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Flexural Capacity of Concrete Beams Reinforced with Basalt Fibre Rebars

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Abstract-An effort to find an alternative for conventional steel in concrete by researchers leads to study the behaviour of basalt fibre reinforced polymer (BFRP) bars in concrete. In the present study the flexural behaviour of basalt fibre reinforced polymerconcrete beams. The tension test on BFRP bars demonstrated that BFRP bars have nearly three times high tensile strength, low modulus of elasticity of nearly one-fourth of conventional steel bars and alsothe stress-strain behaviour is linearwithout any yield point up to failure. In the present study, flexural behaviour of concrete beams reinforced with BFRP rebars comparing with reference beams made with conventional steel reinforcement. Load carrying capacity, deflection at mid-span and mode of cracking is observed. The beam with flexural BFRP reinforcement has load capacity of 46.7 kN whereas for beam with steel rebars has flexural load capacity of 37.6 kN. Deflections of BFRP reinforced concrete beams at midspan during failure is 14mm considerably more than the steel reinforced beam deflection which is 5.6mm, due to much lower modulus of elasticity of BFRP rebars when compared to steel rebars. Average width of cracks at failure in BFRP concrete beams nearly 4 times higher than in the reference steel concrete beams.

Index terms: BFRP, Basalt fibres, FRP, high tensile strength, flexural capacity

I. INTRODUCTION

Fibre reinforced polymer bars are used as alternative to steel rebars in concrete due to their highcorrosion resistance and less conductive to electricity. Density of basalt (2600 kg/m^3) is almost three times less than that of steel (7850 kg/m^3) which means that the BFRP rebars are very light alternative construction material and consumes less energy to produce them than steel rebars which will have an impact on the environment. Basalt rocks are mined and crushes into desired composition and are then melted at 1400 - 1600°C, the molten basalt is then drawn into continuous basalt filaments of12-18μ diameter and are chopped into bundles to be used in concrete.Literature advocates that the rebars to be used in concrete beam shall be made from un-chopped basalt fibres glued into bars and are then pre-stressed up to at least 50% of its tensile strength.

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It was reported that the tensile strength of BFRP rebars in about 1000 – 1300 MPa and that of steel rebars is 500 MPa. Studies also reported that the modulus of elasticity of basalt fibre is very less than the steel, of about 70 GPa. Basalt fibres rebars are manufactured by bonding continuous basalt fibre filaments (un-chopped) with epoxy resin. Sand is glued onto the surface to enhance bond between BFRP bars and concrete.

II. OBJECTIVES

1) To determine the load capacities at first crack and at failure of concrete beams made with basalt fibre rebars
2) To determine the deflection at mid-span at failure of concrete beams made with basalt fibre rebars
3) To observe the cracking behaviour of concrete beams made with basalt fibre rebars

III. EXPRIMENTAL INVESTIGATIONS

For experimental investigations, two sets of concrete beams are prepared. One with BFRP rebars and another with conventional steel rebars. For concrete beams reinforced with BFRP bars, bottom reinforcement is made up of BFRP bars with steel stirrups. Table 1 presents properties of BFRP bars. It's density is 1/3rd of the steel's density, tensile strength is almost 2.4 times the steel's tensile strength and Modulus of Elasticity is almost 3 times less than steel's E value.

The BFRP reinforcement area with respect to gross concrete area (reinforcement ratio) and the span / depth ratio (l/d) governs the failure mode of the BFRP concrete beam specimen. When l/d increases, the failure mode deviations from shear failure to flexural shear failure. The Ultimate flexural load for beams reinforced with BFRP rebars is greater than the flexural load carrying capacity of beams reinforced with conventional steel rebars. Concrete beams reinforced with BFRP rebars will not fail by sudden failure due to high tensile nature of BFRP rebars. Table 3 presents the results of experimentally obtained carrying capacities of the tested BFRP beams reinforced with 10 mm basalt bars Table 2 presents the BFRP beam details.

