Behaviour of Singly Reinforced Concrete Beams Reinforced with Steel and BFRP Bars

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Abstract—Basalt bars (BFRP-Basalt Fibre reinforced polymer) as reinforcement for concrete structures is gaining popularity recently. Due to the limited amount of research on the use of basalt for structural applications, further investigations are still required to provide confidence in the use of the basalt bars to reinforce concrete structures in place of steel bars. This study presents experimental research on the simply supported beams under flexure, reinforced with BFRP bars, compared to the reference beams with steel reinforcement. The tested beams were made of M35 concrete and reinforced with basalt bars with 10 mm diameter. Tensile characterization studies were also performed on 10mm basalt bars. The deflection and cracking behaviour of beams were investigated in detail. The results showed shear failure occurred in steel reinforced beam and the final failure in BFRP reinforced beams was by bond slip failure.

Index Terms— BFRP Bars, flexure, load- deflection relationship. M35.

1 INTRODUCTION

Basalt bars (BFRP) have a number of advantages compared to steel reinforcement and other GFRP and CFRP composites, [1; 2; 3]. Basalt fiber tensile strength varies from 1.5 to 2.9 GPa as the production temperature ranges from 1200~ 1375°C and Young's modulus ranges between 45 and 90 GPa, depending on the source. Most of the literature reports indicates that compared to glass, basalt fiber has higher or comparable modulus and strength and there have been reported some cases of significantly lower strength of basalt fiber than it was declared as well. Basalt has low specific weight: 4 times lighter than steel bars. Due to good thermal insulating properties, basalt is successfully used for fire protection [4]. Basalt fibers are also unique chemical resistance (potash environment, hydrochloric acid, alkali, sea water and other aggressive environments).

The investigation on Basalt Fiber Reinforced Polymer rods and basalt fiber ropes reported concludes that they are going to be used as an alternative to glass, carbon or aramidic fibers in various applications. As beam, when BFRP beams were tested under flexure, it was observed that it do not provide any ductility [4]. From the existing literature, it is noted that there is lack of information's related to the behaviour of basalt reinforced beams. The aim of this study is to clarify the effect of basalt as flexural reinforcement towards ductility, deformability, ultimate strength for beams reinforced with BFRP compared to beams reinforced with steel bars.

2 STUDY OF TENSILE STRENGTH OF BASALT BARS

Tensile Characterization was carried out on basalt rod of 10mm diameter. The specimen length was 500mm with a gauge length of 350mm. The tests were carried out as per ASTM D7205/D7205M-06 (Reapproved 2011) [5], The test setup and final failure pattern of 10mm diameter BFRP rod is shown in Fig .1 and Fig .2 respectively.

The stress vs strain behavior obtained from the experiment is shown in Fig. 3. It is observed that maximum tensile stress is 684 MPa and strain is 4%. Further, the BFRP bar characteristics are given in Table: 1

Fig 1: Tension Test on BFRP Bars

Fig 2: Final Failure of BFRP Bars

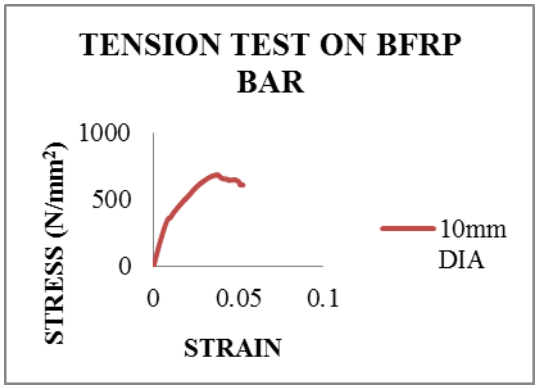

Fig 3: Stress- Strain Curve for BFRP Bars

Table 1: Basalt Fiber Rebar Characteristics

Characteristics	Units	Value
Tensile strength	MPa	684
Modulus of elasticity	MPa	47500
Density	g/cm^3	1.9
External view	-	From dark brown to black

3. **Load Capacity And Deformability Of Rc Beams And Bfrp Beams**

The studies consisted of performing bending test (ASTM: C78/C78M-10) [6] on concrete beam with two numbers bottom reinforcement made of

i) BFRP bars (diameter of 10 mm, fy = 684MPa)
ii) Steel bars (diameter of 10 mm, fy = 415 MPa).

All the tested beams have the following dimensions: b x h x L = 100 x 200 x 1500 mm without shear reinforcements. During the tests, the beams were simply supported on two supports with a span of 1200 mm. The bottom reinforcement was located at a distance of 25 mm from the bottom. Mix proportions details as shown in Table: 2.

- BFRP bar reinforced beam Design as per ACI 440. 1R-06 detailing presented in the Fig.4.
- Steel Reinforced beam Design as per ACI 318-11 detailing is presented in the Fig.4.

Mix proportions details as shown in Table: 2.

