# The Experimental Investigation of Mechanical and Tribological Behavior of Glass Fiber Based Epoxy Hybrid Composite Materials

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***Abstract—Bi-directional glass fiber reinforced polymer composites are widely used in many industrial applications due to several advantages such as low weight, easy of processing, price and noise suspension. The performance of the composites can be further improved by adding particulate filler to them. The "filler" play an important role for the improvement in performance of polymer and their composites. Filler materials are used to reduce the material costs, to improve mechanical properties to some extent and in some cases to improve process ability. Besides, it also increases properties like reduce shrinkage, hardness and wear resistance. Fibre reinforced polymer composites containing different fillers are used many application in which tribological and mechanical properties are critical issues. Also a full understanding of the effects of all system variables on the wear rate is necessary in order to undertake appropriate steps in the design of machine or structural component and in the choice of materials to reduce/control wear.***

***Although a great deal of work has been reported in the literature which discuss the mechanical and wear behaviour of fiber reinforced polymer composites, however very limited work has been done on effect of fiber loading and filler on mechanical and wear behaviour of bi-directional glass fiber reinforced epoxy composites. Against this background, in the present investigation, composites samples are prepared by using simple hand-lay-up technique with varying weight fraction of bi-directional glass fiber (40wt%, 60wt%, and 80wt %). Mustard cake powder (10wt %) is used as filler in composites. The effects of fiber loading and filler on the tribological and mechanical behaviour of glass fiber reinforced epoxy composites are studied. It has been found that wear rate decrease with increasing fiber weight percentage. Mechanical properties of composites are increases with increase of fiber loading. The mechanical and wear behaviour of filled composites is more superior then unfilled composites.***

***Index Terms—composites, bi-directional glass fiber (40wt%, 60wt%, and 80wt %), hand-lay-up technique, fiber reinforced polymer composites***

## I. INTRODUCTION

### 1.1 Motivation And Background

The most primitive composite materials when mixture of mud and straw to create strong and durable building is used by egyptians and mesopotamian settlers. Straw continued to provide reinforcement to ancient composite products including pottery and boats. Later, the mongols invented the first composite bow, using a combination of bone, wood and animal glue. These bows were extremely powerful and accurate composite. however, plastics alone couldn't provide enough strength for structural applications. Reinforcement was needed to provide the strength and rigidity, and then introduce the first glass fiber. Fibre glass, when combine with plastic polymer create a strong structure that is also light weight. This is the beginning of fiber reinforced polymer (frp). The composite materials have advantage over other conventional materials due to their higher specific properties such as tensile, impact and flexural strength, stiffness and fatigue characteristics, which enable structural design to be more versatile. Due to their many advantages they are widely used in a large number of commercial mechanical engineering applications, such as automobile; machine components; thermal control; thermal control and electronic packaging; railway coaches and aircraft structures; mechanical components.

1.1.1 What Is Composite?

A composite material is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. The new material may be preferred for many reasons: common examples include materials which are stronger, lighter, or less expensive when compared to traditional materials.

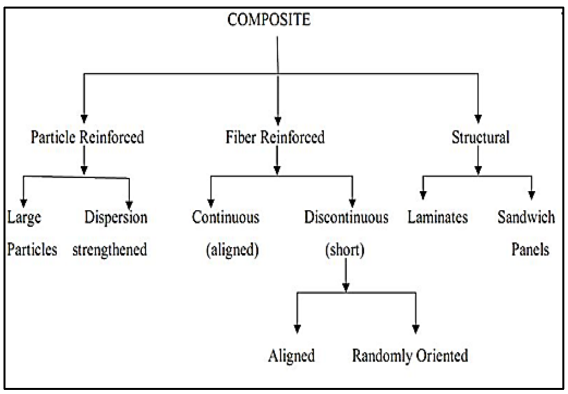


Figure 1: classification of composites

1.1.2 Advantages of Composites

•Composite have merits over other materials because they can be moulded in to complex shapes at relatively low cost. This gives designers the freedom to create any shape or configuration. Boats are a good example of the success of composites.

- Tensile strength of composite is 4 to 6 times greater than that of steel or aluminium (depending on the reinforcements).
- Embedded energy compared to steel or aluminium is lower.
- Composites provide lower vibration transmission than metals and less noisy while in operation.
- Composites products provide long term resistance to serve chemical and temperature environments.
- As molded dimensional accuracy. Tight tolerance, repeatable moldings. ...
- Chemical Resistance.
- Consolidated Parts and Function.
- Corrosion Resistance.
- Design Flexibility.