Table 1 – Properties of BFRP Bars

Property	Value
Rebar diameter	10mm
Density	2600 kg/m^3
Tensile Strength	1200 MPa
Modulus of Elasticity	70 GPa

Table 2- Flexure Test beam details

Beam Section	Grade of Concrete	Beam type	Tension Reinforcement	Nominal Compression Reinforcement	Shear Reinforcement	Beam dimensions
Under reinforced	M30	Conventional Concrete Beam	2 Nos - 10mmφ Fe 415 steel bars	2 Nos - 8mm φ Steel bars	2 legged - 8mm φ Steel @100mm c/c	100 mm x 150 mm x 1100 mm
		BFRP Concrete Beam	2 Nos - 10mmφ BFRP bars	2 Nos - 8mm φ Steel bars	2 legged - 8mm φ Steel @100mm c/c	100 mm x 150 mm x 1100 mm

Table 3 – Flexural load capacities and deflections of BFRP and conventional steel beams

Property	Steel reinforced concrete beam	Basalt reinforced concrete beam
Load at First Crack	12.3 kN	26.8kN
Maximum Load Capacity, F	37.6 kN	46.7 kN
Moment Carrying Capacity, M	9.4 kN.m	11.68 kN.m
Deflection at Mid-span, D	5.6mm	14mm
Crack Width at failure	1mm	4mm

Table 4 - Loads (P) and deflections (δ) of concrete beams

Concrete Beam made with Steel Rebar		Concrete beam made with BFRP Rebar	
Load kN	Deflection at Centre Mm	Load kN	Deflection at Centre mm
0	0	0	0
3.95	1	11.2	1
11.35	2	15.8	2
20	2.5	20.7	3
22.4	3	25.85	4
27.15	3.5	30.7	5
33.85	4	35.5	6
34.7	4.5	37.95	7
35.1	5	40.95	8
37.6	5.6	43.05	9
33.25	10	43.7	10
31	11	43.35	11
30	12	44.5	12
29.2	13	45.55	13
27.8	13.78	46.70	14
		44.55	15
		43.1	16
		42.45	17
		37.1	18
		35.25	19
		30.95	20
		28.4	21
		27.05	22
		24.95	23
		23	23.92

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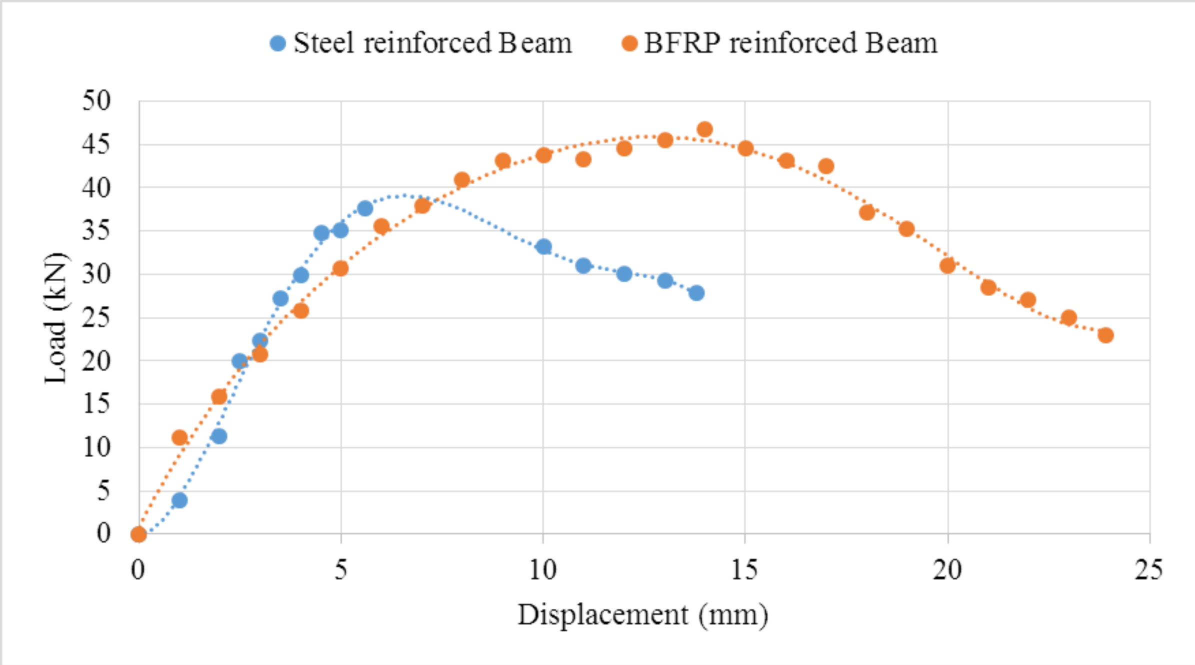

Figure 1- P-δ curve for concrete beams made with conventional steel and BFRP bars

