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Flexure and bonding behaviour of glass fiber reinforced epoxy resin composite beam under two point loading mechanism.

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Abstract: *Glass Fiber – reinforced polymer (GFPR) has been used as an alternative to steel due to high strength –to-weight ratio, high stiffness- to – weight ratio and corrosion and fatigue resistance.GFRP have been found to be more attractive in asian region due to their cost competitiveness. Hence effort is required to find the bonding and flexural behaviors of fiber reinforced composite(FRC) beam made using epoxy resin and glass fiber sheet with Triethylenetetramine (TETA) as hardener for curing of resin. To achieve the objective, an experimental setup was prepared with, specimen of hollow square section is casted and two point loading was applied to specimen. This will help in finding the elastic nature of the section.*
Keywords: *GFRP,Epoxy Resin,Glass Fiber,TETA*

I. Introduction

Composite materials are materials with two or more constituents combined to form a material with different properties than those of the individual constituents. Fiber reinforced composites (FRC) is a composite material that consists of two constituents: a series of fibers surrounded by a solid matrix. FRC is high-performance fiber composite achieved by cross-linking fiber molecules with resins in the FRC material matrix through a proprietary molecular re-engineering process, yielding a product of exceptional structural properties. As with many other composite materials such as reinforced concrete, the two materials act together, each overcoming the deficits of the other. Whereas the plastic resins are strong in compressive loading and relatively weak in tensile strength, the fibers are very strong in tension but tend not to resist compression. By combining these two materials, FRC becomes a material that resists both compressive and tensile forces well.

Objective

The main objective is to study the numerical and experimental Behavior of hollow square FRC beam under flexure. It also enables us to study the strength capacity of the FRCbeam.

II. Components Of Frc

A. FIBER

Fiber is a natural or synthetic substance that is significantly longer than its width. The strongest engineering materials often incorporate carbon fibers, for example fiber and ultra-high-molecular-weight polyethylene. Synthetic fibers are often being produced very cheaply and in large amounts compared to natural fibers. There are two major types of Fiber such as natural and man-made fibers. Here, we go for man-made fiber. Each fiber has its own property. Table-1 shows the some of the man-made fibers with their properties. A Fabric is defined as a manufactured assembly of fibers to produce a flat sheet of one or more layers of fibers. These layers are held together either by mechanical interlocking of fibers themselves or with a secondary material to bind these fibers together. Based on the orientation of the fibers used, and by the various construction methods used to hold the fibers together fabrics are categorized into Unidirectional Fabric, Woven Fabrics, Hybrid Fabrics, Multiaxial Fabrics.

Table-1 Types and Properties of fiber

Fibers	Properties
Glass Fibers	Strength, Elasticity, heat resistance, Moisture resistance, Chemical resistance, Thermal conductivity, Electrical properties, High strength, Lightweight
Wood Fibers	Flexural strength, Tensile modulus, Tensile Strength
Carbon and Aramid Fibers	High stiffness to weight ratio, High strength, Corrosion resistant, Fatigue resistant, Energy Absorption on Impact, Tailored material properties

B. RESIN

The resins that are used in fiber reinforced composites can also be referred to as 'polymers'. All polymers exhibit an important common property that they are composed of long chain-like molecules consisting of many simple repeating units. Man-made polymers are generally called synthetic resins that act as bonding agent and also transfers stress between reinforcing fibers and to protect them from mechanical and environmental damage. Polymers can be classified into thermoplastic and thermosetting resin, according to the effect of heat on their properties. A thermosetting plastic, also known as a thermoset polymer material that irreversibly cures by heat, generally above 200°C (392 °F), through a chemical reaction, or suitable irradiation. Thermoset materials are usually liquid or malleable prior to curing and designed to be moulded into their final form, or used as adhesives. Once hardened a thermoset resin cannot be reheated and melted to be shaped differently. A thermoplastic or thermo softening plastic is a polymer with high molecular weight that becomes pliable above a specific temperature, and returns to a solid state upon cooling. The polymer chains associate through intermolecular forces, which permits thermoplastics to be remoulded. Few resins and their properties are tabulated in Table-2

From the review of literature, it is found that the type and orientation of Fibers, type of resin affects the strength of FRC material. Strength of FRC section also depends on its Structural shape, where previous literatures are available for Box and I-sections. Here Hollow square beam sections are focused. Selection of correct combination of resin and fibers will be a challenge. Here we use Epoxy resin and Glass fibers as it is considered to be stronger than other combinations as well as Economic.

