

Behavior of Concrete Beams Reinforced Internally With BFRP Reinforcement

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Abstract: Recently, basalt fibre reinforced polymer greater than the experiment alone. Rudzink is [3] tested four concrete beams (150×200×1500mm) reinforced with (BFRP) reinforcements are viable alternate to conventional steel reinforcements due to their high tensile strength, light-weight and good corrosion resistance. This paper presents the flexural response of concrete one-way Beams reinforced internally with BFRP and conventional reinforcements. A total of six concrete one -way Beams measuring 2000mm in length, 500mm in breadth and 100mm in depth were constructed. All Beams were tested under four -point bending over a clear span of 1800mm up to failure. The slab test results are described with regard to flexural capacity, deflection, crack width, and failure mode. It has shown that the ultimate load carrying capacity of BFRP Beams were greater than the conventional Beams. However, the BFRP Beams produce higher deflection and crack-widths compared to conventional Beams.

Keywords: basalt fibre reinforced polymer, one- way slab, load, deflection, crack width.

1. INTRODUCTION

Many concrete structures such as marine structures, bridge decks and parking garages reinforced with conventional steel reinforcements are susceptible to corrosion due to aggressive environmental conditions. The non-corrosive fibre reinforced polymers (FRPs) have been used gradually over the past two decades as internal and external reinforcements in concrete structures to avoid these problems. The use of FRP reinforcements in concrete structures affords a potential for increasing life and environmental benefits [1]. The behaviour of FRP reinforced concrete members is typically quite different from that of conventional reinforced concrete members. FRP reinforcements have lower weight, high tensile and transverse shear strength than conventional steel reinforcements. Recently, basalt fibre reinforced polymer (BFRP) has been increased in civil engineering applications due to their advantageous characteristics compared with other FRPs, such as carbon FRP, GlassFRP and Aramid FRP. Several investigations were performed to investigate the flexural response BFRP reinforced concrete members. Zhang et al. [2] investigated the deflection behavior of six concrete beams (180 × 230 × 1,800 mm) reinforced with BFRP bars. The results showed that the flexural capacities equations in the ACI (2006) guideline were suitable for BFRP-reinforced beams, while the effective moment rigidity predicted using ACI (2006) was BFRP reinforcements and found that the cracked section of concrete beams reinforced with BFRP reinforcements deflected nearly twice as much than the concrete beams reinforced with steel reinforcements. However, loads at failure of BFRP reinforced concrete beams were higher than the conventional steel reinforced concrete beams. Urbanski et al. [4] investigated the flexural response of concrete beams (80×120×1200) reinforced with BFRP bars of 8mm diameter with a tensile elastic modulus of 39.5GPa. The results showed that the ultimate load carrying capacity of BFRP reinforced concrete beams was much greater than the conventional steel reinforced concrete beams. The deflection of concrete beams with basalt reinforcements were considerably higher than the beams with conventional steel reinforcements, due to the much low modulus of elasticity of BFRP bars compared to conventional bars. Akiel et al. [5] investigated the flexural performance of six continuous concrete Beams, 200×500×5000mm each, reinforced with BFRP bars. It was found that the continuous concrete Beams failed by rupture of BFRP bars was more sensitive to the hogging - to-sagging BFRP reinforcement ratio than that of Beams that failed by crushing of concrete.

Abramski et al. [6] studied the flexural response of concrete Beams reinforced with carbon FRP and basalt FRP bars. The results showed that the load carrying capacity of Beams reinforced with ribbed BFRP bars were higher than that of Beams reinforced with plain CFRP bars, although the strength as well as modulus of elasticity were higher for the plain CFRP bars than for the ribbed BFRP bars. The plain CFRP bars cannot be properly anchored in concrete to sustain bending moments. Rizkalla [7] tested six one-way concrete Beams (152 × 610×3,658 mm) reinforced with BFRP bars under four-point bending. The test results indicate that the measured failure loads compared well with the nominal flexural capacities predicted using the ACI (2006) equation and detailed layered-sectional analyses. The measured short-term deflections at service load level were higher than the values predicted by ACI (2006) by 20-60%. In this paper, the flexural performance of concrete one-way Beams reinforced internally with basalt fibre reinforced polymer (BFRP) and conventional reinforcements are reported.