Table: 2. Mix Proportions:

Type	Water	Cement	Fine Aggregate	Coarse Aggregate
M35	0.45	1	1.669	1.856

TENSION REINFORCEMENT ONLY

FOR BFRP BAR FOR STEEL BAR

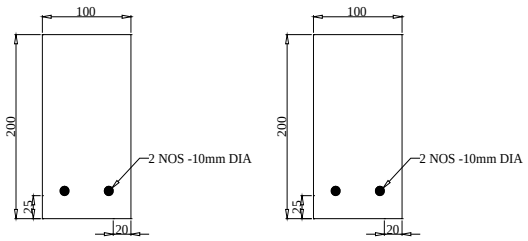

Fig 4: Reinforcement Detailing of Beam

From the test, Ultimate loading capacity of steel reinforced beam is 59.91 kN. It is observed that shear failure occurred in steel reinforced beam since shear reinforcement is not provided in that beam. The Final failure pattern of RC beam is shown in Fig .5. It is also observed that steel reinforced beam deflection is 5.36 mm. Load vs Displacement of Steel reinforced beam as shown in Fig.6

Energy absorption for Steel beam = (1/2) x (OPQ)
= (1/2) x (59.91x 5.36)
= 160 J

Fig 5: Failure of Steel Reinforced Concrete Beam

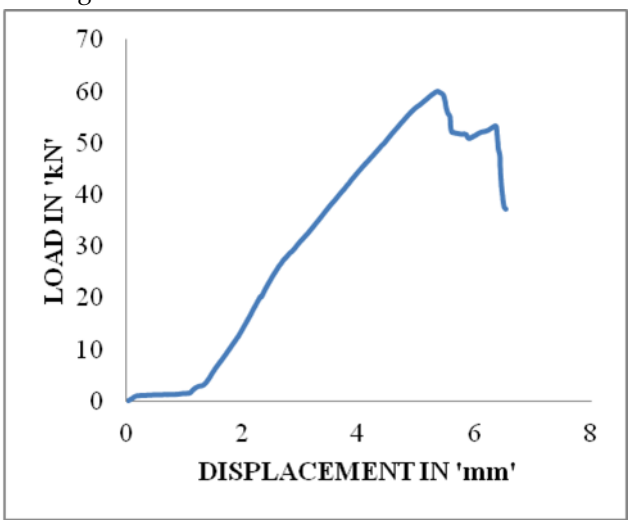

Fig. 6: Load vs Displacement of Steel reinforced beam

From the test, Ultimate loading capacity of BFRP rein-

forced beam is 68.11kN, the final failure in BFRP reinforced beams are by bond slip failure as shown in Fig .7. It is also observed that BFRP reinforced beam deflection is 16.92 mm. Load vs Displacement of BFRP reinforced beam as shown in Fig.8

Energy absorption for BFRP beam = (1/2) x (OAB)
= (1/2) x (68.11 x 16.92)
= 576 J

Fig 7: Failure of Basalt Bar Reinforced Concrete Beam

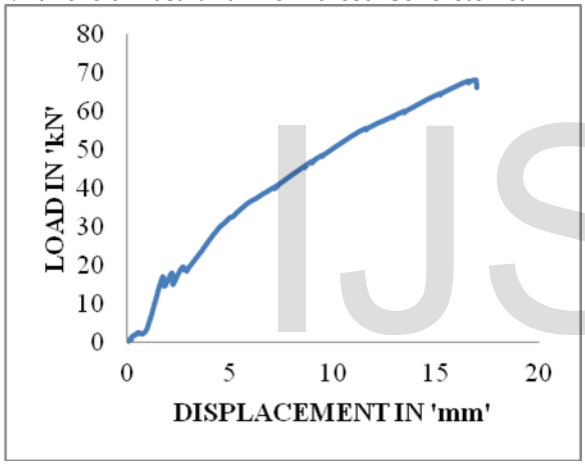

Fig 8: Load vs Displacement of Basalt reinforced beam

Moment capacity, displacement, % of reinforcement and energy absorption provided are shown in Table: 3. Steel reinforced beam. However, energy absorption in BFRP reinforced beam is more compared to steel reinforced beam.

Table 3: Experimental Results:

Type of Beam	Exp. Moment Capacity (M_u) kNm	Exp. Displacement (mm)	% Tension Reinf.	No. of Bars	Energy Absorption (J)
BFRPB	13.62	16.92	0.924	2	576
SRB	11.98	5.36	0.924	2	160

Comparison BFRP Beam with Literature Review Results

For this paper presents that BFRP beam could carry ultimate moment capacity is 13.62 kNm, whereas BFRP beam Marek Urbanski -2013 [4] carry only 7.9 kNm. This paper gives high ultimate load carrying capacity beams.

4 Conclusion

1. Experimental investigations were carried out for concrete beams reinforced with BFRP bar and for steel reinforced beams. It is observed that for 0.924% of reinforcement, BFRP reinforced beam could carry load of 68.11 kN and corresponding displacement is 16.92 mm. Whereas in the case of 0.924% of reinforcement, steel reinforced beam could carry load of 59.91 kN and corresponding displacement is 5.36 mm.
2. This BFRP beam strength is 43.30% higher compared to BFRP beam for Marek Urbanski-2013 [4].
3. It can be concluded that due to the relatively lower elasticity modulus of basalt rods, compared to steel, the deflection can be a major factor in designing the BFRP reinforced concrete beams.

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