Table-2 Properties and Application of resins

Resins	Application	Properties
Polyester	Transportation and marine	Excellent resistance to water and acidic environments
Vinyl ester	Corrosion application such as tanks, pipes and ducts	Resistance to Aggressive environments
Phenolic resins	Mass Transit - Fire Resistance & High Temperature	Low flammability, low smoke production
Epoxy resins	FRC Strengthening Systems, FRC Rebar, FRC Stay-in-Place Forms	excellent electrical insulation, are less affected by water and heat, low shrinkage, high strength, low toxicity

III. Material Collection And Testing

C. EPOXY RESIN

Epoxy resins are low molecular weight pre-polymers or higher molecular weight polymers which normally contain at least two epoxide groups. The epoxide group is also sometimes referred to as a glycidyl or oxirane group. Epoxy resins may react (cross-linked) either with themselves through catalytic homo polymerization, or with a wide range of co-reactants including poly functional amines, acids (and acid anhydrides), phenols, alcohols and thiols. These co-reactants are often referred to as hardeners or curatives, and the cross-linking reaction is commonly referred to as curing. Reaction of polyepoxides with themselves or with poly functional hardeners forms a thermosetting polymer, often with high mechanical properties, temperature and chemical resistance. Testing and results of epoxy resin are given below in table -3.

Table-3 Chemical Properties of Resin

S.no.	Tests performed	Test method	Specification	Results
1.	Visual appearance	In house	Clear liquid resin	Clear liquid resin
2.	Color Index, Gardner	ISO-4630-2	0 - 1	0.1
3.	Epoxide index (Eq/Kg)	ISO-3001	5.3 – 5.45	5.43
4.	Viscosity dynamic at 250C , mPa.s	ISO- 12058	10000 – 12000	10250
5.	Chlorine content (hydrolysable), ppm	AMTM 116	0.0 – 400	240

D. HARDENER

Hardeners are substances that are used for the setting/Curing of the resins. The chemical hardener used here is “Triethylenetetramine”. It is primarily used as a cross linker in Epoxy curing. Triethylenetetramine abbreviated TETA and trien, is an organic compound with the formula [CH2NHCH2CH2NH2]2.It is soluble in polar solvents and exhibits the reactivity typical for amines. For FRC using epoxy resin, the mix proportion is 150 grams of hardener is mixed with 1000 grams of Epoxy resin as per company recommendation. Tests and results of TETA are given in table-4.

Table-4 Chemical Properties of Hardener

S.no	Tests parameter	Test method	Specification	Results
1.	Appearance	Visual	Colorless to pale yellow liquid without impurities	OK
2.	Color index ALPHA	ISO- 6271-1	0-50	
3.	Viscosity dynamic at 250C , mPa.s	ISO- 12058-1	10-20	14
4.	Moisture content. %	ISO- 760	0-0.5	0.3

E. GLASS FIBER

Glass Fibers are among the most versatile industrial materials known today. Fiberglass is much more sustainable than Aluminium, steel or timber. There are no large smoke plumes or other forms of environmental pollution from the manufacture of fiberglass. They exhibit useful properties such as hardness, transparency, resistance to chemical attack, stability, and inertness, as well as desirable fiber properties such as strength, flexibility, and stiffness. This acts as the reinforcing material in FRC. Glass reinforcements used for fiberglass are supplied in different physical forms such as microspheres, chopped or woven and reinforcing bars which are given in Fig-1. Glass fibers are categorized into Low-cost General-Purpose fibers and Premium special-Purpose fibers. Over 90% of all glass fibers are general-purpose products.