2. EXPERIMENTAL PROGRAM

Material properties

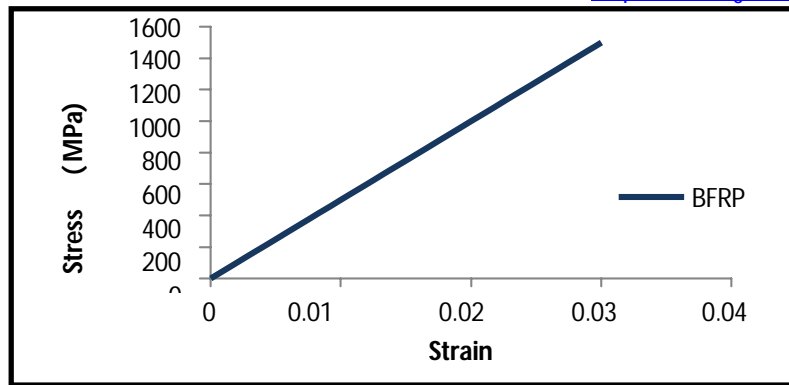
BFRP reinforcing bars

BFRP bars with a diameter of 8mm and 10mm used in this study (Figure-1) were provided by Arrow Technical Textiles Pvt. Ltd, Mumbai. All the BFRP bars supplied by these industries were manufactured by pultrusion process. BFRP bars had fibre content of 80.1% and 80.3% for 8mm and 10mm- diameters, respectively. The density of the BFRP bars was 2044kg/m³ and 2065kg/m³ for 8mm and 10mm-diameters, respectively. The tensile properties of these BFRP bars were determined by testing of five specimens as per ASTM D7205 guidelines. The tensile test setup, stress-strain relationship and failure pattern of tested BFRP bars as shown in Figure-2. It was observed that the ultimate tensile strength of BFRP bars of 8mm and 10mm-diameters were 1378MPa and 1475Mpa respectively. The scanning electron microscopy (SEM) images of tensile fractured BFRP specimens are presented in Figure-3.



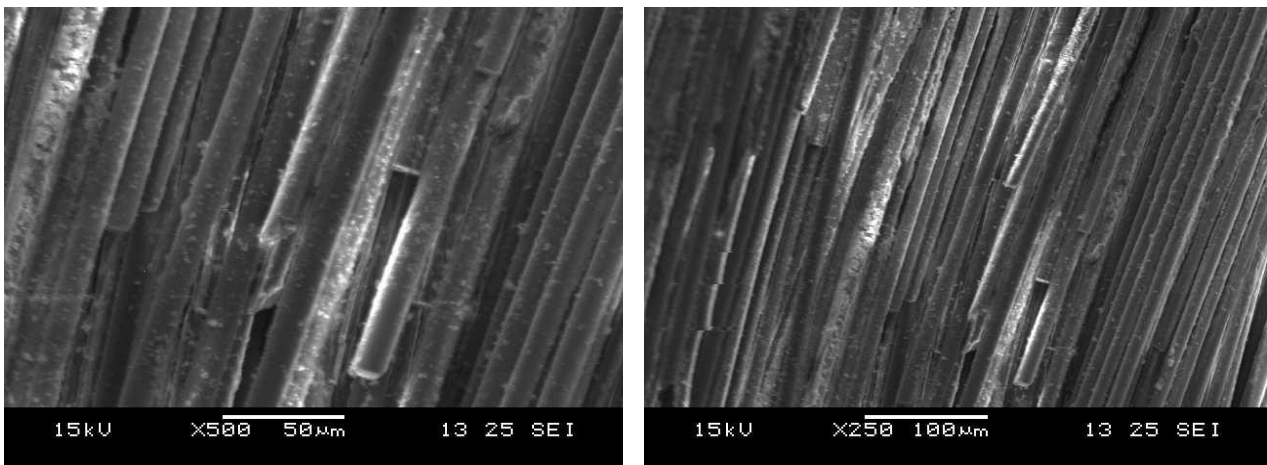
Figure-1. BFRP bars of different diameters





(c)

Figure-2. Tensile test (a) Test setup (b) Failure pattern (c) Stress-strain response of BFRP bars.



(a)

(b)

Figure-3. SEM images of the tensile fracture surfaces of BFRP specimens at different magnifications (a)×250(b)×500.

