Experimental Study on the Shear Behaviour of Basalt Fiber Reinforced Concrete Beam with Steel and BFRP Stirrups

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Abstract— This paper deals with the shear behaviour of self compacting concrete (SCC) beams reinforced with basalt fiber-reinforced polymer (BFRP) bars. Fifteen concrete beams were, respectively, made with steel and BFRP shear reinforcements. The beams were tested in a static two point bending load setup by kept the shear span-to-depth (a/d) ratio as 1.952. The test results are presented in terms of crack patterns, failure modes, load-deflection, load-strain behaviour, and shear capacity. It was observed that the shear capacity and ductility of SCC beams increased by using BFRP reinforcements. The test results were compared with predictions of different available codes and design guidelines. Standard provisions predictions were conservative.

Keywords— Basalt rebar, BFRP, Crack pattern, deflection, Self Compacting Concrete (SCC), Shear failure, Stirrups

INTRODUCTION

Concrete is the most common and widely used structural material in the construction world. It is more versatile but modern day engineering structures require more demanding concrete owing to the huge applied load on smaller area and increasing adverse environmental conditions [13]. In recent years a lot of studies were carried out to improve the performance of concrete in terms of strength and durability. This lead to the development of self compacting concrete (SCC), it maintains durability and characteristics of concrete and also lower the time needed for construction.

Many reinforced concrete structures are exposed to serious deterioration problems due to the corrosion of the steel rebar inside the concrete. Therefore, the need for non-corroding materials has become important. In the past three decades fiber-reinforced polymer (FRP) materials have emerged as an alternative material to steel as reinforcing bars for concrete structures. Fiber-reinforced polymer composites have several advantages over steel such as high strength, high stiffness to weight ratios, resistance to corrosion and chemical attacks, controllable thermal expansion, good damping characteristics, and electromagnetic neutrality [11; 12]. The most commonly used FRP types in infrastructure are glass FRP, carbon FRP, and aramid FRP. Basalt fiber-reinforced polymer (BFRP) is not common compared with other FRPs due to the lack of research, design specifications, and construction guidelines.

In this paper, the study on shear capacity of concrete beams reinforced with BFRP longitudinal bars made with steel and BFRP stirrups are discussed. Experimental results are compared with the available design codes and given formulas.

SIGNIFICANCE OF THE WORK

A. Scope of the Work

The main problem with the steel reinforcement is the corrosion that finally affects the life and durability of the concrete structures. Many techniques such as epoxy coating and high performance concrete are used to avoid the corrosion. However, it was found that such remedies might not eliminate the problem of corrosion of steel reinforcement in the concrete structures. New materials such as FRP reinforcement is identified as an alternative to steel reinforcement in aggressive environments. Although BFRP has many advantages over other FRP materials limited studies have been done. In addition, these studies didn’t include larger BFRP reinforcement bar diameters that are mostly used in practice. Therefore, the shear behaviour of larger beam sizes with larger BFRP reinforcement bar diameters are needed to investigated. And the application of BFRP stirrups in BFRP bar reinforced concrete beams is need to be scrutinized.

B. Objective of the Work

The objective is the introduction of new material for reinforcing the concrete structures other than steel and to check the shear capacity of such beams compared with conventional steel beams.

C. Methodology

The methodology of the work consists of:

(1) Selection of self compacting concrete grade; S25
(2) Mix design for S25 grade SCC
(3) Casting beam specimens of normal RC beams, Normal SCC beams, BFRP reinforced beams with steel stirrups, BFRP reinforced beams with steel and BFRP stirrups, BFRP reinforced beams with BFRP stirrups
(4)Conducting two point loading test using 50t loading frame.
(5) Study on the obtained the results
(6) Comparing the experimental result with available results in the design codes

MATERIAL TESTS

The materials selected for S25 mix were OPC (Ordinary Portland Cement) 53 grade BHARATHI CEMENTS, fly ash collected from Coimbatore, M sand as fine aggregate, 20 mm size coarse aggregates, water and Master Glenium SKY 8233 as admixture. Each material except the admixture was tested as per the specifications in the relevant IS codes. The results are provided in Table I. The beam is reinforced with BFRP bars using steel and BFRP stirrups. Basalt fiber reinforced polymer bars were collected from Nickunj Eximp Entp P Ltd, Mumbai. The properties of BFRP bars provided in Table II.

