EXPERIMENTAL INVESTIGATION OF MECHANICAL BEHAVIOUR OF GLASS-EPOXY COMPOSITES

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ABSTRACT

This paper reports on the manufacturing of the glass fibre reinforced epoxy composite laminate as per the ASTM (American Society for Testing and Materials) Standards. This laminate consists of matrix and reinforcement. Epoxy is used as a structural matrix material which is then reinforced by glass fiber, combining glass fibres with resin matrix results in composites that are strong, lightweight, corrosion-resistant and dimensionally stable. They also provide good design flexibility, high dielectric strength and act as inflammable materials. Their tremendous strength-to-weight and design flexibility make them ideal in structural components for the aerospace industry.
In this paper the glass fibre reinforced epoxy composite is manufactured into six different parts each having ratios of glass fibre to epoxy resin as 0:100, 20:80, 40:60, 60:40, 80:20, 100:0 respectively and are compared for ultimate tensile strength, impact strength and flexural strength of the material by conducting experiment such as tensile test, flexural test and impact test.
KEY WORDS: *frp composites, glass fibre, tensile strength*

INTRODUCTION

Historically, technical developments have centered around two main areas, firstly the development of more powerful and efficiently energy sources and secondly to obtain maximum possible motive power from the available energy. The second development is heavily dependent on the properties of engineering materials. In aircraft and aerospace industries, a union of opposites i.e., lightweight in combination with high stiffness is demanded. In pressure vessels technology, high strength and corrosion resistance are both prerequisites for efficient operation. Whenever, a designer faces such situations composite materials provide an efficient solution to such problems. The flexibility that can be achieved with composite materials is immense. Merely by changing the composition variety of properties can be altered thus making the composites versatile and reliable substitutes for the conventional structural materials.

1.1 COMPOSITES

A composite material is a combination of at least two chemically distinct materials with a distinct interface separating the components. The two phases that make up a composite are

MATRIX
REINFORCEMENT

The matrix is the less strong phase being strengthened by the stronger reinforcing phase. Reinforcements can have carious geometries like particles, fibers, flakes etc. The reinforcement basically enhances the flexural strength.

A composite material is considered to be any multiphase material that exhibits a combination of properties that makes the composite superior to each of the components phases. In microscopic composites the dispersed phase is of microscopic dimensions. Structural details are accessible by means of micrographic examinations in contrast the dispersed phase for macroscopic composites is much larger examples are sand & gravel in concrete.

2. METHODOLOGY

2.1. MANUFACTURING PROCESS OF THE COMPOSITE LAMINATE

2.1.1. MATERIALS REQUIRED

The different materials and components required for this manufacturing process of glass epoxy composite are as below.

SL. No	Materials	Quantity
	Glass fiber (mat form)	500 gm.
	Glass fiber (cloth form)	500gm.
	Epoxy resin LY-556	2 lit.
	Hardener HY-556	250 ml
	Poly Vinyl Alcohol	500 ml
	Glass mould (160x160x3) mm	10
	Plain Glass (200x200x3) mm	10
	Wax polish	50gm
	OHP sheets	50
	Measuring jar	2
	Stirring rod	2
	Gloves	4
	Knife	2
	Hot air oven	1
	Weighing instrument	1
	Bricks	30
	Scissors	2

Table 2.1 Required materials for manufacturing.

2.1.2. GLASS FIBRE:

Bundle of glass fiber is material made from extremely fine fibers of glass. It is used as a reinforcing agent for many polymer products; the resulting composite material, properly known as fiber-reinforced polymer (FRP) or glass-reinforced plastic (GRP), is called "fiberglass" in popular usage. Glassmakers throughout history have experimented with glass fibers, but mass manufacture of fiberglass was only made possible with the invention of finer machine tooling, What is commonly known as "fiberglass" today, however, was invented in 1938 by Russell Games Slayter of Owens-Corning as a material to be used as insulation. It is marketed under the trade name Fiberglass, which has become a generalized trademark. A somewhat similar, but more expensive technology used for applications requiring very high strength and low weight is the use of carbon fiber.