Concrete mix

The pullout test was carried out by testing five specimens according to ASTM D7913. The detailed mix ratio of cement-water- fine aggregate- coarse aggregate-superplasticizer was 1:0.38:1.56:2.72:0.005. The maximum size of coarse aggregate was 20mm and the fine aggregate was river sand with particle size of 0-5mm. The specific gravity of fine aggregate and coarse aggregate was 2.63 and 2.72. This concrete mix ratio was used to cast the concrete specimens. The concrete specimens were demoulded after 20 hours and then cured in a water storage tank for 28 days. The average compressive strength of concrete at 28 days was 48.5 MPa. The bond stress-slip response of BFRP bars are shown in Figure- 4. The bar slip was not obtained in all the specimens at free ends (unloaded ends) until the specimen reached to ultimate load whereas the loaded end slip was obtained in all the specimens at all stages of loading. The maximum bond stress and corresponding slip was noted in all the specimens at free ends, these slips are very smaller (0.09mm). At loaded ends, the slips of 3.65mm were reached at maximum bond stress. The average bond strength of BFRP bars was about 70% that of the conventional bars.

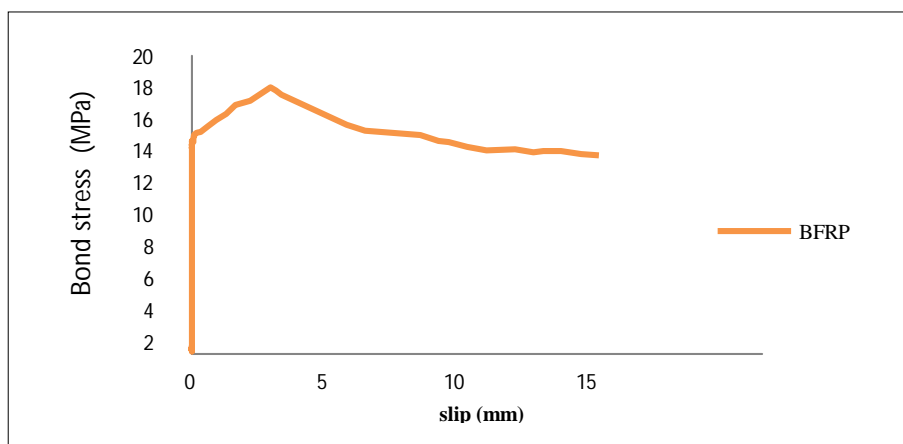


Figure-4. Bond stress-slip response of BFRP bars.

Test specimens

A total of six concrete one-way Beams reinforced with BFRP and conventional steel reinforcements were tested. The Beams measured 2000mm long, 500mm wide and 100mm depth. A clear concrete cover of 20mm thickness was kept constant for all reinforcement. The reinforcement ratios ρ_f [0.58% (3bars), 0.79% (4 bars), 0.98%(5 bars)] and concrete compressive strength 40Mpa were used. The reinforcement ratios (ρ_f) were higher than the balanced reinforcement ratios (ρ_{fb}) according to ACI 440.1R-06 guidelines. The expected failure mode of BFRP reinforced Beams were mostly the concrete crushing. Figure-5 shows the slab specimens after casting. The reinforcement ratio (ρ_f) and balanced reinforcement ratio (ρ_{fb}) were determined by Eqs (1) and (2), $A_f \rho_f = (1) b d E_f \beta_1$ is the modulus of elasticity of concrete (Mpa) and β_1 is the strength reduction factor.

Test setup and procedure

All slab specimens were tested under four-point bending up to failure at the Advanced structural laboratory, Annamalai University. Load frame of capacity 50Tonnes was used for testing the slab specimens. All Beams were equipped with a dial gauge at mid span and at one-third points for measuring deflections. Demec gauge pellets were fixed at the top most compression fibre and at the level of reinforcements of slab to observe the strains. The static loads were gradually applied on the Beams via hydraulic jack and measured with a proving ring (Figure-6). During loading, the crack formation and the corresponding loads was marked on both slab sides until failure. The crack width was measured by using handheld electronic microscope.



Figure 6. Experimental Test setup

3. TEST RESULTS AND DISCUSSIONS

From the theoretical and experimental test results, it is observed that the increase in reinforcement ratios exhibited greater strengths, lesser deflections and reduced crack widths than those of identical Beams (Ahmed H.Ali et al. [8], Craig. R et al.[9]). By increasing the reinforcement ratios 0.79% and 0.98%, the ultimate load carrying capacity of the BFRP reinforced Beams increases by 10% and 20% respectively than the BFRP reinforced slab of reinforcement ratio 0.58%. At the same time, the ultimate deflection of BFRP reinforced Beams reduces to 1.02 and 1.04 times than that of reference slab. Also, the crack widths of BFRP reinforced Beams were 1.27 and 1.56 times lesser than that of reference slab. When the reinforcement ratios of conventional steel reinforced $\rho_{fb} = 0.85 \beta_1$