1.1.3 Disadvantages Of Composites

- Most composites use thermoset matrices that cannot be reshaped.
- They are difficult to repair
- For all composites, the design and the testing to get all the properties is complex and costly.
- Properties in composites vary from point to point in the material. Most engineering structural materials are homogeneous.

1.1.4 Application of Composites

Product made up of composite materials are used in everywhere, fig. 1.1 shows application of composite materials.

(a)frp door &door frame
(b)typical composite building

(c) jute-coir composites boards
(d) composite artificial limbs

(e) modular frp toilets for railway coaches
(f)composite pressure vessel

(g) train made up of frp composites
(h) composite hand rails and grid
Fig. 1.1 (a-h) application of composite materials

## II. RESEARCH GAP

An exhaustive literature review of the present study lacks tremendously a consistent analysis of effect of natural filler on mechanical and wear behaviour of glass fiber reinforced polymer composites.

A number of researchers have been investigated that the mechanical and wear behaviour of either fiber reinforced composites or particulate composites. however, a possibility that the incorporation of both fibres and particulates in polymer could provide a new class of composite and this new class may be provide improved performance as compared to other old classes of composites.

### 2.1 The Objectives of This Work Are Outlined As Follows:-

The basic aim of the present work is to develop and characterize a new class of composites with a polymer called epoxy-filler as the matrix and the glass fiber as the reinforcing material.

1) Fabrication of a series of a glass fiber reinforced epoxy matrix composite with and without mustard cake fillers.
2) Characterization of mechanical properties such as tensile strength, flexural strength and inter laminar shear strength.
3) Wear behaviour of this new class of composites is investigated in this project work. Dry sliding and abrasion wear is performed on the composites.
4) This work is expected to introduce a new class of polymer composites suitable for tribological applications.

## III. MATERIALS AND METHODS

Materials used for the processing of composites and deals with the details of the experimental procedures (such as dry sliding and abrasive wear tests, flexural test, inter laminar shear strength test and tensile test).
The raw materials used in this work are:

- E-glass fiber mat
- Mustard cake powder
- Epoxy resin
- hardener

### 3.1 Materials

#### 3.2.1 Matrix Material & Fillers

Epoxy (ly 556) is chosen as a matrix material for the present research work. It chemically belongs to the epoxide family and its common name is bisphenol-a-diglycidyl-ether. The hardener with iupac name nn0-bis (2-aminoethylethane-1, 2-diamin) used with the epoxy has the designation hy-951. The epoxy resin and hardener were supplied by r.b electronics india limited. Process density of epoxy is 1.1 g/cm3. Mustard cake powder is used as filler of density 1.27 g/cm3 as shown in fig. 3.1. Mustard cake was supplied by rural area of uttar pradesh, india.

Fig. 3.1 raw materials of filler (mustard cake) used in fiber glass reinforced

3.2.2 Fibre Material

Bi-directional e-glass fiber mat is taken as the reinforcement in the epoxy matrix to fabricate composites. Process density and modulus of e-glass fiber is 2.55 g/cm3and 72 gpa.

3.3 Composite Fabrication

The fabrication of the various composite materials is carried out through the hand lay-up technique. The composite fabrication consist of three steps: (a) mixing of epoxy resin and filler using a mechanical stirrer, (b) mixing of the curing agent with the filled epoxy resin, and (c) fabrication of composites. Resin and hardener (hy 951) mixed in a ratio of 10:1 by weight as recommended. Mustard cake powder of average size 100-200 µm mixed with epoxy resin by stirring at room temperature and poured in to the wooden mould of Dimension (210x210x40) mm3. The dimension each glass fib mm. A releasing agent (silicon spray) is used to facilitate easy removal of composites from The mold after curing. The composite sample of three different compositions samples i.e. Sample egf-1 (60% epoxy + 40% bidirectional e- glass fiber), sample egf-2 (40% epoxy + 60% bidirectional e- glass fiber), egf-3 (20% epoxy + 80% bidirectional e- glass fiber), in which no particulate is used. The other composite sample of three different sample i.e. Egfp-1 ( 50% epoxy + 40% bidirectional e- glass fiber + 10% mustard cake powder), egfp-2 ( 30% epoxy + 60% bidirectional e- glass fiber + 10% mustard cake powder), egfp-3 (10% epoxy + 80% bidirectional e-glass fiber + 10% mustard cake powder). The designations of these composites are given in table 3.1.the cast of each composite is Cured under a load of about 25 kg for 24 hours before it removed from the mould. Then This cast is post cured in the air for another 24 hours after removing out of the mould. The fabricated samples are shown in fig. 3.2.

