Studies on Flexural Behaviour of Concrete Beams Reinforced with Basalt Rebars

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Abstract. The use of reinforcement of Fibre- Reinforced Polymer (FRP) in concrete structures has increased rapidly in the last 25 years due to its excellent corrosion resistance, fire resistance, high alkali resistance, high tensile strength to weight ratio, durability, flexural strength, insulation, good fatigue properties and magnetic transparency properties. Basalt concrete reinforcement bars called Basalt Fiber Reinforced Polymer (BFRP) are a new material, so it is important to define the mechanical properties and drawback of their use in the concrete structures in comparison to conventional reinforced concrete members.

In this study Flexural behaviour of concrete beams reinforced with basalt rebars will be tested and compared with the Flexural strength obtained from experimental result with RC Beams and ACI-440 codal provision. It has been shown that much lower cross-sectional stiffness of the BFRP basalt bars produces higher deflections and crack widths compared to the steel bars beams of the same cross-section. Comparisons between the flexural strength obtained from the ACI-440 codal provision and that experimentally values in the current investigation elsewhere indicates disagreement.

1. Introduction

The use of fibre reinforced polymer (FRP) reinforcement in concrete structures has rapidly increased because of excellent corrosion resistance, high strength to weight ratio and good non-magnetizing properties. As a result it can have many applications in structures used in marine environments, in chemical plants, in temporary structures. Bridge decks, floor slabs and wall type structures are examples of such structural components. However, the reinforced concrete members of the FRP behave differently from those reinforced with steel due to the linear elastic stress-strength relationship of the FRP bars to rupture. In addition, the low elasticity modulus of the FRP induces a significant decrease in the flexural stiffness of the reinforced concrete members of the FRP after cracking. Due to their mechanical characteristics, deflections and cracking in FRP RC beams are greater than those seen in conventional RC members. As a result, the construction of reinforced concrete FRP members is often controlled by the serviceability limit rule. Therefore, the use of reinforcement of the FRP requires a better understanding of the behaviour of reinforced concrete FRP members. [1].

Basalt bars are the latest type of FRP reinforcement used in civil engineering. The mechanical characteristics of basalt bars are identical to those of glass, so it can be assumed that BFRP and GFRP RC members can be designed in accordance with the same design rules. However, BFRP bar...
is a relatively new material, the most attractive feature of BFRP is its integrated properties that are superior to traditional FRP composite, including its strength being 20% higher and modulus, comparable cost, and higher chemical stability relative to GFRP, a wider range of working temperatures and a significantly lower cost than CFRP. While BFRP has competitive characteristics compared to conventional materials. Therefore, the actions of BFRP RC members should still be thoroughly analysed [2].

The objective of this study is to test the mechanical characteristics of BFRP bars as well as the flexural behaviour of concrete beams reinforced with basalt rebars and comparing with the Flexural strength obtained from experimental result with the ACI-440 codal provisions.

2. Experimental program

2.1. Objectives

Objectives of the experimental investigation are as follows:

- To study the Mechanical characteristics of BFRP bars and compare with Steel bars.
- To calculate the Flexural strength of Concrete beams reinforced with Basalt rebars for different grades of concrete viz. M20, M40, M60 and M80 with a constant reinforcement of 0.243% and compare with beams reinforced with Steel by experimentally
- To compare the Flexural strength obtained experimentally with ACI-440 codal provisions.

2.2. Materials used

The materials used in this experiment were cement, fly ash, fine aggregate, coarse aggregate, water, BFRP bar and Steel bar. Cement of OPC of 43 and 53 grade will be used. The chemical composition of fly ash is as SiO₂-51.12%, Al₂O₃-29.53%, Fe₂O₃-5.57%, CaO-2.99%, K₂O-2.38%, SO₃-1.34%, MgO-1.03%, Na₂O-0.5%, BaO-0.06%, Others-2.42% and Loss of ignition-3.06%. Fineness modulus of sand 2.74 was used as fine aggregate and coarse aggregate was 20 mm size crushed stone and fineness modulus of 6.55.

2.3. BFRP and steel bars characteristics

The reinforcement materials used in the beam was BFRP and steel bars. The diameter of the BFRP bars was 8 and 10 mm shown in Fig. 2.1. It was supplied by Nickunj Eximp Enterprise Privet Limited. According to the manufacturer the properties BFRP rebar are listed in Table 1. The characteristics of BFRP and steel bars of all beams are tested in Universal Testing Machine but it was failed in slip of BFRP bar shown in Fig. 2.2.

2.4. Mix proportion of concrete

All the beams were made of M20, M40, M60 and M80 concrete grade. The mix proportion presented in Table 2.