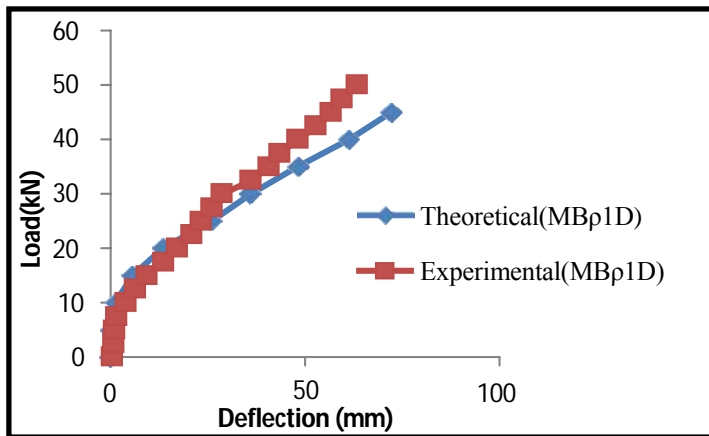
$$f_c A_f \rho_f = \beta_1 b d E_f \rho_{fb} \quad (2)$$

Beams were increased 0.79% and 0.98%, the ultimate load carrying capacity increases by 11% and 16% than that of conventional steel reinforcement ratio of 0.58%. However, Where A_f is the area of FRP reinforcement (mm^2), f_c is the compressive strength of concrete (Mpa), b is the width of slab (mm), d is the effective depth of slab (mm), f_{fu} is the design tensile strength of BFRP reinforcement (MPa), ϵ_{cu} is the ultimate strain in concrete, the ultimate load carrying capacity of BFRP reinforced Beams were partially higher than the ultimate load carrying capacity of conventional steel Beams. These BFRP reinforced Beams produce higher deflection and crack widths compared to conventional steel Beams. All Beams reinforced with BFRP reinforcements failed by concrete crushing due to higher designed strength of BFRP bars whereas the Beams reinforced with conventional reinforcements failed by steel yielding followed by concrete crushing.

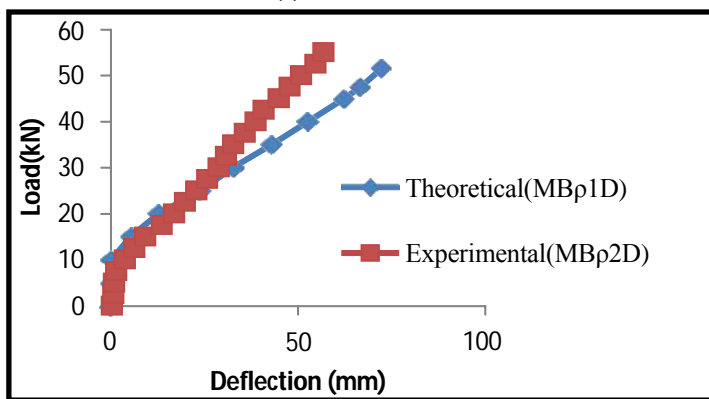
Table-1. Experimental and Theoretical results of BFRP and conventional steel reinforced Beams

S.No	Designation of Beams	Theoretical	Experimental	δ_{Theo}	δ_{Exp}	W_{cr}
		P_u	P_u			
1	MBp1D	45.21	50	72.16	63.16	2.18
2	MBp2D	51.45	55	71.32	62.42	1.72
3	MBp3D	56.13	60	69.89	60.89	1.40
4	MSp1D	23.07	25	33.54	29.72	0.34
5	MSp2D	30.66	32.5	31.27	26.56	0.33
6	MSp3D	36.84	37.5	28.05	25.41	0.32

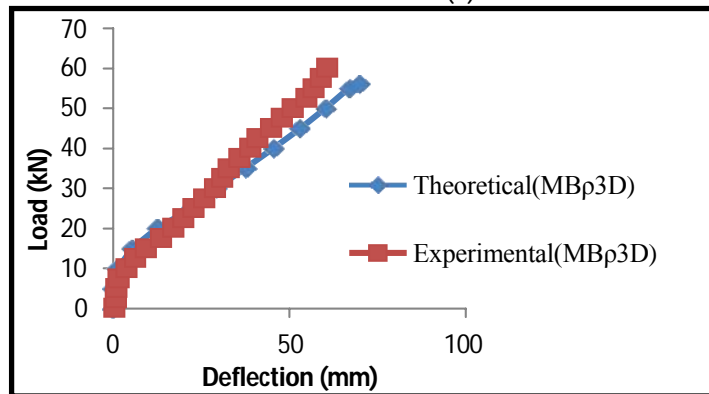
M=Grades of concrete M 40; B,S=Basalt fibre reinforced polymer and steel reinforcements; ρ_1, ρ_2, ρ_3 = Different reinforcement ratios 0.58 %, 0.79 %, 0.98 % respectively; D=Thickness of slab,100mm; P_U =Static ultimate load in kN; δ = Ultimate deflection in mm; W_{cr} =Crack width in mm.