Fig. 3.2 different samples of glass fiber reinforced polymer composites with & without filler (mustard cake powder) fabricated by hand- lay- up techniques.

Table 3.1 designation, fabrication technique and composition of composites

| Designation | Fabriction Technique | Composition |
|---|---|---|
| Egf-1 | hand lay-up | 60% epoxy + 40% Bidirectional e- glass fiber |
| Egf-2 | hand lay-up | 40% epoxy + 60% Bidirectional e- glass fiber |
| Egf-3 | hand lay-up | 20% epoxy + 80% Bidirectional e- glass fiber |
| Egfp-1 | hand lay-up | 50% epoxy + 40% Bidirectional e- glass fiber + 10% mustard cake powder |
| Egfp-2 | hand lay-up | 30% epoxy + 60% Bidirectional e- glass fiber +10% mustard cake powder |
| Egfp-3 | hand lay-up | 10% epoxy + 80% Bidirectional e- glass fiber +10% mustard cake powder |

3.4 Physico-Mechanical Characterization

3.4.1 Density And Void Fraction

The theoretical density of composite materials in terms of weight fraction can easily be obtained as for the following equation given by agarwal and broutman[30]. the Composites under this investigation consi particulate.hncefillerthe modified form of the composite can be written as

$$\rho_{ct} = \frac{1}{(W_f/\rho_f) + (W_m/\rho_m) + (W_p/\rho_p)} \qquad (1)$$

Ƿ ct = theoretical density of the composites
Ƿ m and wm= density of matrix (1.1 g/cm3) and weight fraction of matrix.
Ƿ fand wf= density of matrix (2.55 g/cm3) and weight fraction of matrix.
Ƿ pand wp= density of matrix (1.27 g/cm3) and weight fraction of matrix.
The experimental density of the composite however can be determined experimentally by simple water immersion techniques.

Ƿ exp= m/δh (2)

Ƿ exp= experimental density of specimen (g/cm3)
M = mass of specimen (g)
Δh = change in height of water level
The volume fraction of voids (vv) in the composite is determined by using the following equation.

$Vv = (Ƿct - Ƿce)/Ƿct$ (3)

3.4.2 Mechanical Testing

3.4.2.1 Tensile Test

The tensile test was carried out using instron1195. The dimension of the samples for the test is 150 mm x 10 mm and thickness of sample varies with different fiber loading. The test is performed in the universal testing machine instron1195 at across head speed of 10 mm per minute and the test is repeated three times for each sample to obtain the mean value of tensile strength. The astm standard test methods for tensile properties of fiber resin composites have the designation d 3039-76 [31]. Fig. 3.3 shows the specimen and experimental set up and loading arrangement for the specimens for tensile test. The tensile strength of any composite specimens is determined by using the following Equation.

T = w/bt (4)

T = tensile strength of specimen, w =load
B = width of specimen, t = thickness of specimen


Fig. 3.3 specimens and experimental set up for tensile test.

3.4.2.2 Inter Laminar Shear Strength And Flexural Strength

The short beam shear (sbs) test is performed on the composite samples for calculating inter-laminar shear strength (ilss). The test is conducted as per the astm-d2344-84 [32] standard for the pre-pared samples. The dimension of the samples for the test is 60 mm x10 mm and thickness of sample varies with different fiber loading. Universal testing machine instron1195 is used for the test. The cross head speed for the test is maintained at 10 mm/min and the test is repeated three times for each sample to obtain the mean value of inter laminar shear strength. The ilss is calculated as per following equation (5).

Ilss = 3p/4bt (5)

Here, p is the maximum load applied, b is the width of specimen and t is the thickness of the specimen. A span of 150mm is used for obtaining flexural strength. Fig. 3.4 shows experimental set up and specimens for flexural strength test.

F.s = 3pl/2bt2 (6)

Equation (5) and (6) are generally used to obtain the ilss and fs respectively for composite materials.

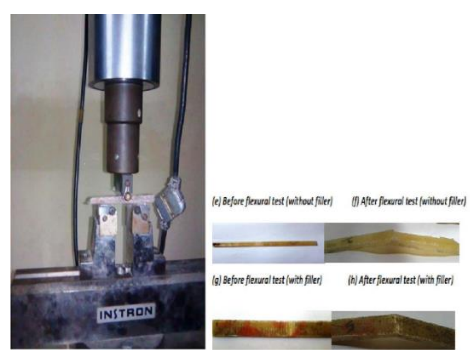


Fig. 3.4 experimental set up and specimens for flexural strength test.

