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# Experimental Study on Behaviour of Retrofitted GFRP Wrapped Beams

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**Abstract**
The recent environmental deterioration and decrease in natural resources, urges the need to increase the life of the existing structures. The study on various methods of rehabilitation techniques, methods of its application, its behaviour after rehabilitation over concrete structures is being carried out in a wide spread manner. In the recent years, the use of Glass fibre wrapping over the structural members seems to be the most competitive method for all the structural elements like column as well as beams. This Fibre Reinforced Polymers (FRP) wrapping increases the confinement there by the acts as an outer strengthening layer to the structural elements. This study focuses on the laboratory analysis of Concrete beam strengthened with various types of FRP and it applications at various places to increase the flexural as well as the shear strength of the beam subjected to static loading.

## Introduction
Rehabilitating a structural member is a huge task, which requires a wide knowledge about the causes of failure of structures. Even though there are various rehabilitation techniques available, the most popular among the field is being the external bonding techniques. This technique not only seems to be used in the places of repairing and restoration but also widely applied for strengthening of the structural members.

The traditional way of retrofitting a concrete structural member is by means of shortening the span, section enlargement and external bonding of steel plates. Although these methods proved to increase the strength and the stiffness of the structure, it has the following disadvantages of increase of self weight, susceptible to corrosion and difficult to install.

Recent development in the field of composite materials like Fibre reinforced polymer (FRP) with its high specific tensile strength, corrosion resistance and ease to work becomes an attractive alternative to the traditional materials used. In this research paper, the performance of various glass fibre reinforced polymer (GFRP) wrapped in various pattern, for retrofitting the structural beam for flexure and shear are studied.

## Experimental Program
The types of fibre used in this study are, Woven type (Woven Roving Mat fibre) and the Non woven type (Chopped strand mat fibre). These mats are glued to the partially failed beam elements using epoxy resin in various layers and zone to enhance the flexure as well as the shear strength of the beam.

## Material details
### Concrete
Cement used in the present investigation was of 43 Grade and fineness of 5% with standard consistency of 29%. The specific gravity of the cement used was found to be 3.15. The coarse aggregate used in the present study was of size 20mm and fineness modulus of 7.3. The specific gravity and water absorption of the coarse aggregate were found to be 2.6 and 0.50% respectively. The fine aggregate used in the present study was passing through 4.75mm sieve with fineness modulus of 3.5 and specific gravity of 2.6. The water absorption of the fine aggregates were found as 1.0%

### Steel
High yield strength deformed bars of 12mm diameter and 6mm diameter are used for longitudinal and lateral reinforcement respectively.

## Properties of the Glass Fibre used for Retrofitting
### Composition
E-Glass is a low alkali glass with a typical nominal composition of $SiO_2$ 54 %, $Al_2O_3$ 14 %, CaO + MgO 22%, $B_2O_3$ 10 % and $Na_2O$ + $K_2O$ less than 2 % by weight. Some other materials may also be present at impurity levels.

### Key Properties
Properties that have made E-glass so popular in fibre glass and other glass fibre reinforced composite include:
- Low cost
- High production rates
- High strength
- High stiffness
- Relatively low density
- Non-flammable
- Resistant to heat
- Good chemical resistance
- Relatively insensitive to moisture
- Able to maintain strength properties over a wide range of conditions
- Good electrical insulation

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Table - 01 Comparison of typical properties for some common fibres

| Materials | Density ($g/cm^3$) | Tensile Strength (MPa) | Young's Modulus (GPa) |
|---|---|---|---|
| E-Glass | 2.55 | 2000 | 80 |
| S-Glass | 2.49 | 4750 | 89 |
| Alumina | 3.28 | 1950 | 297 |
| Carbon | 2.00 | 2900 | 525 |
| Kevlar 29 | 1.44 | 2860 | 64 |
| Kevlar 49 | 1.44 | 3750 | 136 |

The advantageous properties of E-glass generally outweigh the disadvantages which include:

- Low modulus
- Self abrasiveness if not treated appropriately leading to reduced strength
- Relatively low fatigue resistance
- Higher density compared to carbon fibres and organic fibres.

## Binder Used
The binder used in the present study comprises of resin, accelerator and catalyst. Accelerator and catalyst are added to the resin in calculated quantities in order to increase the binding strength of the resin.

## Concrete Mix Design
The properties of the materials are determined by the laboratory tests and Design mix for grade M25 is adopted for all the specimens. The mix proportion arrived is 1:1.3:2.6 with a water cement ratio of 0.53.

## Details of the beam specimen
The size of the beam specimen used for the study is 1400mm x 100mm x 170mm.

The beam is designed as a balanced section with Main Reinforcement of 2 numbers of 12mm diameter at top and bottom. The shear reinforcements consist of 2 legged 6mm diameter spaced at 100 mm centre to centre.