TABLE I
MATERIAL TEST RESULTS

Test	**Material**	**Equipment Used**	**Values Obtained**
Specific Gravity	Ordinary Portland Cement	Le-Chatelier Flask	3.15
Specific Gravity	Fine Aggregates	Pycnometer	2.7
Specific Gravity	Coarse Aggregates	Vessel	2.94
Specific Gravity	Fly ash	Le-Chatelier Flask	2.13

TABLE II
PROPERTIES OF BFRP BARS

Properties	**Obtained Values**
Tensile strength	1273.25 MPa
Modulus of elasticity	0.94 GPa
% Elongation	12.5%

Fig.1 BFRP longitudinal bar and shear reinforcement

MIX DESIGN

Many different test methods have been developed in attempts to characterize the properties of SCC. So far no single method or combination of methods has achieved universal approval and most of them have their adherents. Many trail mixes were prepared and comparing the test results with the standard values. Mix proportioning values are given in Table III.

TABLE III
S25 MIX PROPORTIONING

Cement (Kg/m^3)	561
Fly ash	99
Fine aggregate (kg/m^3)	1055.275
Coarse aggregate (Kg/m^3)	623.158
Water (l/m^3)	167.45
Water cement ratio	0.2537
Mix ratio	1:1.6:0.9

EXPERIMENTAL INVESTIGATION

A. Experimental Procedure

Fifteen, 1250 mm long, concrete beams with a 150 × 200 mm was included in this experimental investigation.. Six beams were casted as control specimens with steel reinforcement and steel stirrups using M25 mix and S25 mix. Details of specimens cast are shown in Table IV. Three beams were made up of using BFRP reinforcement with steel stirrups. Three were made up using BFRP reinforcement with BFRP stirrups and remaining three beams were made with BFRP reinforcement and stirrups were a combination of steel and BFRP. The steel RC beams were designed as per IS 456:2000 specifications and the BFRP RC beams were designed as per ACI 440.1R (ACI 2006) specifications. The main lower reinforcement was 2-12 mm in diameter and 8mm diameter stirrups for both steel RC beams and BFRP RC beams. And the spacing adopted for steel RC beams were 130 mm and for BFRP RC beams were 125 mm.

All BFRP beams were casted using Self Compacting Concrete. The beams were cured using jute bags with room temperature for 28 days. The compressive strength of the concrete mix was measured after 28 days using standard cubes. The mean compressive strength for the mix was 27.6 MPa.

TABLE IV
DETAILS OF SPECIMENS CAST

Sl. No:	Number Of Beams	Designation Used	Flexure bar type	Shear reinforcement type	Spacing Adopted
1	3	NS130	Steel	Steel	130
2	3	SS130	Steel	Steel	130
3	3	SBS125	BFRP	Steel	125
4	3	SBSB125	BFRP	Steel &BFRP	125
5	3	SBB125	BFRP	BFRP	125

NS - Normal Steel beams
SS - SCC Steel beams
SBS - SCC BFRP beams with Steel stirrups
SBSB - SCC BFRP beams with Steel and BFRP stirrups
SBB - SCC BFRP beams with BFRP stirrups

B. Test Procedure

The shear strength of the specimens was tested using a 50 ton loading frame. A dial gauge was attached at the bottom of the beam to determine the deflection at the centre of the beam. The effective span of the beam is taken as 990mm in the case of 1250mm beam. A proving ring of 500kN is connected at the top of the beam to determine the load applied.

The shear strength of the beam is tested as a two point loading system using a hydraulic jack attached to the loading frame. The behaviour of beam was observed from beginning to the failure. The loading was stopped when the beam was just on the verge of collapse. The first crack propagation and its development and propagation were observed. The values of load applied and deflection were noted. The load in kN is applied with uniformly increasing the value of the load and the deflection under the different applied loads is noted. The applied load increased up to the breaking point or till the failure of the material.