Fig-1 Forms of Fiber Reinforcement

IV. Specimen Casting And Analysis

A. FRC HAND LAY-UP PROCESS

A release agent, either in wax or liquid form, is applied to the chosen mould. This will allow the finished product to be removed cleanly from the mould. Resin is mixed with its hardener and applied to the surface. Sheets of fiber matting are laid into the mould, then more resin mixture is added using a brush or roller. The material must conform to the mould, and air should not be trapped between the fiber and the mould. Additional resin is applied and possibly additional sheets of fiber. Hand pressure, vacuum or rollers are used to make sure the resin saturates and fully wets all layers, and any air pockets are removed. The work must be done quickly enough to complete the job before the resin starts to cure, unless high temperature resins are used which will not cure until the part is warmed in an oven. In some cases, the work is covered with plastic sheets and vacuum is drawn on the work to remove air bubbles and press the FRC to the shape of the mould. The process is explained in Fig-2.

B. CASTING PROCEDURE

Mould is prepared according to the dimensions mentioned in table-5. The casting is done by Hand Lay-up Process which is the most common and easy method. A chemical resistant film coating is given along the surface of the mould to ease up the releasing process once the specimen is cured. The resin and hardener is mixed together according to the mix proportion as per the manufacturer's recommendations. Then a thin coat of the resin mixture is applied over the mould which is shown in Fig-3. Once the layer starts to harden, then the glass fiber sheet is placed over it and again the resin is applied on it by a paint brush or a roller as shown below in Fig-4. This process will continue in a cyclic manner until the desired thickness has been achieved. 16 coats of fiber and resin is coated to get an effective thickness of 15mm. Only 4mm were fabricated per day as the chemical reactions are exothermic and would release enormous amount of heat during the curing process. It took a total of 4 days to complete the casting and curing of the specimen.

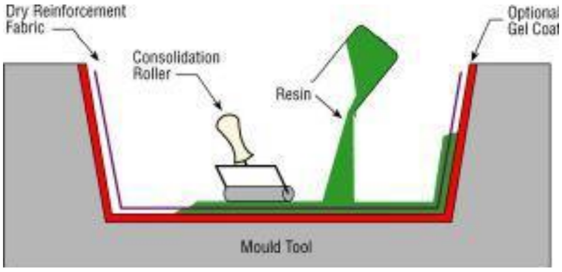

Fig-2 Hand lay-up process

Table-5 dimensions and properties of specimen

Prop erty	Dimension
Shape	Hollow square section.
Side	100mm x 100mm
Length	1000mm
Thickness	15mm
Support condition	1 end is hinged, other end is roller supported
Young's modulus	39 GP

Fig-3 Casting of specimen

Fig-4 Casting of Specimen-FRC layers

C. THEORETICAL ANALYSIS

The beam is theoretically analyzed by the following formula.

$\Delta = (Pa/24EI)(3l2\text{-}4a2)$

Where the deflection result are tabulated in Table-6

Table-6 theoretical result

Load	Deflection (mm)
10	1.159
15	1.739
20	2.319
25	2.89
30	3.47
35	4.05
40	4.639
45	5.21
50	5.79
55	6.379
60	6.95
65	7.539
70	8.119
145	16.81

D. EXPERIMENTAL ANALYSIS

The section was analyzed using loading frame Capacity of 50 tonne. The experimental setup is shown below in Fig-5. A two point loading was applied to the specimen at a distance of 250mm from both ends. The values for loads and deflection are tabulated in table-7 below.

Table-7 Experimental result

Load	Deflection (mm)
10	0.7
15	1.1
20	1.95
25	2.55
30	3.40
35	4.10
40	5.70
45	6.40
50	7.20
55	8.30
60	8.90
65	8.2
70	9.70
145	12.3

V. Results And Discussion

The summary of theoretical and experimental study results of our specimen is discussed in this paper. In the experimental study, the column will be able to withstand loads around 1500kN, but due to practical difficulty the experiment was stopped at 540kN, as the loading frame was limited to 50 tonnes. The load deflection curve is shown below in fig-6 and fig-7.