3.5 Wear Test

3.5.1 Dry Sand Abrasion Test

The abrasion testing of composite specimens is performed on a standard abrasion test rig (supplied by ducom) as per astm g65 standard. The pictorial and schematic diagram of abrasion test rig and specimens used in abrasion test are shown in fig.3.5. The surface of the specimens was cleaned with a soft paper soaked in acetone before the test. The specimen weight was recorded using a digital electronic balance (0.1 mg accuracy) before it was mounted in the specimen holder. The difference between initial and final weight of the specimen was a measure of wear loss. The composite specimen of size (76mm x 25 mm) is pressed against a rotating wheel with a chlorobutyl rubber tyre of specified hardness. The abrasive was fed at the contacting between the rotating rubber wheels and test specimen and the rate of feeding the abrasive was 365 g/min. A series of test conducted for constant time 14 min under different normal loadings 5 n, 10n, 20 n and 20n with test speed of 2.39 m/s. Specimen cut from the composite plates for abrasion test are shown in fig. 3.6.the material losses from the composite surface are measured by using precision electronic balance and then find the specific wear rate by using following equation.

Ws=δm/ρlfn (7)

Ws= specific wear rate (mm3/n-m)

ƿ =density of specimen (g/cm3)

L = abrading distance (m)

Fn= normal load (n)

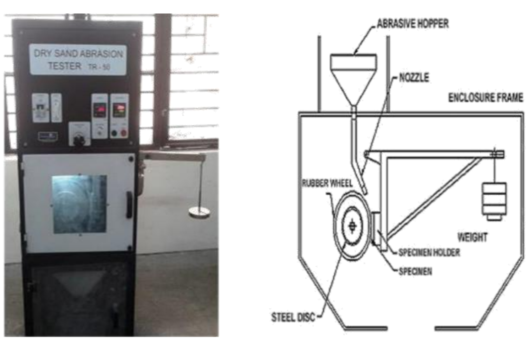


Fig. 3.5 Pictorial And Schematic Diagram Of Dry Sand Abrasion Test Set Up

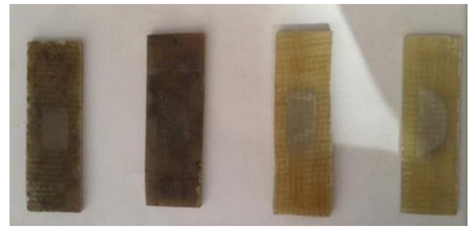

Fig. 3.6 specimens after abrasion test

3.5.2 Dry Sliding Wear Tests

Pin-on-disc type friction and wear monitoring test rig (tr-20 le, supplied by ducom) is used to evaluate the wear performance of the investigated composites under dry sliding conditions as per astm g-99

A series of test are conducted with constant sliding velocity 1.25m/s and time 60 min under different normal loadings 5n, 10n, 15n and 20n are given in table 3.3. The material losses from the composite surface are measured by using precision electronic balance and then find the specific wear rate by using equation (8). The specific wear rate is defined as the volume loss of the specimen per unit sliding distance per unit applied normal load.

Ws=δm/ρlfn (8)

Ws= specific wear rate (mm3/n-m), ρ=density of specimen (g/cm3), l=sliding distance(m) ,fn= normal load (n)

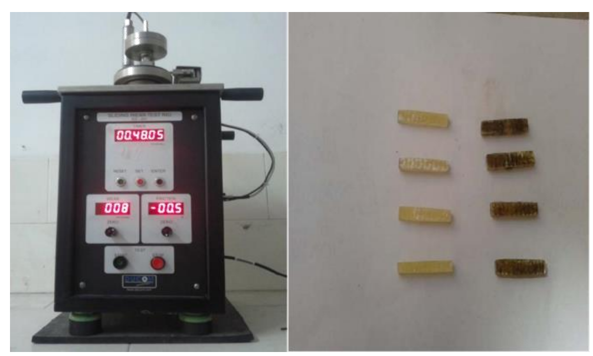

Fig. 3.7 Experimental Set Up And Specimens For Dry Sliding Wear Test

IV. RESULTS & DISCUSSIONS

The results of various characterization tests are reported here:

- Void fraction
- Tensile strength
- Flexural strength

- Inter laminar shear strength
- Specific wear rate

4.2 Physico-Mechanical Characteristics of Composites

4.2.1 Density & Void Fraction

Agarwal and broutman equation are used to determine the theoretical density of composite material in term of weight fraction. The experimental density can be easily determined by using archimedes principle. Density of a composite depends on the relative proportion of matrix and reinforcing materials and this is one of the factors determining the properties of the composites. The void content is the cause for the difference between the value true densities and theoretically calculated one. The knowledge of void content is desirable for estimation of the quality of the composites. It is understandable good composite should have favourable voids.

