wear process was performed using a Taguchi experimental design.
5. Using an optical microscope, examine the surface morphology of cracked samples.

3. MATERIALS AND METHODS

3.1 Matrix Materials

Because of their availability, ease of manufacture, light weight, and low cost, polymer matrices are the most prevalent and commonly utilized matrix material. Epoxy resin, the matrix material employed in this study, is a thermoset polymer that has an epoxide group as its functional ingredient, in which one oxygen atom is connected to two carbon atoms.

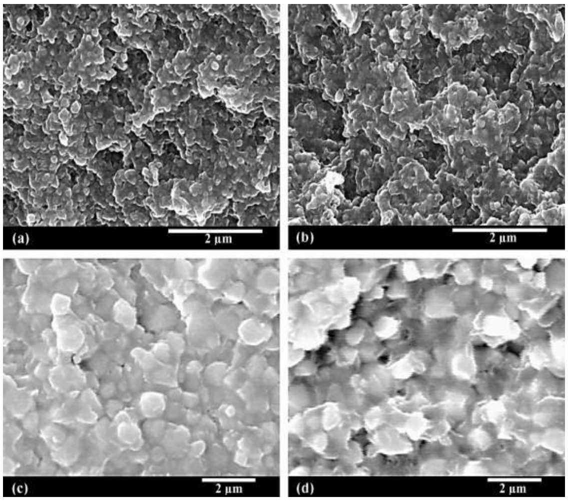


Fig 3.1: Microstructure of Epoxy resign

Epoxy resin is the most often used thermoset resin as a matrix material. After an irreversible chemical reaction, it creates three-dimensional cross-link structures. It has significant advantages over other thermoset resins, including higher mechanical strength, good bonding with a variety of fibres, reduced shrinkage after curing, and chemical resistance. Epoxy resin LY-556 is chosen as the matrix material because it has various advantages over other types of resin.

3.2 Fibre Material

Among numerous composite materials, glass fibres are the most prevalent reinforcing agent. Glass fibres come in woven fabric, chopped strands, long continuous fibre, and short discontinuous fibre forms. As a reinforcing agent, randomly oriented short E-glass fibre is used in this study. E- glass fibre is roughly 6 mm long on average. It's essentially a regular borosilicate glass with less than 1% alkali oxide content.

Fig 3.2: E-Glass Fibre

3.3 Filler Material

In polymer-based composites, different forms of particle filler are utilized as reinforcement. The most common traditional fillers are silicon carbide (SiC), alumina (Al_2O_3), and titanium (TiO2).Alumina (Al_2O_3) is employed as a filler material in this study. Al_2O_3's chemical inertness, high hardness, strong strength, and low cost made it ideal for applications where friction and wear are common.

Fig 3.3: Alumina filler material

Table 3.1 Types of fibres

Name of the composite	combination
EE-I	Epoxy + 0 wt % of E-glass fibre
EE-II	Epoxy + 10 wt % of E-glass fibre
EE-III	Epoxy + 15 wt % of E-glass fibre
EE-IV	Epoxy + 20 wt % of E-glass fibre
EEA-I	Epoxy + 10 wt % E-glass fibre + 5 wt % Alumina
EEA-II	Epoxy + 15 wt % E-glass fibre + 5 wt % Alumina
EEA-III	Epoxy + 20 wt % E-glass fibre + 5 wt % Alumina

3.4 Sliding Wear Test of Composite

Under dry sliding conditions, the wear behavior of composites is investigated using a pin-on-disc apparatus. The schematic design and pictorial representation of the pin-on-disc configuration are shown in Figures 3.8 and 3.9, respectively. The sliding wear test is performed according to ASTM G99 test standards, and the wear monitoring equipment was provided by DUCOM (standard test method for wear testing with a pin-on-disk apparatus). The specimen is maintained still in the pin assembly while the counter disc rotates and the usual load is applied by a lever arm mechanism. Case hardened steel (72HRC, EN-32, 0.6m surface roughness) is used for the counter disc. At various sliding velocities and under typical load, a series of wear tests are carried out. Weight loss of composites is assessed using a high-precision electronic balance.