## Casting of test specimens
Eight numbers of concrete beams were cast in the laboratory and kept under 28 days curing. Out of the eight beams cast, one is kept as a control beams while the others are subjected to initial crack loading as that of the control specimen and confined with FRP wrapping. The beams are wrapped with Woven and chopped mat at the bottom face alone and at bottom and shear face in single and double layers.

## Test setup
The test specimens were subjected to middle third load to achieve pure bending at centre of the span. The load is applied through the hydraulic jack and the value of load applied is measured with the help of proving ring. The deflection at the centre of the test specimen is measured with the help of LVDT (Linear Variable Displacement Transducers). Test set up kept for the experimental study is shown in fig - 01.

## Experimental Study
The control beam is subjected to gradual static load until it reaches the ultimate failure. The deflection at ultimate load is noted down and the load at which the initial crack arrived is also noted. The initial crack appeared at about 60% of the ultimate load.

The other test specimens are subjected to initial crack load arrived from the control specimen and then rehabilitated with FRP wrapping specimen. The types of wrapping adopted are,

1. Woven Mat at bottom alone single layer (WB1)
2. Woven Mat at bottom alone double layer (WB2)
3. Woven Mat at bottom and sides all-round in shear zone single layer (WBS1)
4. Chopped Mat at bottom alone single layer (CB1)
5. Chopped mat at bottom alone double layer (CB2)
6. Chopped Mat at bottom and sides all-round in shear zone single layer (CBS1)
7. Chopped Mat at bottom and sides all-round in shear zone double layer (CBS2)

Fig-01 Test Set-up

## Results and Discussion
The ultimate load carrying capacities of various types of rehabilitated beams along with their maximum deflection are given in table 1. The ultimate load carrying capacity of various beams is shown in Fig 1. The load Vs Deflection Curve for various types of FRP wrapped beams are shown in Fig 2.

Table-01 Ultimate load capacity of beams

| TYPE OF SPECIMEN | AVERAGE ULTIMATE LOAD IN KN | MAXIMUM DEFLECTION IN MM |
|---|---|---|
| Control specimen | 65.00 | 3.356 |
| WB1 | 65.00 | 1.370 |
| WB2 | 85.00 | 1.232 |
| WBS1 | 66.50 | 1.239 |
| CB1 | 65.00 | 2.370 |
| CB2 | 84.00 | 3.519 |
| CBS1 | 70.00 | 1.239 |
| CBS2 | 80.00 | 1.567 |

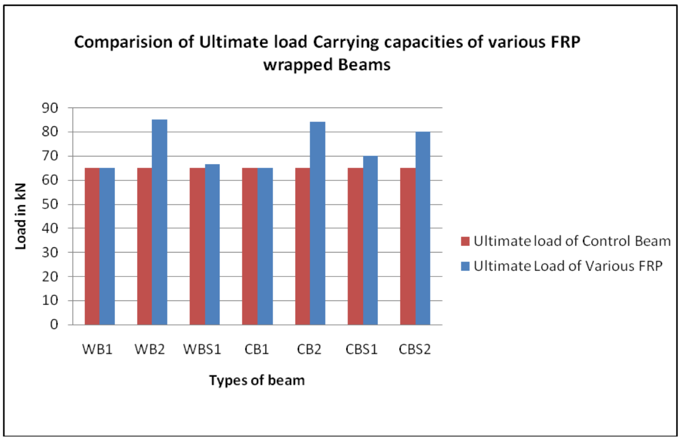


Fig-02 Ultimate Load Carrying Capacity of Various FRP wrapped Beams

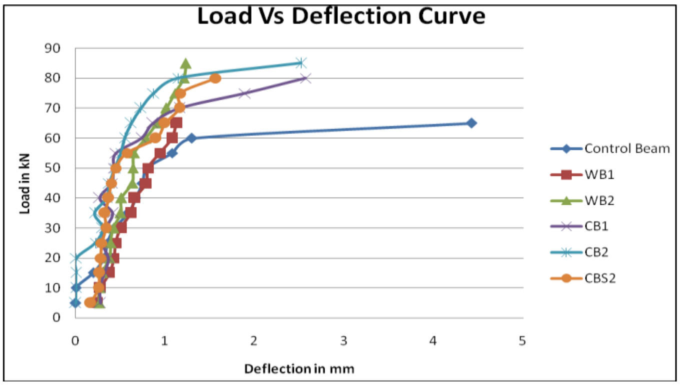


Fig-03 Load Vs Deflection curves

## Conclusion

Based on the experimental results of the study, the FRP confined or rehabilitated beams are found to show the increased load carrying capacity as well as it increases the stiffness of the beam by reducing the deflection in the beam.

The beam wrapped with double layers of both woven as well as Chopped strand mat found to behave well when it is bonded in bottom face alone. They increased the load carrying capacity of the beam by 30 percent than the control beam. The deflection is reduced by 4 times that of the control beam. The mode of failure in control beam is crushing failure in compression zone where as in FRP confined beams it is the peeling failure (delamination) of the FRP confinement.

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