The density increases with increase of wt % of glass fiber in glass fiber reinforced epoxy composites. The density of neat epoxy resin in this study is 1.1 g/cm3which increases to 1.405 g/cm3 (with a void fraction of 1.45 %) with the reinforcement of 40 wt % of glass fiber in it. But when this glass fiber reinforced epoxy is filled with micro-sized mustard cake particles, the density of resulting hybrid composites is Increases to 1.42 g/cm3 (with a void fraction of 2.27 %). 1.605 g/cm3 (void fraction of 3.89 %) and 1.913 g/cm3 (void fraction of 5.34 %) with the reinforcement of 60 wt % and 80 wt% of glass fiber, but these same wt % of glass fiber reinforced epoxy is filled with filler (mustard cake powder), the density of hybrid composites is increase to 1.635 g/cm3 (void fraction of 4.04 % ) and 1.692 g/cm3(void fraction of 7.15 %).Order of theoretical density, experimental density and void fraction of different specimens of composite.

Egf-1 < Egf-2 < Egf-3

Egfp-1 < Egfp-2 < Egfp-3

Fig. 4.1 to fig. 4.3 gives the variation of experimental density, theoretical density and void fraction. The theoretical density, experimental density and void fraction of new material increases with increases of wt % of fiber in composite and the theoretical and experimental density of particulate filled specimen are higher as compared to without filled specimens on same fiber loading. This may be due to present of higher air content with addition of mustard cake powder filler in epoxy resin the volume fraction of void is increased.

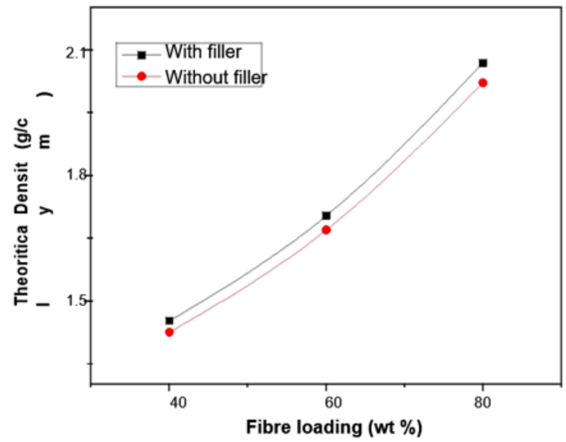


Fig. 4.1 variation of experimental density with fiber loading

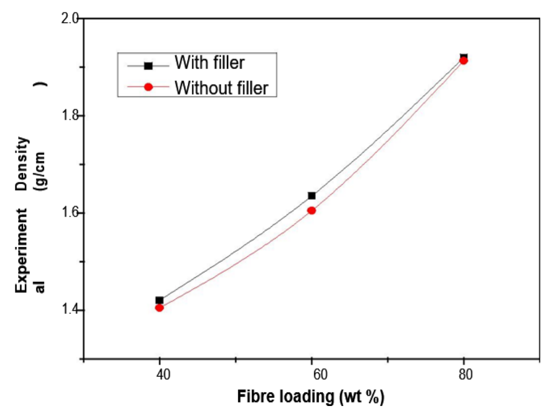


Fig. 4.2 variation of theoretical density with fiber loading

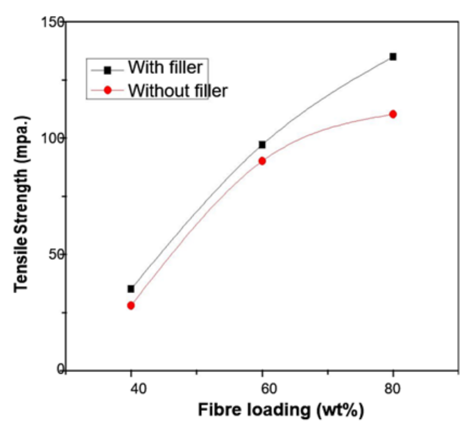


Fig. 4.3 variation of void fraction with fiber loading.