The specific wear rate of material is obtained by the equation

$Ws = \Delta m / (L*\rho*F)$

Where Δm = Difference in mass of the samples before and after the test

L = Sliding distance (mm)

ρ = Density of composite (gm/mm3)

F = Applied load (N)

3.5 Taguchi Method

The Taguchi method is a strategy that involves designing experiments in "orthogonal array" with the goal of obtaining the best collection of controls to evaluate the sensitivity of a test of response variables to a set of control factors (or independent variables). The number of rows and columns, as well as the number of levels in each column, are all displayed in an array. Taguchi technique, design of experiment (DOE), and regression analysis are significant tools for resilient design. L4 (23) contains four rows and three "2 level" columns, for example. The number of rows in the orthogonal array denotes the number of experiments necessary.

S/N ratio falls into the category of smaller is preferable when it comes to minimum specified wear rate. It can be stated mathematically as

$$S/N = -10 \log (\Sigma (1/ Y^{2}) / n)$$

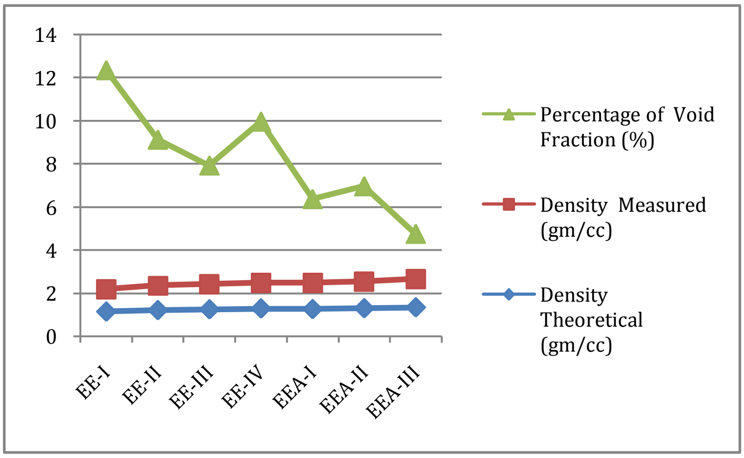
n = number of observations
y = observed data

4. RESULTS

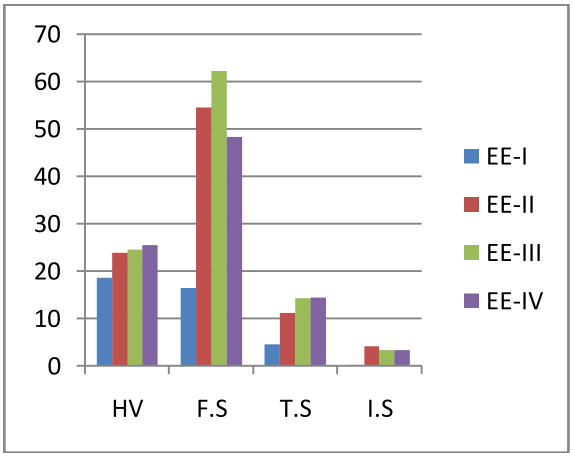
4.1 Physical Properties of composites

Name of the composite	Density Theoretical (gm/cc)	Density Measured (gm/cc)	Percentage of Void Fraction (%)
EE-I	1.149	1.033	10.19
EE-II	1.215	1.132	6.79
EE-III	1.253	1.182	5.5
EE-IV	1.293	1.196	7.49
EEA-I	1.264	1.216	3.89
EEA-II	1.303	1.245	4.42
EEA-III	1.346	1.316	2.09