Fiberglass is a lightweight, extremely strong, and robust material. Although strength properties are somewhat lower than carbon fiber and it is less stiff, the material is typically far less brittle, and the raw materials are much less expensive. Its bulk strength and weight properties are also very favorable when compared to metals, and it can be easily formed using molding processes. The plastic matrix may be epoxy, a thermosetting plastic (most often polyester or vinyl ester) or thermoplastic.

Common uses of fiberglass include boats, automobiles, baths, hot tubs, water tanks, roofing, pipes, cladding, casts and external door skins.

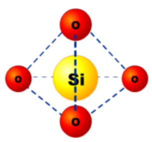


Fig 2.1 Molecular Structure of Glass

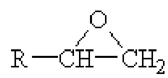
2.1.3. MATERIAL PROPERTIES OF GLASS FIBRE:

SL. No	Parameter	Value
1.	Specific density	1850 kg/m^3

2.	Rockwell hardness	110 M scale
3.	Bond strength	>1000 kg
4.	Flexural strength	>345 MPa
5.	Tensile strength	>310 Mpa
6.	Impact strength	>44 Nm/m
7.	Compressive strength	>415 MPa
8.	Dielectric strength	20 kV/mm
9.	Permittivity	4.8
10.	Dissipation factor	0.017
11.	Young's modulus	3.5x10^6 psi
12.	Poisson's ratio	0.136

Table: 2.2 Properties of glass fiber

2.1.4. EPOXY RESIN:



Epoxy resin is defined as a molecule containing more than one epoxide groups. The epoxide group also termed as, oxirane or ethoxyline group. These resins are thermosetting polymers and are used as adhesives, high performance coatings and plotting and encapsulating materials. These resins have excellent electrical properties, low shrinkage, good adhesion to many metals and resistance to moisture, thermal and mechanical shock. Viscosity, epoxide equivalent weight and molecular weight are the important properties of epoxy resins.

Fig 2.2 Molecular Structure of epoxy resin

2.1.5. MATERIAL PROPERTIES OF EPOXY RESIN:

SL. No	Parameter	Value
1.	Specific gravity	155 kg/m^3
2.	Rockwell hardness	80 M scale
3.	Elastic modulus	2415 MPa
4.	Flexural strength	>120 MPa
5.	Tensile strength	>90 Mpa
6.	Impact strength	>20 Nm/m
7.	Compressive strength	>173 MPa
8.	Dielectric strength	300 V/mil
9.	Thermal conductivity	0.188 $w/m^{-0}c$
10.	Dissipation factor	0.017
11.	Elongation at break	3-9 %
12.	Poisson's ratio	0.145

Table 2.3 Properties of epoxy resin

2.1.6. DETERMINATION OF REQUIRED EPOXY RESIN AND GLASS FIBER:

Generally for measuring the required amount of materials for manufacturing composite laminate, we require an electronic weighing machine which measures exactly in grams. In this project we are using five different ratios of glass fiber to epoxy resin.

SL. No	Ratio of Glass fiber	Ratio of Epoxy resin
1	0 %	100 %
2	20 %	80 %
3	40 %	60 %

4	60 %	40 %
5	80 %	20 %
6	100 %	0 %

Table 2.4 Ratios of glass fiber to epoxy resin

For determining the exact weight of the material, we need to find out the density of the glass fiber. Density formulae can be given as

$d = \frac{m}{v}$

Where

d = density

m = mass

v = volume

Density = 1.45 g/cm^3

Volume of the glass fiber = 160x160x3 mm

= 16x16x0.3 cm

= 76.8 cm^3

Mass = (density) x (volume)

= 1.45 x 76.8

=111.36 g

This means for every 100% of glass fiber composite material, we require 111.36 grams of glass fiber. Now we require only 20% of glass composite hence the weight will be reduced to 22.24 grams. Similarly for 40% of glass composite the weight of glass fiber will be 44.48 grams. Similarly for 60% of glass composite the weight of glass fiber will be 66.64 grams. Similarly for 80% of glass composite the weight of glass fiber will be 88.86 grams. Similarly when we consider epoxy resin we require binder solution to fasten the adhesiveness of the epoxy. We consider 500 ml for every 100% of epoxy. Similarly for 20% of composite we consider 100 ml of epoxy. . Similarly for 40% of composite we consider 200 ml of epoxy. . Similarly for 60% of composite we consider 300 ml of epoxy. And for 80% of composite, we consider 400 ml of epoxy resin. We should be adding 10ml of araldite binder solution for every 100ml of epoxy resin.