4.2.2 Mechanical Characteristics of Composites

The characterization of composites reveals that the glass fiber reinforced epoxy composites (with & without filler) with different fiber

Table 4.2 mechanical properties of composites with different fiber loading.

| Composite (Mpa) | Strength (Mpa) | Flexural (Mpa) | Inter Laminar Shear Strength (Mpa) |
|---|---|---|---|
| Egf-1 | 28.058 | 163.264 | 13.56 |
| Egf-2 | 90.106 | 173.715 | 16.5 |
| Egf-3 | 110.24 | 191.46 | 18.51 |
| Egfp-1 | 35.2 | 250.20 | 14.7 |
| Egfp-2 | 97.170 | 312.28 | 18.57 |
| Egfp-3 | 134.963 | 538.310 | 20.81 |

4.2.3 Effect of Fiber Loading On Tensile Strength of Composites

The variation of tensile strength of both filled and unfilled composites with different fiber loading under this investigation is presented in fig. 4.4. It can be seen that the tensile strength of mustard cake powder filled glass-epoxy composites is more as compared to glass fiber reinforced epoxy composites. Similar observations have been found by mahapatra et al [33] and findik et al [34] increasing trend in tensile strength of glass fiber reinforced epoxy composites without filler with increasing fiber loading. This increment may be due to more wt % of fiber are the load carrying member in the fiber reinforced polymer composites. There can be two reasons for this increment of the tensile property of composites. One possibility is that the good compatibility of bi-directional glass fiber and epoxy resin. Another possibility is that the chemical reaction at the interface between the filler particles and the matrix is too strong to transfer the tensile load.

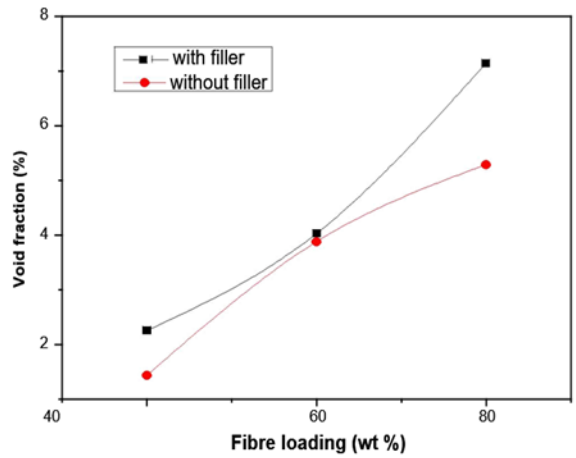


Fig. 4.4 variation of tensile strength of composites with fiber loading.

4.2.4 Effect of Fiber Loading On Flexural Strength of Composites

Composite materials used in structure are prone to fail in bending and therefore development of new composites with improved flexural characteristics is essential. It clearly indicates that inclusion of glass fiber improves the load bearing capacity and ability to withstand bending of the composites. The flexural strength of efgp is more superior as compared to egf. But flexural strength of both specimens in increasing orders. Maximum flexural strength obtained at 80 wt % of glass fiber with 10% epoxy and 10% filler (egfp-3). This may be again due to the good chemical reaction at the interface between the filler particles and matrix

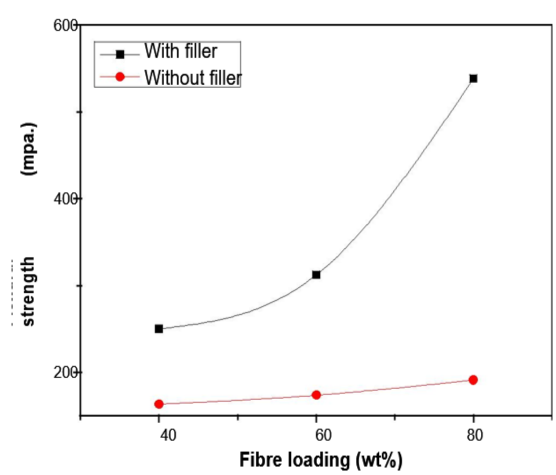


Fig. 4.5 variation of flexural strength of composites with fiber loading.

4.2.5 Effect of Fiber Loading On Inter Laminar Shear Strength of Composites

The stress between the consecutive lamina of layered composite is called inter laminar shear stress. The result on inter laminar shear strength of the glass-epoxy composite (with & without fillers) are presented in table 4.2. In the present work short beam shear test is carried out on the composites with different fiber loading to determine the ilss (interlaminar shear strength). The ilss of composites is gradually increases with increase of wt % of bidirectional glass fiber. Similar observation has been reported by alok sathapay et al [35] in case of jute fiber epoxy composites. The ilss on 40 wt % of glass fiber with and without filler epoxy composites is measured as 14.7 mpa and 13.56 mpa and at 80 wt % is measured as 20.81 mpa and 18.51 mpa, this may be due to better compatibility between glass fiber and epoxy matrix and also due to better chemical reaction between fillers and matrix.