Table 4.1: physical properties of composites

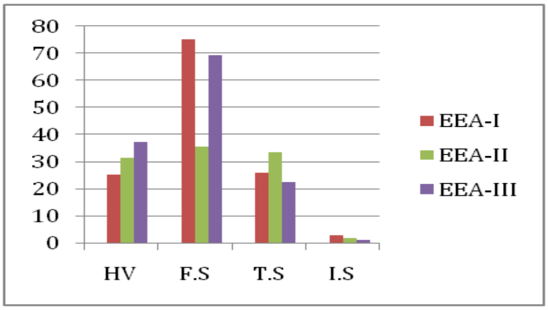


Graph4.1: comparison of physical properties of composites



Graph 4.2 properties of composites without filler

HV – Hardness F.S – Flexural Strength (MPa) T.S – Tensile strength (MPa) I.S - Impact strength (J)



Graph 4.3: properties of composites with filler

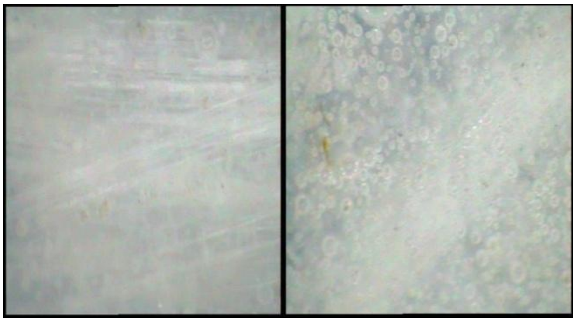


Fig 4.1: microscope picture before tensile test

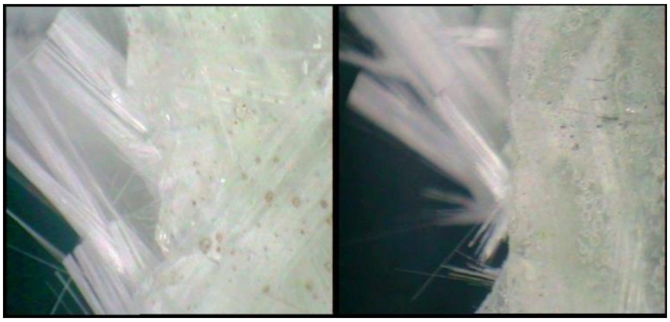
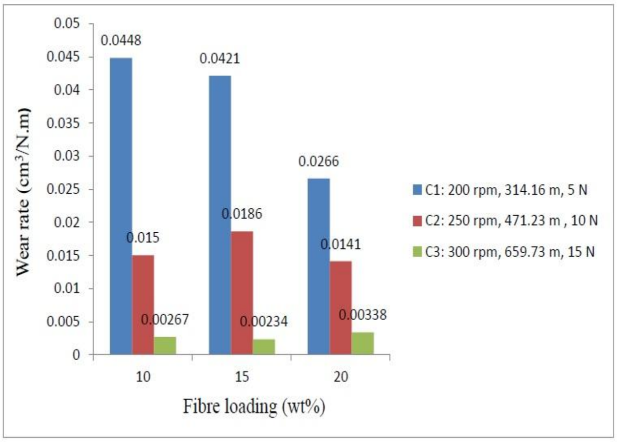
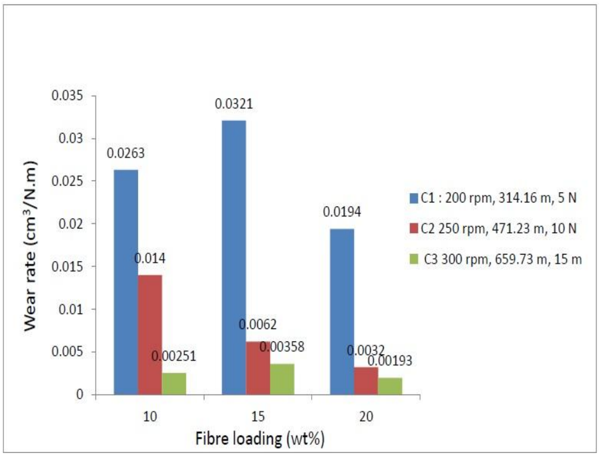