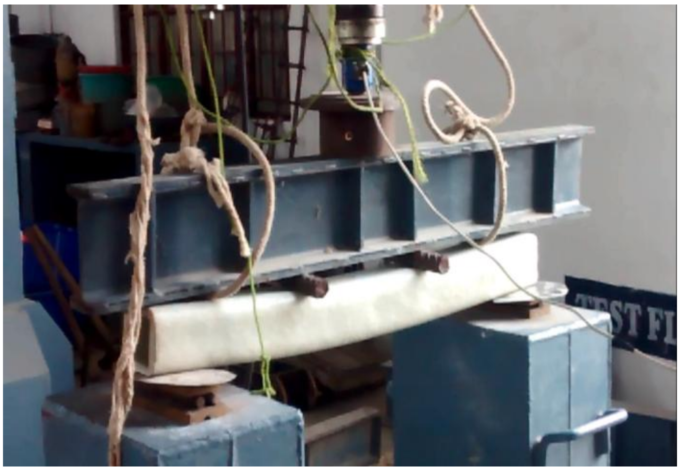

Fig-5 loading setup-deflection mode

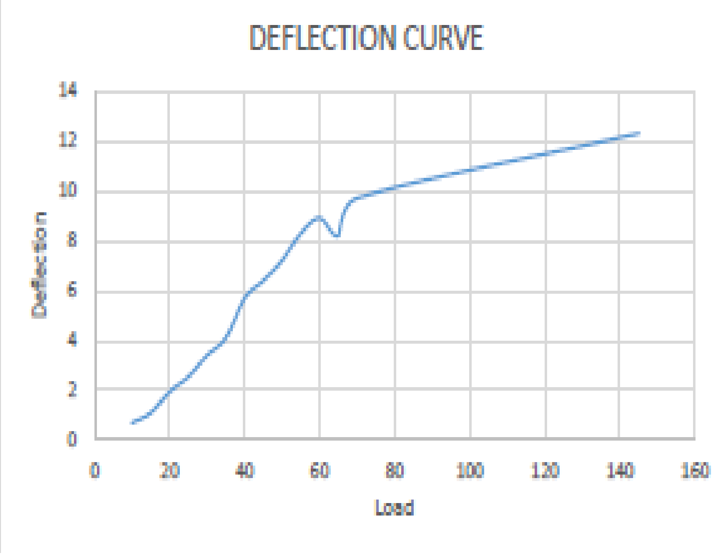

Fig-6 Load vs deflection curve for experimental analysis

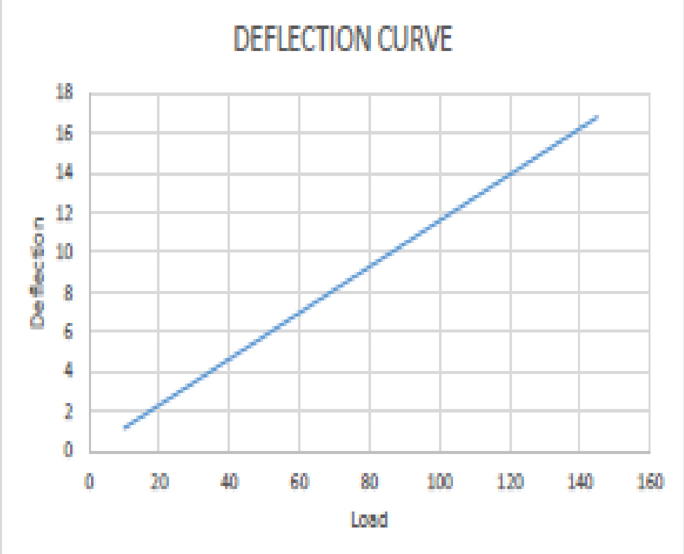

Fig-7 Load vs deflection curve for theoretical analysis

VI. Conclusion

Our FRC Beam is tested experimentally and theoretically, which gives more over similar results. So we convince with our result that our FRC Beam can carry more weight with good elastic nature and restore to its original position when the load is removed. The FRC is also weightless in nature which makes it easier for transportation and hoisting. It is also resistant against corrosion. With these many advantages, FRC can be used at places where conventional steel or concrete cannot be used.

VII. Frc- Limitations

A. Warping

One notable feature of FRC is that the resins used are subject to contraction during the curing process. For polyester this contraction is often of the order of 5-6%, and for epoxy it can be much lower, about 2%.
When formed as part of FRC, because the fibers don't contract, the differential can create changes in the shape of the part during cure. Distortions will usually appear hours, days or weeks after the resin has set.

B. Health Problems

Inhaling these fibers can reduce lung function and cause inflammation in animals and humans. FRC can cause skin, eye and throat irritation. At higher exposure levels, FRC also has been associated with skin rashes and difficulty in breathing.

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