After calculating the weights of required material, we need to cut the glass fiber in the dimension 160x160 mm according to ASTM standards.

2.1.7. ESTIMATION OF WEIGHTS:

Material	**Quantity**	
Composite ratio	**Glass fiber (gm.)**	**Epoxy (ml)**
100% pure epoxy	0	500
20% glass fiber, 80% pure epoxy	22.24	400
40% glass fiber, 60% pure epoxy	44.48	300
60% glass fiber, 40% pure epoxy	66.64	200
80% glass fiber, 20% pure epoxy	88.86	100

Table 2.5 Estimation of weights

3. PREPARATION OF MOULD:

For making the test specimen different sample plates were prepared for tensile test and density, of the glass mould of dimensions 200 x 200 x 3mm thick plates were cut and a mould cavity of 160 x 160 x 3mm is made by fixing 3mm thick glass plates of width 20mm and thickness 3mm on four sides of the plate using araldite. The mould was cured in the furnace at temperature of 50^{0}C for about 5 hours and for making sample plates in each test.

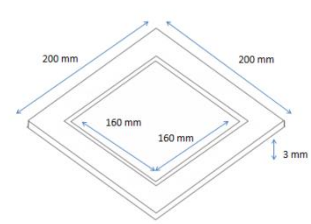


Fig: 3.1 Glass mould to prepare composite material

Fig 3.2. Cutting of glass fiber

Fig 3.3. Electronic weighing machine.

3.1. CUTTING OF GLASS FIBRE

Glass fiber must be cut into several layers each of dimension 160x160 so that it will exactly fit into the glass mould. Normal scissors can be used to cut the glass fiber. And the weight can be measured by electronic weighing machine.

3.2. PREPARING THE MOULD

Fig 3.4.Applying PVA to the mould

Before the final lay-up of composite material, the glass mould must be kept in oven for 30 minutes at 50^0 c. After that the glass mould must be removed and wax must be applied. Wax must be applied uniformly all over the mould and the wax must be applied thoroughly along the four edges. Wax helps in easy removal of composite material and prevents it from sticking to the mould. After applying the wax, Poly vinyl alcohol (PVA) must be spread all over the mould. PVA Release Agents are a liquid solution of polyvinyl alcohol resin in a mixture of water and industrial methylated spirits sometimes including small quantities of dye and/or matting agent dependent upon the grade. Available in clear or blue and both glossy and matt versions. They have been developed to give best results if spray applied but glossy versions can also be applied by sponge or soft brush. PVA Release Agents can be applied over waxed or polish but the wax polish must be silicone free. Soluble in water therefore can be washed off moulds and mouldings with water even when dried. Matt versions are especially useful when producing low gloss finished mouldings.

After applying PVA, the glass mould must be kept in oven for 60 minutes at a temperature of 85^0

Fig 3.5. Placing moulds inside an oven

Fig 3.6.Hot air oven

Hot air ovens are electrical devices used in sterilization. The oven uses dry heat to sterilize articles. Generally, they can be operated from 50 to 300 °C (122 to 572 °F). There is a thermostat controlling the temperature. These are digitally controlled to maintain the temperature.

Their double walled insulation keeps the heat in and conserves energy, the inner layer being a poor conductor and outer layer being metallic. There is also an air filled space in between to aid insulation. An air circulating fan helps in uniform distribution of the heat. These are fitted with the adjustable wire mesh plated trays or aluminum trays and may have an on/off rocker switch, as well as indicators and controls for temperature and holding time. The capacities of these ovens vary. Power supply needs vary from country to country, depending on the voltage and frequency (hertz) used.

3.3. STAGES IN MANUFACTURING:

The different stages encountered during the process of manufacturing are

LIQUID STAGE:

This is stage resembling a jelly. The surface should not touch during this stage. This stage is also known as green stage. This gelation time at 50^0C for the resin chosen varies from 45 to 55 min. Pure epoxy is laid on the glass mould and layers of glass fibre are added. This process is continued till the composite height reaches 3mm.