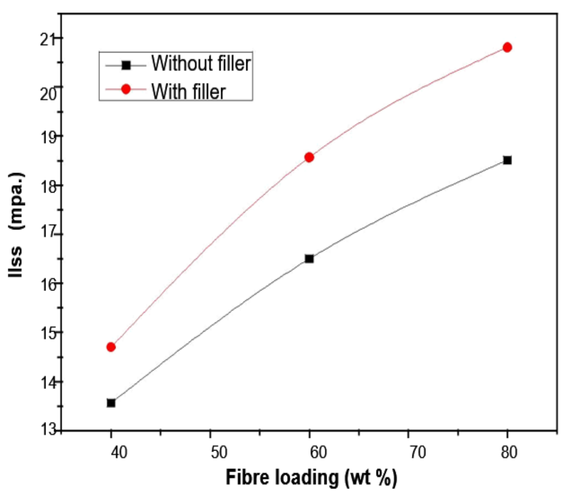


Fig. 4.6 variation of inter laminar shear strength with fiber loading

4.3 Wear Behaviour of Composites

4.3.1 Study of Dry Sliding Wear Behaviour

The sliding distance is constant at 4500m and the applied loads are 5n, 10n, 15n and 20n. It is seen that specific wear rate is decrease with increasing fiber loading. At 80 wt % of glass fiber reinforced epoxy composites with filler and 20 n loads applied give better wear resistance as compared to other composites. It is also noted that wear rate is high for 20 wt % of glass Fiber epoxy composite at 5n.

Table 4.3 specific wear rate of composites (under dry sliding condition)

| Load (N) | Normal Specific wear rate ( mm3/N-m) x 10-6 | | | | | |
|---|---|---|---|---|---|---|
| | Egf-1 | Egf-2 | Egf-3 | Egf p-1 | Egf p-2 | Egf p-3 |
| 5 | 6.93 14 | 5.46 46 | 5.40 53 | 5.43 43 | 5.30 22 | 5.73 79 |
| 10 | 5.94 14 | 4.60 72 | 4.30 39 | 4.88 9 | 4.65 65 | 4.53 09 |
| 15 | 3.66 57 | 3.34 34 | 3.59 37 | 3.20 21 | 3.32 33 | 3.17 67 |
| 20 | 2.25 31 | 1.44 56 | 1.40 4 | 1.54 56 | 1.12 54 | 1.03 69 |

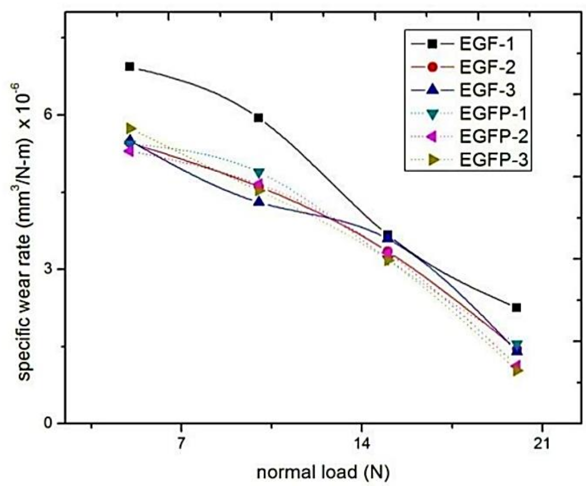


Fig. 4.7 variation of specific wear rate with normal load (dry sliding)

4.3.2 Study Of Dry Sand Abrasion Wear

Each standard test was conducted for 2000 m of sliding distance and 2.39 m/s of sliding Velocity. Fig 4.8 shows the variation of specific wearer steady rate w state conditions for bidirectional e-glass fibere poxy reinforced composites withand Without filler. It is observed that at load (5n) and (40 wt %) of glass fiber in composites (without filler) exhibit highest wear rate. At load (20n) and (80 wt %) of bi-directional glass fiber in composites (with filler) exhibit lowest wear rate.

