Experimental Study On Flexural Behaviour Of Beams Reinforced With GFRP Rebars

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Abstract. In saline, moisture and cold conditions corrosion of steel is inevitable and the lot of economy is used for rehabilitation works. Corrosion of steel is nothing but oxidation of iron in moisture conditions and this corrosion leads to the spalling of concrete which intern reduces the strength of the structure. To reduce this corrosion effects, new materials with resistance against corrosion have to be introduced. Many experiments are going on using Glass Fiber Reinforced Polymer (GFRP) as alternate material for steel due to its non-corrosive nature, weight of GFRP is nearly one third of steel and ultimate tensile strength is higher than steel. In this paper, six beams are casted in which three beams are casted with steel as main and shear reinforcement and another three beams are casted with GFRP as main reinforcement with steel as shear reinforcing material. All beams casted are of same dimensions with variation in reinforcement percentage. The size of the beams casted is of length 1200 mm, breadth 100 mm and depth 200 mm. The clear cover of 25 mm is provided on top and bottom of the beam. Beams are tested under two-point loading with constant aspect ratio (a/d) and comparing the flexural strength, load deflection curves and types of failures of beams reinforced with GFRP as main reinforcement and beams reinforced with conventional steel. The final experimental results are compared with numerical results. M30 grade concrete with Conplast as a superplasticizer is used for casting beams.

Key words: GFRP bars, aspect ratio, flexural strength and superplasticizer.

1. Introduction
Corrosion is one of the main problem for the steel reinforced concrete structures in moisture conditions. The steel in concrete structures corrode due to the carbonation of metal. Generally cement is very high alkaline in nature and when react with water forms hydrated calcium silicates (CSH) and calcium hydroxide. All these elements are very high alkaline in nature in fresh concrete and in ages this alkalinity is neutralized by reaction of lime with atmospheric carbon dioxide and pH value of concrete comes below 10 and corrosion starts in steel. To overcome this corrosion new material has to be introduced. Fiber Reinforced Polymer FRP materials are getting more popular due to its high strength and non-corrosive nature. There are different types of FRP in which Glass Fiber Reinforced Polymer (GFRP), Carbon Fiber Reinforced Polymer (CFRP) and Basalt Fiber Reinforced Polymer (BFRP) are more popular. In this project GFRP is adopted as reinforcing material. GFRP is popular not only for its non-corrosive property but also for its light weight, nonmagnetic and high strength properties. Manufacturing of GFRP bars are simple and it requires bonding material to hold fibers together. Manufacturing of GFRP rods is quite simple than that of Steel production, GFRP production
Process involves pultrusion process. The roving’s of GFRP fiber is given a resin bath and sent in to a mould of required thickness. The fibers are treated under 160 degrees Celsius in mould and rod is constantly pulled out from mould with constant rate. These rods are kept under 140 degrees Celsius as a part of post curing process [1]. In different types of FRPs, GFRP is most economical material with less tensile strength value. Main variables that influence the flexure behavior of GFRP reinforced beams are low modulus of elasticity and rupture strain [2]. In a balanced reinforced section the tensile reinforcement reaches its ultimate strength when compression concrete reaches its maximum strain i.e. 0.0003 (ACI 2003). Using of GFRP rods as main reinforcement had reduced the ultimate load of 23% for beam prototype and failure of beam is under flexure. Replacing GFRP as main and shear reinforcement showed the reduction of 33% in ultimate load and beam showed shear failure [3]. GFRP reinforced beams fails mainly due to bond failure between GFRP rods and concrete, reduced post cracking stiffness [4]. Effect of GFRP reinforcement in transverse direction shows significant change in shear strength of beam. There is no significant increase in strength of beam with increase in concrete strength. Mode of failure changes with change in ratio of longitudinal reinforcement [5]. In direct pull out test between GFRP and concrete shows failure of GFRP rod layers and increase in diameter of bar decrease in bond strength [6]. GFRP reinforced slabs shows more deflection and more number of cracks when compared with steel reinforced concrete [7]. Concrete beams reinforced with GFRP bars shows higher strain, deflection values. Behavior of stress strain curve is linear before crack and after crack beam behaves linearly with reduced stiffness [8]. Increase in a/d ratio decreases the ultimate load carrying capacity and stirrups in GFRP reinforcement shows higher strain than in steel reinforced beams [9].

3. Experimental Program
The experimental program consists of preparing and testing of six prototype beams under two point loading system. Beams are casted with M30 grade concrete, the grade of concrete is finalized after few trail mixes and the ratio is 1:1.67:2.54. Three beams casted with GFRP reinforcement with ratios 1%, 1.5%, and 2.5% along with corresponding control beams are casted with steel as main reinforcement providing same reinforcement ratios. The width, depth and length of the beam were 100 mm, 200 mm and 1200 mm respectively. All the beams were casted and cured for 28 days.

4. Material Properties
The properties of the materials used in experimental program is illustrated below
4.1 Cement
OPC 53 grade cement of locally available NAGARJUNA cement satisfying IS 12269:1987 [10] is used, which comprises of good quality. Chemical configuration of cement is given in Table 1.