Fig 4.2: microscope picture after tensile test

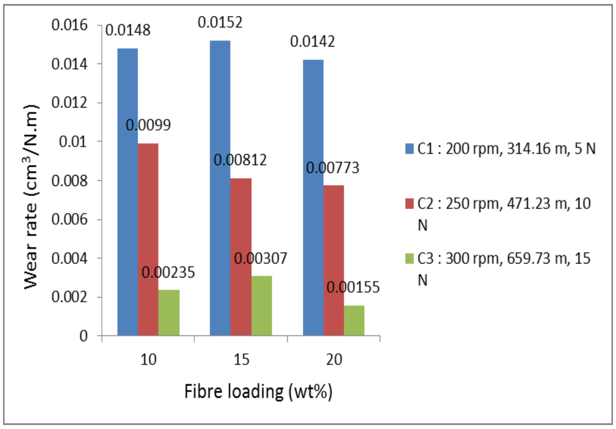
4.2 Sliding Wear Rate Results Of E-Glass



Graph 4.4: uncoated unfilled composite wear rate



Graph 4.5: uncoated filled composite wear rate



Graph 4.6 coated unfilled composite wear rate

By observing the above results, it can be seen that uncoated and unfilled composites have the most wear. The inclusion of Al_2O_3 filler improves the wear resistance of uncoated composites. The stiff Al_2O_3 particles occupy the area between the matrix and the fibre, and makes composite brittle and reducing wear. Addition of an aluminium coating to the surface of unfilled composites improved their wear resistance even more. When samples of aluminium coated come into contact with the environment, an oxide layer forms, and this oxide film breaks down during sliding wear, providing a lubricating action that minimizes composite wear.

4.2 Taguchi Results

For 50 distinct iterations, the total mean value for the S/N ratio of specific wear rate was found to be 41.23 db. Results shows that a 5%filler content , coating thickness of 0.25 percent, a sliding speed of 0.6280 m/s, a sliding distance of 659.74 m, a normal load of 10 N, and a fibre loading of 20 wt% results in the lowest specific wear rate.

4.3 Morphology of Composite

Fig 4.3 E-Glass before wear test

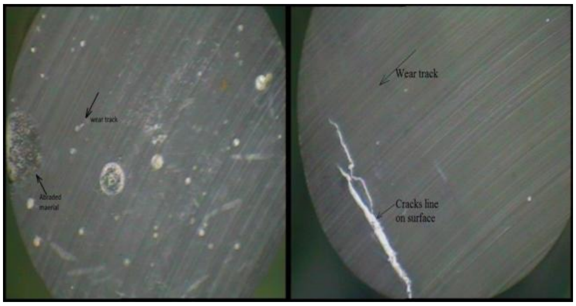


Fig 4.4: E-Glass after wear test

5. CONCLUSIONS

This research was done to study the effect of filler content and fibre loading on the mechanical properties as well as the effect of coating of E-glass reinforced Epoxy composite results in sliding wear behavior. The following are the conclusions that are obtained.

1. With the help of simple hand layup method, the fabrication of E-glass fibre reinforced epoxy composites with and without filler composites was done.
2. Glass fibre reinforced epoxy composites were coated with thin film of aluminum. The thickness of coating on the fabricated composites surface is 0.25µm.
3. Improvement in sliding wear resistance of glass Epoxy composites is seen due to the supply of filler in glass Epoxy composites. Anyhow the specific wear rate of aluminum coated glass Epoxy composites is less than that of the composites of glass Epoxy and Al2o3 filled glass Epoxy.
4. Minimum specific wear rate can be obtained by maintaining 5% factor combination of filler content, 0.6280m/s sliding speed,0.25% coating thickness, sliding distance of 659.73m,fibre loading of 20%wt and 10N normal load .
5. Finally it is revealed from the ANOVA study that the specific wear rate of glass Epoxy composites was significantly effected by the thickness of coating, filler content, fibre loading and the sliding distance

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