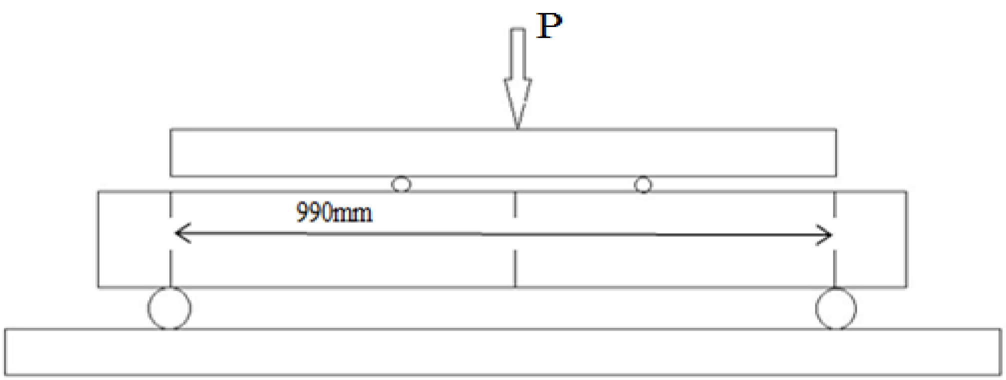


Fig. 2 Schematic Set Up of Testing

EXPERIMENTAL RESULTS

A. Load Deflection Behavior

As the load increases the deflection of the beams increases and all beams exhibited a linear load deflection relationship for same a/d ratio. The stiffness of the BFRP reinforced beams increases with the increase of load and deflection compared to the conventional beams. Compared to conventional beams the BFRP reinforced beam deflect more without failure and sustain more loads. Among the BFRP reinforced beams SBB125 deflect more and taken more loads.

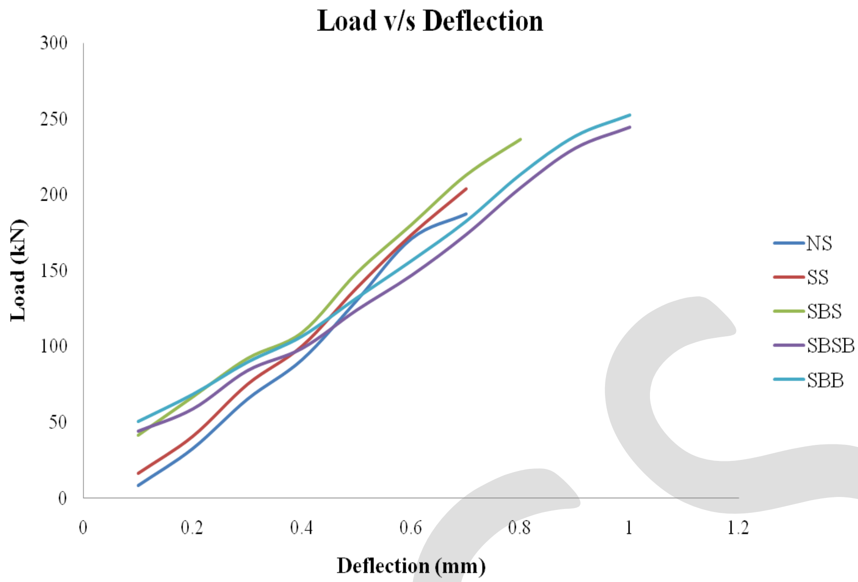


Fig.3 Load - deflection curve

B. Load Carrying Capacity

Ultimate strength of beams under two point loading was the maximum load indicated by the proving ring at the time of loading. Table V shows the ultimate load carrying capacity of all tested beams. From the results it was found that the BFRP reinforced beams exhibit more load carrying capacity than conventional beams. SBB125, the beam fully replaced by BFRP reinforcement has the maximum load carrying capacity compared to the beams partially replaced by BFRP.