Figure 2- Testing of beam reinforced with steel rebar

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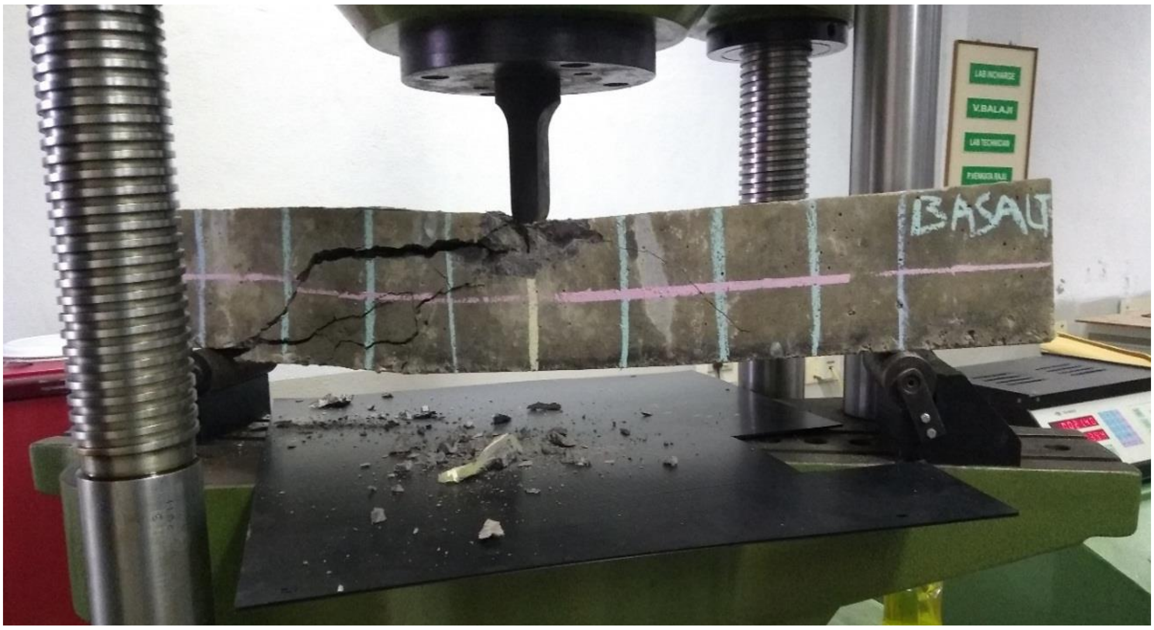

Figure 2- Testing of beam reinforced with basalt rebar

Average width of cracks at failure in BFRP concrete beams nearly 4 times higher than in the reference steel concrete beams. Deflections at mid-span and crack width at failure are more in concrete beam made with BFRP rebar than concrete beam with steel reinforcement which may be major factors in designing the beams. Table 4 presents load – deflections of beams made with BFRP and conventional steel rebarsDeflections of BFRP reinforced concrete beams is considerably more than the steel reinforced beam deflection, due to much lower modulus of elasticity of BFRP rebars when compared to steel rebars.The beam with flexural BFRP reinforcement has load capacity of46.7 kNwhereas for beam with steel rebars has flexural load capacity of 37.6 kN.Modulus of elasticity of BFRP rebars is less than steel rebars because of which there will be excessive deflection at service loads in concrete beams made with BFRP rebars than the concrete beams made with steel bars. Since basalt rebars are purely elastic and don't exhibit yield point unlike steel rebars during tension test its stress-strain curve is linear till failure In the present study the BFRP concrete beams are under-reinforced so the beams fail suddenly due to reinforcement fracture with large deflections. It was observed that steel reinforced concrete beams have failed in flexure whereas BFRP reinforced concrete beams failed in shear so it is suggested that in the design of BFRP concrete beams is little different from that conventional beam design because the BFRP reinforcement area with respect to gross concrete area (reinforcement ratio) and the span / depth ratio (l/d) governs the failure mode of the BFRP concrete beam specimen. When l/d increases, the failure mode deviations from shear failure to flexural shear failure. So specimen length and depth are chosen in such a way so that failure should be flexure failure or shear reinforcement design should be adequate.

IV. CONCLUSIONS

1. The beam with flexural BFRP reinforcement has load capacity of 46.7 kN whereas for beam with steel rebars has flexural load capacity of 37.6 kN.
2. Deflections of BFRP reinforced concrete beams at midspan during failure is 14mm considerably more than the steel reinforced beam deflection which is 5.6mm, due to much lower modulus of elasticity of BFRP rebars when compared to steel rebars.
3. Average width of cracks at failure in BFRP concrete beams nearly 4 times higher than in the reference steel concrete beams

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