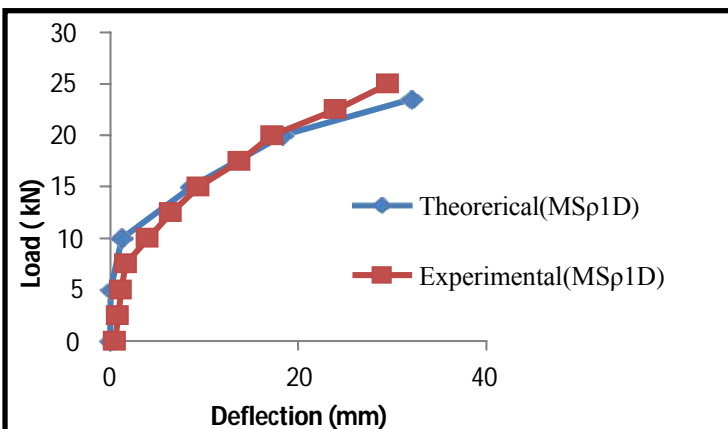
(a)



(b)



(c)



(d)

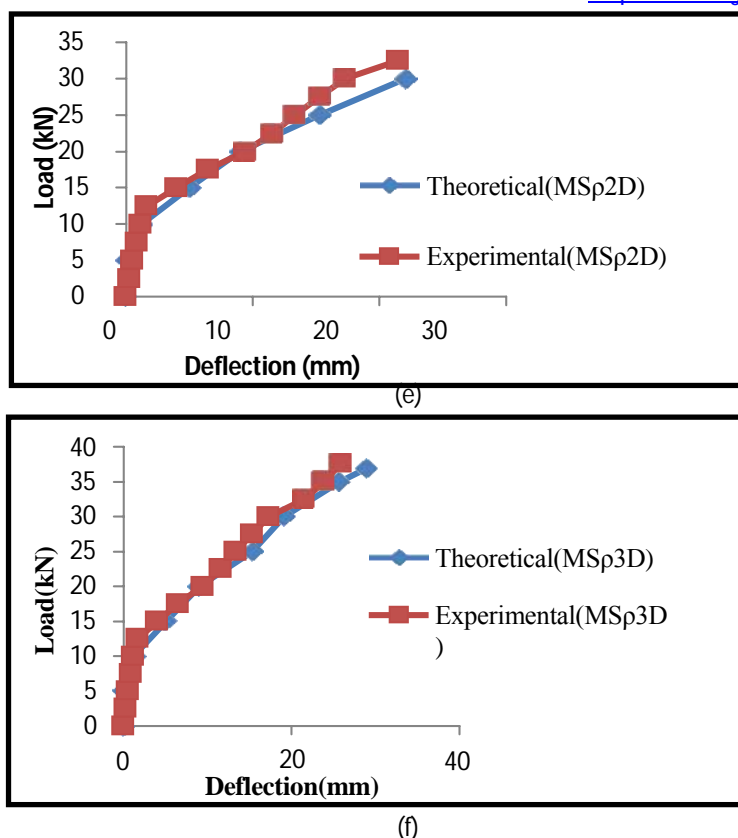


Figure-7. Theoretical and Experimental load and deflection relationship of Beams(a)MBp1D(b) MBp2D(c) MBp3D (d) MSp1D (e) MSp2D(f) MSp3D.

4. CONCLUSIONS

Reinforcements made from basalt FRP composites have good physical and mechanical behaviours and are able to provide structural strengthening and application in innovative new construction. Based on the theoretical and experimental data of this study the following conclusion can be made: It is confirmed that the ultimate load carrying capacity of BFRP reinforced Beams were much greater than the ultimate load carrying capacity of conventional steel Beams. However, these BFRP reinforced Beams produce higher deflection and crack widths compared to conventional steel Beams. All Beams reinforced with BFRP reinforcements failed by concrete crushing whereas the Beams reinforced with conventional reinforcements failed by steel yielding.

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