For 5n

Egfp-1 < egf-3 < egfp-1< egfp-3 < egf-2 < egf-1

For 10n

Egf-3 egfp≤-3 < egf-2 < egfp-1 < egfp-2 < egf-1

For 15n
Egfp-3 < egfp-1 < egf-1 < egfp-2 < egf-2 < egf-3
For 20n
Egfp-3< egfp-2 < egf-3 < egfp-1 < egf-2 < egf-1
Egf-1 composite sample exhibit highest wear rate because at this loading there are less fibers to support the epoxy matrix and therefore abrasive particle create large depth grooves and serves as cutting mode of abrasive wear. Egf-3 composite sample exhibits lower wear rate as compared to other composites without filler because at high fiber loading there is comparatively good adhesion between the fiber and matrix moreover with simultaneous occurrence of different orientation of the fiber surface seems to lead to a synergetic behavior that is wear protective performance. Similar observation was found by siddhartha et al [36]. Samples with filler addition shows lowest wear rate as compared to composites without filler this can be attributed to the fact that filler particles, due to their flaccid nature, acts as barrier between the sand particles and matrix thus reduces the wear rate.

Table 4.4 specific wear rate of composites (under dry sand abrasion condition)

| Normal Load (n) | Specific wear rate ( mm3/n-m) x 10-3 | | | | | |
|---|---|---|---|---|---|---|
| | Egf-1 | Egf-2 | Egf-3 | Egfp-1 | Egfp-2 | Egfp-3 |
| 5 | 6.3914 | 5.9875 | 5.6403 | 5.6549 | 5.3045 | 5.9739 |
| 10 | 5.1494 | 4.807 | 4.3863 | 4.845 | 4.8481 | 4.5208 |
| 15 | 3.2862 | 3.487 | 3.5937 | 3.2711 | 3.3272 | 3.1875 |
| 20 | 2.153 | 1.6043 | 1.439 | 1.6003 | 1.292 | 1.0369 |

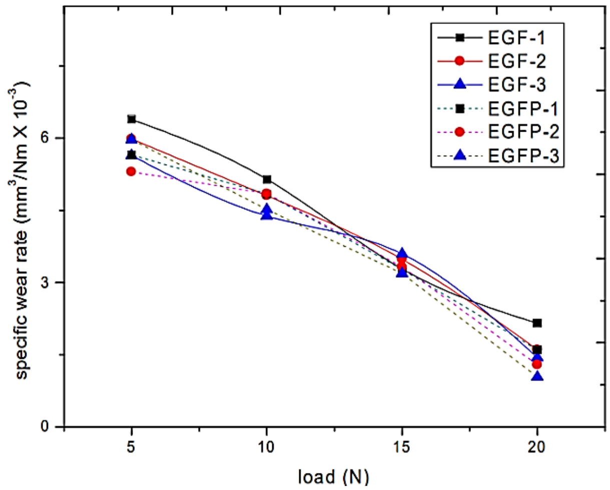

Fig. 4.8 variation of specific wear rate with normal load (dry sand abrasion)

## V. CONCLUSION

This experimental investigation of mechanical and tribological behavior of glass fiber based epoxy hybrid composites leads to the following conclusion:

- This work shows that successful fabrication of a glass fiber reinforced epoxy matrix composite with different fiber loading and mustard cake fillers has been done by simple hand-lay-up technique.
- The physical properties like void fraction and density of glass fiber based epoxy hybrid composites have been studied. The density and void fraction of filled composites is increased as compared to unfilled composites. This may be due to present of high air content in the reinforcement.
- It has been noticed that the mechanical properties of the composites such as tensile strength, inter laminar shear strength and flexural strength of the composite also greatly influenced by the fiber loading and fillers.
- The present investigations revealed that 80wt% fiber loading shows superior tensile strength, flexural and inter laminar shear strength. As far as inclusion of mustard cake powder filler (10wt%) in the glass fiber based epoxy composite, the mechanical properties are found superior as compared to unfilled composites. This may be due to better chemical strength between matrix and filler particles.
- The abrasive and sliding wear performance of glass-epoxy composites improve with incorporation of particulate fillers. Among the four

weight percent of glass fiber in the composites, 80 wt % glass fiber mustard cake filled composites has shown maximum wear resistance. This is again due to good chemical bonding between filler and matrix and better compatibility between glass fiber and matrix.

5.1 Scope of Future Work

- This investigation leaves wide scope for future study. It can be extended to newer composites using other reinforcing phases and the resulting experimental findings can be similarly analyzed.
- Different types of polymer matrix and filler can be tried.
- Remaining mechanical properties like charpy impact test and hardness test are to be conducted for evaluating the mechanical properties of the composites.
- The work should be extended to study other properties composites such as dielectric strength, chemical resistance and thermal conductivity.

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