2.5. Testing program

In the experimental work the Flexural behaviour of M20, M40, M60 and M80 mix design will be analyzed. The mix is designed by using IS 10262-2009. The cubes of size 150 mm × 150 mm × 150 mm for this mix design will be cast to analyze the compressive strength for 7 and 28 days respectively.

Eight slender beams size of 230mm X 300mm X 1200mm with shear span to depth ratio of 1.85 ( a / d = 500/ 270 ) and effective length to effective depth ratio 3.70 ( l / d = 1000/270 ) are will be cast by providing constant Flexural reinforcement ratio ( 0.243% ) with different grade like M20,M40,M60 and M80. The Flexural behaviour is tested in 500kN capacity displacement controlled actuator under three point loading as shown in Fig.3.5. A linear deflection transducers (LVDT) is used at centre-span section to measure the displacement during the test. The load is
applied through a 500 kN servo controlled actuator. A data acquisition system is employed for measuring the displacements. Table 3 Shown Designation of four RC beams and Table 4 Shown Designation of four BFRP beams along with characteristics of main bar and concrete. Fig. 2.3 shows reinforcement details of SB2, BB2, SB6, BB6, SB8 and BB8. Fig. 2.4 shows reinforcement details of SB4 and BB4.

Table 1. Mechanical characteristics of BFRP and Steel bar.

| Sl. No | Bar of Diameter | Weight/m (gm) | Young’s modulus (GPa) | Yield stress (Mpa) | Ultimate stress (Mpa) | Breaking stress (Mpa) |
|--------|-----------------|---------------|-----------------------|--------------------|-----------------------|-----------------------|
| 1      | 8 mm (BFRP)     | 104           | 55                    | -                  | 1200                  | -                     |
| 2      | 10 mm (BFRP)    | 162           | 52                    | -                  | 1200                  | -                     |
| 3      | 6 mm (Steel)    | 228           | 200                   | 250                | 325.26                | 260                   |
| 4      | 8 mm (Steel)    | 420           | 200                   | 504.12             | 547                   | 507.39                |

Table 2. Mix Proportion of Concrete.

| Concrete Grade | M 20 | M 40 | M 60 | M 80 |
|----------------|------|------|------|------|
| Mix Proportion | 1:1.83:2.8 | 1:1.55:2.4 | 1:1.35:2.19 | 1:1.06:1.89 |
| w/c ratio      | 0.5  | 0.43 | 0.29 | 0.27 |
| Cement (kg/m³) | 387  | 438  | 450  | 450  |
| Fly ash (kg/m³) | -   | -    | 54.21(12%) | 140.436(31%) |
| Sand (kg/m³)   | 708.21 | 678  | 683.24 | 626.2176 |
| Coarse aggregate (kg/m³) | 1083.6 | 1051 | 1108.13 | 1117.136 |
| Super plasticizers | - | 1% of cementitious material | 0.8% of cementitious material | 1% of cementitious material |
| Compressive strength at 28 days in MPa | 26 | 45 | 66.5 | 84.5 |

Fig. 2.1. BFRP bars.
3. Results and discussion

3.1. Mechanical characteristics of BFRP and Steel bars

According to mechanical characteristics of BFRP and Steel bar are listed in Table 1 shows that the Modulus of elasticity (55 GPa) and Density (2680 Kg/m$^3$) of BFRP bar is 3.64 and 2.93 times less than that of Steel bar (200 GPa, 7850 Kg/m$^3$) respectively. The tensile strength (1200 MPa) of BFRP bar is 2.4 times more than that of Steel bar (500 MPa).

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**Fig. 2.2.** Universal Testing Machine.

**Fig. 2.3.** Reinforcement details of SB2, BB2, SB6, BB6, SB8 and BB8 Beams.

**Fig. 2.4.** Reinforcement details of SB4 and BB4 Beams.
Table 3. Designation of RC beams, features of main bar and concrete.

| Beam notation | Main bar (mm) | Reinforcement Ratio, ρf (%) | Balanced section Ratio, ρfb (%) (ACI 440) | Balanced section Ratio, ρfb (%) (IS 456) | Concrete compressive Strength, fck (MPa) |
|---------------|---------------|----------------------------|------------------------------------------|------------------------------------------|----------------------------------------|
| SB2           | 3#8           | 0.243                      | 1.610                                    | 0.962                                    | 26                                     |
| SB4           | 2#10          | 0.243                      | 2.810                                    | 1.929                                    | 45                                     |
| SB6           | 3#8           | 0.243                      | 3.612                                    | 2.895                                    | 66.5                                   |
| SB8           | 3#8           | 0.243                      | 4.821                                    | 3.859                                    | 84.5                                   |