Fig 3.7. Epoxy

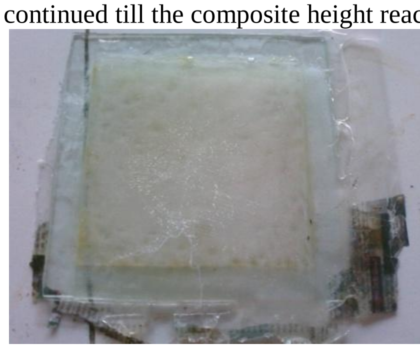


Fig 3.8.Glass fibre

SETTING STAGE:

This is stage in which resin resembles hard cheese and it breaks up when pressed by hand. Employing a long pointed nail can check this stage. When without excessive pressure the resin breaks up or indents the resin is set but not cured. We need to check the surface of the glass mould for any trapped air bubbles inside the epoxy layer. If found any, we must remove that trapped air bubble by placing OHP sheet on the mould and pushing the surface of the sheet from one side, Thus by leveling the epoxy layer inside the mould. Later plane glass should be placed on the mould and weights are added on the mould for setting. Usually it takes 24 to 36 hours for a mould to set completely. Weights added are 4 clay bricks each weighing 3 kilograms. A total weight of 12 kilograms is placed on the mould.

Fig 3.9. Setting stage

Fig 3.10. Weights on mould

3.5.1.CURED STAGE:

An Advanced set stage when surface of moulding is hard is known as the cured stage. In this stage the moulding can be removed from the mould. Mould is broken by using hammer and the composite material is separated from the mould.

Fig 3.11 Breaking the mould

Fig 3.12. Removing the mould

FINAL CURED STAGE:

This is a stage at which the best physical properties of any moulding are developed. Once the material is formed, it is kept in oven for about 4 hours under the temperature of 100^0 c. This stage can be recognized by knocking the mould on the floor. If a metallic sound is heard the final cured stage has been attained. The material formed is ready to be tested.

Fig 3.13.Glass epoxy laminate.

TESTING OF SPECIMEN

Specimen used for testing should be cut into three different shapes for three different tests. For tensile test it should be in dimension of 120x25x3 mm. For Impact test it should be in dimension of 100x20x3 mm. For Flexural test it should be in dimension of 100x25x3 mm.

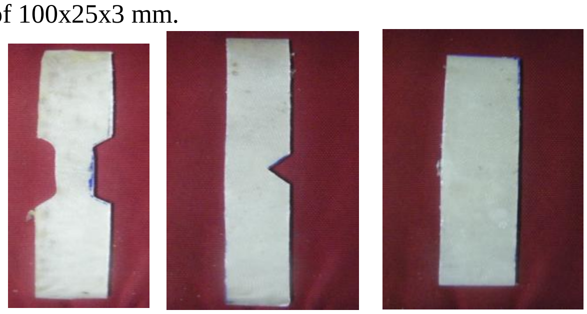


Fig: 3.14. Specimen for Tensile, Impact, Flexural tests

TENSILE TEST

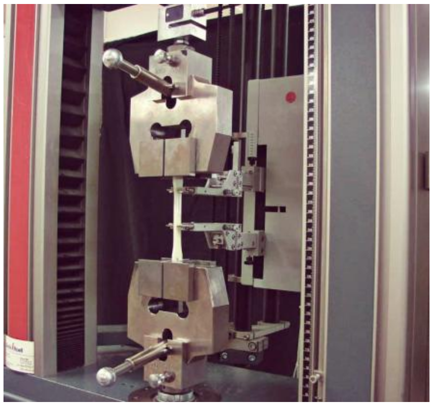


Fig 3.15. Tensile Testing Machine

Tensile testing is a fundamental materials science test in which a sample is subjected to uniaxial tension until failure. The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under other types of forces. Properties that are directly measured via a tensile test are ultimate tensile strength, maximum elongation and reduction in area. The test process involves placing the test specimen in the testing machine and applying tension to it until it fractures. During the application of tension, the elongation of the gauge section is recorded against the applied force. The data is manipulated so that it is not specific to the geometry of the test sample. The elongation measurement is used to calculate the engineering strain, ε, using the following equation

$$€ = \frac{\Delta L}{L_0} = \frac{L - L_0}{L_0}$$

Where ΔL is the change in gauge length, L_0 is the initial gauge length, and L is the final length.