4.2 Fine Aggregate For fine aggregates, uncrushed and naturally available local river sand of maximum size 4.75 mm with a fineness modulus of 3.35 and specific gravity of 2.65 using IS 2386 (Part III):1963[11] was used.

| Description | Composition |
|-------------|-------------|
| Physical Properties | |
| Color | Grey |
| Specific gravity | 3.15 |
| Specific surface area (cm$^2$/g) | 3540 |
| Standard consistency (%) | 29 % |
| Final setting time | 175 minutes |
| Initial setting time | 33 minutes |
| Chemical Composition | |
| CaO (%) | 61.3 |
| SiO2 (%) | 19.8 |
| Al2O3 (%) | 5.3 |
| Fe2O3 (%) | 4.01 |
| MgO (%) | 2.85 |
| Na2O (%) | 0.13 |
| K2O (%) | 61.96 |

4.3 Coarse Aggregate
The coarse aggregates size used for casting ranges between 12.5 mm to 20 mm of specific gravity 2.74 using IS 2386(Part III):1963[11]. Specifically, the mixture having 70% of 20 mm and 30% of 12.5 mm by weight is used. The preliminary test results are shown in Table 2.

| Property | Fine aggregate | Coarse aggregate |
|----------|----------------|------------------|
|          | 20mm down | 10mm down |
| Fineness modulus | 3.35 | 7.56 | 3.20 |
| Specific gravity | 2.65 | 2.74 | 2.69 |
| Water absorption (%) | 1.20 | 1.83 | 1.35 |
| Bulk density | 1753 | 1741 | 1711 |
4.4 Chemical Admixture
CONPLAST is used as chemical admixture complies with IS: 9103:1999 [12] and having a specific gravity of one was used as a high range water reducing agent, 0.5% of cement is added to concrete to increase workability and strength.

4.5 Water
Ordinary Potable tap water was used for mixing and curing.

4.6 Reinforcement
Steel bars of Fe500 grade and sand coated GFRP bars were used for main reinforcement. Yield tensile stress, young modulus and yield strain of steel bars tested in Universal Testing Machine (UTM) were 512 MPa, 210 GPa, and 0.0028 respectively. As for the steel used in shear reinforcement, the values were found to be 164 GPa, 433MPa and 0.0028 as the modulus, yield stress and yield strain respectively. The tensile yield strength of GFRP bar obtained is 617 N/mm$^2$ and the young’s modulus is 45 N/mm$^2$. Sand coating is done to increase the bond strength between GFRP and concrete. The physical properties of reinforcement used in the experiment is detailed in the Table 3.

Table 3 Physical properties of steel and GFRP

| S. No | Description          | Value        |
|-------|----------------------|--------------|
|       |                      | GFRP         | Steel        |
| 1     | Density              | 2100 kg/m$^3$| 7850 kg/m$^3$|
| 2     | Young’s modulus      | 41 GPa       | 210 GPa      |
| 3     | Thermal coefficient  | $6 \times 10^{-6}$/°c | $12 \times 10^{-6}$/°c |
| 4     | Poisson’s ratio      | 0.2          | 0.3          |
| 5     | Shear modulus        | 12 GPa       | 81 GPa       |
5. Concrete

5.1 Mix Proportions
Mix design of concrete was done by using IS 10262-2009 and IS 456-2000. Concrete grade for M30 is prepared and the ratio by weights is obtained as 1:1.87:2.43, superplasticizer as water reducing agent is added and detailed proportion is given in Table 4.

| MATERIAL       | WEIGHT in kg/m³ |
|----------------|-----------------|
| Cement         | 380             |
| Fine aggregate | 710.6           |
| Coarse aggregate | 965            |
| Water cement ratio | 0.42      |
| Superplasticizer | 0.5% by weight of cement |

5.2 Specimen Casting and Testing
150 mm cubes and 150 mm diameter with 300 mm height cylinders were casted and found the average compressive strength and split tensile strength after 28 days of curing and is given in Table 5

| Description | Compressive strength | Tensile strength |
|-------------|----------------------|------------------|
| With admixture | 34.63 MPa           | 3.45 MPa         |
| Without admixture | 30.52 MPa           | 2.82 MPa         |

6. TEST MATRIX AND SPECIMEN PREPARATION
In total 6 prototype beams were casted with same dimensions of width 100 mm, depth 200 mm and length 1200 mm. Longitudinal reinforcement bars used are of three different diameters i.e. 10, 12 and 16 mm. Anchorage reinforcement used is of 8 mm in diameter and shear reinforcement used is 6 mm diameter bars with uniform spacing of 100 mm. Concrete with water reducing chemical admixture is used for casting beam prototypes. Based on type of longitudinal reinforcement provided beams are divided in two groups and identity is given to each beam based on reinforcement percentage. Group S consist of beams reinforced with steel and Group G consists of beams reinforced with GFRP as main reinforcement.
Table 6 Test matrix

| Group | Specimen ID | Longitudinal reinforcement | Reinforcement (%) |
|-------|-------------|-----------------------------|-------------------|
| S     | M30-S1      | Steel                       | 1                 |
|       | M30-S2      | Steel                       | 1.5               |
|       | M30-S3      | Steel                       | 2.5               |
| G     | M30-G1      | GFRP                        | 1                 |
|       | M30-G2      | GFRP                        | 1.5               |
|       | M30-G3      | GFRP                        | 2.5               |