Table 4. Designation of BFRP beams, features of main bar and concrete.

| Beam notation | Main bar (mm) | Reinforcement Ratio, ρf (%) | Balanced section Ratio, ρfb (%) (ACI 440) | Balanced section Ratio, ρfb (%) (IS 456) | Concrete compressive Strength, fck (MPa) |
|---------------|---------------|----------------------------|------------------------------------------|------------------------------------------|----------------------------------------|
| BB2           | 3#8           | 0.243                      | 0.212                                    | 0.137                                    | 26                                     |
| BB4           | 2#10          | 0.243                      | 0.382                                    | 0.274                                    | 45                                     |
| BB6           | 3#8           | 0.243                      | 0.482                                    | 0.411                                    | 66.5                                   |
| BB8           | 3#8           | 0.243                      | 0.641                                    | 0.548                                    | 84.5                                   |

3.2. Load- displacement response at midspan

Fig. 3.1 shows load vs displacement graph for M20 grade RC and BFRP beam. The RC beam failed at an ultimate load of 130 kN and BFRP beam of 104.985 kN. The RC beam has 1.238 times the ultimate load of BFRP beam. The displacement BFRP beam at an ultimate load of 104.985 kN is 8.745 mm i.e 3.102 times the displacement of RC beam (2.819 mm) at the same load because of lower elasticity modulus BFRP bar.

Fig. 3.2 shows load vs displacement graph for M40 grade RC and BFRP beam. The RC beam failed at an ultimate load of 120 kN and BFRP beam of 100 kN. The RC beam has 1.2 times the ultimate load of BFRP beam. The displacement BFRP beam at an ultimate load of 100 kN is 12.952 mm, i.e. 1.785 times the displacement of RC beam (7.162 mm) at the same load because of lower elasticity modulus BFRP bar.

Fig. 3.1. Load v/s deformation for M20 grade RC and BFRP beam
Fig. 3.2. Load v/s deformation for M40 grade RC and BFRP beam.

Fig. 3.3. Load v/s deformation for M60 grade RC and BFRP beam

Fig. 3.4. Load v/s deformation for M80 grade RC and BFRP beam.

Fig. 3.3 shows load vs displacement graph for M60 grade RC and BFRP beam. The RC beam failed at an ultimate load of 133 kN and BFRP beam of 117 kN. The RC beam has 1.137 times the ultimate load of BFRP beam. The displacement BFRP beam at an ultimate load of 117 kN is 14.919 mm, i.e., 1.742 times the displacement of RC beam (8.567 mm) at the same load because of lower elasticity modulus BFRP bar.

Fig. 3.4 shows load vs displacement graph for M80 grade RC and BFRP beam. The RC beam failed at an ultimate load of 127 kN and BFRP beam of 121 kN. The RC beam has 1.050 times the
ultimate load of BFRP beam. The displacement BFRP beam at an ultimate load of 121 kN is 13.357 mm, i.e., 1.159 times the displacement of RC beam (11.525 mm) at the same load because of lower elasticity modulus BFRP bar.

3.3. Comparisons between theoretical and experimental flexural strength

BFRP reinforcement was chosen to analyze two types of flexural failure, namely BFRP reinforcement break and concrete crushing. The first mode is accomplished by using a reinforcement ratio $\rho_f$ less than the balanced section ratio $\rho_{fb}$ according to the guidelines ACI 440.1R-06 [7], whereas the second mode by using a reinforcement ratio greater than $\rho_{fb}$. The reinforcement ratio, $\rho_f$, and balanced section ratio, $\rho_{fb}$, respectively, calculated from Eqs. (1) and (2), as defined in the guidelines ACI 440.1R-06:

$$\rho_f = \frac{A_f}{b_d}$$

$$\rho_{fb} = 0.85\beta_1 \frac{f_{cu}}{f_{fu}} \left(\frac{E_f \varepsilon_{cu}}{E_f \varepsilon_{cu} + E_f \varepsilon_{cu} + f_{cu}}\right)$$

where $A_f$ is the area of BFRP reinforcing bars, $f_{cu}$ is the compressive strength of concrete (MPa), $b$ is the width of the beam (mm), $d$ is the effective depth of the beam (mm), $f_{fu}$ is the ultimate tensile strength of BFRP bars (MPa), $\varepsilon_{cu}$ is the ultimate strain in concrete, $E_f$ is the elasticity modulus of BFRP bars (MPa), and $\beta_1$ is the strength reduction factor that can be calculated on the basis of the ACI 440.1R-06 in SI units:

$$\beta_1 = 0.85 - 0.05\left(\frac{f_{cu} - 27.6}{6.7}\right)$$

The experimental and theoretical moment capacities for the beams tested are shown in Table 5. Experimental moment failure at centre-span is calculated. The theoretical moment capacities, $M_{the}$, of mid-span are calculated based on ACI 440.1R-06 Eqs. (4) and (5) when $\rho_f \geq \rho_{fb}$ and Eqs. (6) and (7) when $\rho_f < \rho_{fb}$:

$$M_{the} = \rho_f \frac{f_{fu}}{f_{cu}} \left(1 - 0.59 \frac{\varepsilon_{cu}}{f_{cu}}\right)bd^2$$

$$f_{fu} = \sqrt{\left(\frac{E_f \varepsilon_{cu}}{4}\right)^2 + \left(\frac{0.85\beta_1 f_{cu} E_f}{\rho_f} 0.5 E_f \varepsilon_{cu} + f_{cu}\right)^2}$$

$$M_{the} = A_f f_{fu} \left(d - \frac{\beta_1 C_b}{2}\right)$$

$$C_b = \left(\frac{f_{cu}}{\varepsilon_{cu} + \varepsilon_{fu}}\right)$$

where $\rho_f$, $\rho_{fb}$ and $\beta_1$ are defined in Eqs. (1) – (3), $f_{fu}$ is the BFRP stress at which concrete crushing failure mode occurs, and $C_b$ is the depth of neutral axis for balanced failure as defined by Eq. (7). Comparisons between the theoretical and the flexural strength of the beams tested in this study are shown in Table 5. The present study indicates disagreement between the predicted value according to ACI 440.1R-06 and experimental results.

3.4. The failure load and crack width of the beams

The nature of cracking and crack patterns in BFRP beams under flexural loading was similar to the RC beams. Crack width of BFRP beams was 1.2 to 1.55 times higher then the RC beams, because of the low modulus of BFRP bars relative to steel bars. Table 6 shows failure loads and crack width of the beams.
Table 5. Comparisons of theoretical and experimental flexural strength.

| No | Beam name | $M_{exp}$ (kNm) | $M_{th}$ (kNm) | $M_{exp}/M_{th}$ | $M_{exp}/f_{ck}bd^2$ | $M_{th}/f_{ck}bd^2$ | failure Mode |
|----|------------|-----------------|----------------|-----------------|---------------------|---------------------|-------------|
|    |            |                 | ACI 440         |                 |                     |                     |             |
| 1  | BB2        | 26.246          | 46.234          | 0.568           | 0.078               | 0.138               | FRP rupture |
| 2  | BB4        | 25              | 46.630          | 0.536           | 0.038               | 0.069               | FRP rupture |
| 3  | BB6        | 29.250          | 47.035          | 0.622           | 0.029               | 0.047               | FRP rupture |
| 4  | BB8        | 30.250          | 47.324          | 0.639           | 0.023               | 0.035               | FRP rupture |

Table 6. Failure loads and crack width of the beams.

| Beams | Failure Load (kN) | Crack Width at failure (mm) |
|-------|-------------------|----------------------------|
| SB2   | 70                | 2                          |
| BB2   | 78                | 3                          |
| SB4   | 120               | 2                          |
| BB4   | 99                | 3                          |
| SB6   | 100               | 3.5                        |
| BB6   | 108               | 4.5                        |
| SB8   | 105               | 4                          |
| BB8   | 90                | 5                          |

3.5. Crack profile and Failure mechanisms

Fig. 3.5 Crack Profile & Failure of Beam SB2

Fig. 3.6 Crack Profile & Failure of Beam BB2

Fig. 3.7 Crack Profile & Failure of Beam SB4

Fig. 3.8 Crack Profile & Failure of Beam BB4
4. Conclusions
The following conclusions have been drawn on the basis of the objectives set in the present study and the experimental work conducted in the laboratory.

- The Modulus elasticity (55 GPa) and Density (2680 Kg/m³) of BFRP bar is 3.64 and 2.93 times less than that of Steel bar (200 GPa, 7850 Kg/m³) respectively. The Tensile strength (1200 MPa) of BFRP bar is 2.4 times more than that of Steel bar (500 MPa).
- The Flexural strength of BFRP beams was 0.87 times the RC beams.
- Deflection of the BFRP beams was significantly higher (average of 1.95 to 3.10) than that of the RC beam because of the low modulus of the BFRP bars relative to the steel bars.
- The nature of cracking and crack patterns in BFRP beams under flexural loading was similar to the RC beams. Crack width of BFRP beams was 1.2 to 1.55 times higher then the RC beams, because of the low modulus of BFRP bars relative to steel bars.
- The present study indicates disagreement between the predicted value according to ACI 440.1R-06 and experimental results.

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