3.6.1. IZOD IMPACT TEST

Impact test was performed to evaluate the impact strength. A specimen of rectangular shape with standard specification was cut from the composite plate readymade.

Fig 3.16. Izod impact testing machine

The load at break was noted from the scale after failure. The same procedure was repeated for other specimens cut from the same composite plate. Later, the average load at the break was noted and impact strength was calculated on the basis of the following formula.

$$\text{Impact Strength} = \frac{\text{Average load break (j)}}{\text{Width of specimen (m)}}$$

FLEXURAL TEST ON SIMPLY SUPPORTED BEAM:

Flexural strength was determined using three point simply supported bending equipment attached with precision dial gauge and digital load indicator.

Fig 3.17. Flexural testing machine.

The test was repeated in the descending order and the average deflection was noted. The stiffness and Flexural Strength were calculated by the formula shown below.

Stiffness = $\frac{\text{Weight (kg)}}{\text{Deflection (mm)}}$ Flexural Strength = $\frac{3PL}{2bd2}$

Where: P= Load applied (kgs)

L= Span length of beam (mm)

b= Width of Specimen

d= Depth (Thickness of specimen)

Where: b and d are the width and thickness of the test specimen in mm respectively.

4. RESULTS AND DISCUSSIONS

4.1 TENSILE TEST

The tensile strength for the composite material with different blending compositions of epoxy resin and glass fibers are presented in table 6.1 tensile strength was calculated using the equation,

S = $\frac{F}{A}$

Where,

S= the breaking strength (stress)

F= the force applied that caused the failure

A= the least cross-sectional area of the material.

% WEIGHT FRACTION OF COMPOSITES		TENSILE STRENGTH (N/mm^2)
GLASS	EPOXY	
0	100	22.03
20	80	83.54
40	60	95.65
60	40	110.35
80	20	135.01
100	0	146.35

Table 4.1 Tensile test

4.2 IMPACT TEST

The impact load at break for a composite with different blending compositions of epoxy resin and glass fibers are presented in table 6.2 the impact strength was calculated using the equation. Izod impact test is conducted on the composite materials and the impact strength on the composite material is calculated.

$$\text{Impact Strength} = \frac{\text{Impact energy (J)}}{\text{Width of specimen (m)}}$$

% WEIGHT FRACTION OF COMPOSITES		IMPACT STRENGTH (J/m)
GLASS	EPOXY	
0	100	46.38
20	80	165.04
40	60	220.35
60	40	300.14
80	20	401.43
100	0	526.99

Table 4.2 Impact test

4.3 FLEXURAL TEST

The flexural load at break for a composite with different blending compositions of epoxy resin and glass fibers are presented in table 6.3 the flexural strength was calculated using the equation.

$$\text{Flexural Strength} = \frac{3PL}{2bd^2}$$

Where: P= Load applied (kgs)

L= Span length of beam (mm)

b= Width of Specimen

d= Depth (Thickness of specimen)

Where: b and d are the width and thickness of the test specimen in mm respectively.

% WEIGHT FRACTION OF COMPOSITES		FLEXURAL STRENGTH (MPa)
GLASS	EPOXY	
0	100	16.12
20	80	60.13
40	60	76.13
60	40	82.45
80	20	96.15
100	0	116.40

Table 4.3 Flexural test.

5. CONCLUSIONS

From Tensile strength table we conclude that the composite material shows higher tensile strength with the percentage increase in glass fibre. The material with low percentage of glass fibre and high percentage of epoxy has less tensile strength. And the material with high percentage of glass fibre and low percentage of epoxy has high tensile strength.

From impact test table we conclude that the composite material with the higher percentage of glass fiber shows high impact strength. The material with low percentage of glass fibre and high percentage of epoxy has less impact strength. And the material with high percentage of glass fibre and low percentage of epoxy has high impact strength.

From flexural test table we conclude that the composite material with the higher percentage of glass fiber shows high flexural strength. The material with low percentage of glass fibre and high percentage of epoxy has less flexural strength. And the material with high percentage of glass fibre and low percentage of epoxy has high flexural strength.

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