7. TEST SETUP

Two point Load is applied on prototype using single point loading unit from which load is distributed equally for both points. LVDT are placed in bottom face at mid-section and one third of beam length to note the deflection. The first crack load and crack pattern is noted on both sides of beam at regular intervals. Gauge length between load points is 300 mm and the constant aspect ratio of 150 mm is provided. All specimens are tested under same setup conditions and load applied on beam at a constant rate of 10 kN/min in 1000 kN load cell. Automatic data acquisition technique is used to record the load and deflections.

8. Results and Discussion

8.1 Ultimate Load Carrying Capacity

The ultimate load carrying capacity is the load at the failure of the specimen. The values obtained from the two point loading bending test for different specimen reinforced with GFRP and steel reinforcement is given in the table 7 and we can clearly observe the increase in the ultimate load value for M30 G1 than M30-S1.

Table 7 Ultimate loads for Beams

| SL.No. | Reinforcement Ratio | Ultimate Load (kN) | Steel | GFRP |
|--------|---------------------|--------------------|-------|------|
| 1      | 1                   | 88.5               | 126   |      |
| 2      | 1.5                 | 124.3              | 74.80 |      |
| 3      | 2.5                 | 162.9              | 48    |      |
8.2 Load Vs Deflection Behavior

The Load Vs Deflection behavior for different percentages is shown in Figures 4. It is clearly shown that M30-G1 beam takes maximum load than M30-S1 beam and steel reinforced beams take maximum load than GFRP reinforced beam. The deflections for GFRP reinforced beams are similar to their corresponding control beams.

8.3 Stiffness

M30-S1 shows more stiffness than M30-G1, it shows that the GFRP reinforced beams under goes more deflection for small loads. The initial stiffness for M30-G1 and G2 beams is higher than M30G1 and nearly equal to M30-S2 and S3 respectively. Stiffness for beams with steel shear reinforcement is more and with the increase in shear reinforcement will increase stiffness. The load vs stiffness graphs for beams are compared and shown in figure 5.
Figure 5 Stiffness

8.4 Crack Pattern

a) Increase in reinforcement ratio in controlled specimen changes the crack pattern from flexural failure to pure shear failure and GFRP reinforced beams has local and pure shear cracks. The behavior of crack failure for beams are mentioned in Table 8
Table 8 Modes of Failure of Beams

| Sl.No | Reinforcement Ratio | Modes of failure of beams reinforced with STEEL | GFRP |
|-------|----------------------|-----------------------------------------------|------|
| 1     | 1 %                  | Flexure                                       | Flexure with web shear cracks |
| 2     | 1.5 %                | Flexure with prolonged shear cracks           | Flexure |
| 3     | 2.5 %                | Pure shear                                    | Flexure with brittle behavior |

b) The spacing between cracks is less in GFRP reinforced beams and width of cracks is more. The crack pattern for the beams are shown schematically in figure 6.

c) The crack to crack spacing in GFRP reinforced beams are less and number of cracks is more. This is due to the lesser modulus of elasticity of GFRP rods.

d) The crack behavior of GFRP reinforced beam with 2.5% of reinforcement is very similar to the over reinforced flexure member.

Figure 6 Crack Patterns
9. Conclusion

1) Experimental results obtained for conventional beams are satisfied with theoretical values from IS 456-2000 but GFRP reinforced beams with 1.5% and 2.5% reinforcement disagrees with IS 456-2000.

2) With the increase in percentage of steel reinforcement there is an increase in peak load value and with increase in GFRP percentage there is decrease in peak load value.

3) The failure of GFRP reinforced beams shows that with increase in the percentage of reinforcement concrete reaches its ultimate stress first and beams fails under flexure (which is similar to a over reinforced section).

4) The peak load value for M30-G1 is 36% more than M30-S1, M30-G2 is 39% less than M30-S2.

5) The initial stiffness for GFRP beams is very high when compared with corresponding steel reinforced beams but increase in load stiffness for GFRP beams reduced.

6) Number of cracks is more in GFRP reinforced beams than steel reinforced beams for same reinforcement percentage.

7) The decrease in load value with increase in GFRP reinforcement is due to the bond failure bond slip between GFRP bars and concrete.

8) Modes of failure for GFRP reinforced beams is due to pure and local flexure but in steel reinforced beams failure changes from flexure to shear with increase in reinforcement percentage.

9) The load between first crack and ultimate load is very less in GFRP reinforced beams but in steel reinforced beams takes more load between first crack and ultimate load.

Acknowledgement

The authors would like to thank to the authorities of SASTRA University, Thanjavur, for providing laboratory facilities and administrative assistance to perform the present research work in the School of Civil Engineering.

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