TABLE V
ULTIMATE LOAD OF BEAMS

Beam Specimen	**Ultimate Load (kN)**
NS130	187.45
SS130	203.75
SBS125	236.35
SBSB125	244.5
SBB125	252.65

C. Ultimate Shear Capacity

The shear capacity (V_{ult}) of the RC beams was quantified by summing the contribution of shear in the concrete (V_c) and shear in transverse reinforcement (V_s). The shear capacity of BFRP reinforced beam provided in Table VI. SBB125 beams exhibits more shear capacity than other beams. BFRP reinforced beams in this study failed in shear, the ultimate shear strength presented in terms of the normalized shear as given by Eq. (1) where b and d are the width and depth to flexural reinforcement of the section and V_n is the Ultimate shear load of the beam.

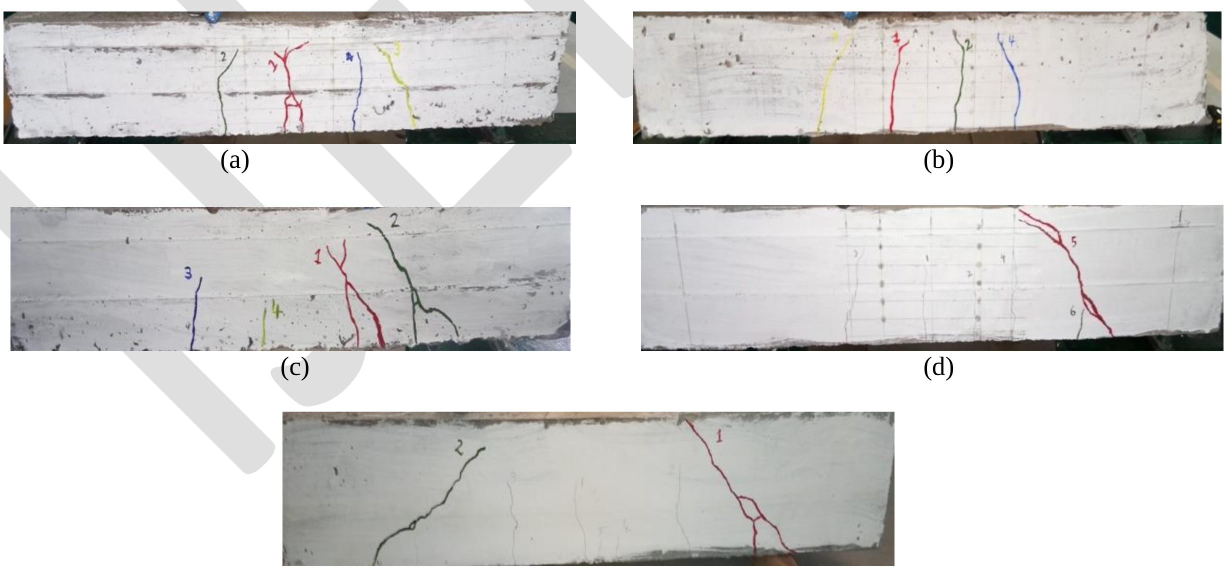
$$V_{norm}=\frac{V_n}{\sqrt{f'c}}\frac{1}{bd} \qquad (1)$$

TABLE VI
SHEAR CAPACITY OF BEAMS

Beam Specimen	**Shear Load (kN)**	**Peak Normalized Shear (N/mm^2)**
SBS125	118.175	0.89
SBSB125	122.25	0.92
SBB125	126.325	0.95

D. Crack Pattern

The crack pattern beams are presented in Figs. 4(a) and 4(e). For conventional beams the first flexural crack initiated in the middle of the beam. As the load increased, more flexural cracks initiated and propagate. There were no shear cracks in NS130 and SS130 beams. In the case of BFRP RC beams mainly shear cracks were developed from the supporting points and widened up as the load increased. Like conventional beams, flexural cracks were first developed in the BFRP RC beams but it was very minute cracks. The shear cracks continued to widen as the load increased. After the release of load, the flexural cracks suddenly disappeared and the shear cracks were diminished.



(a) (b) (c) (d) (e)

Fig.4 Crack patterns of beams: (a) NS130; (b) SS130; (c) SBS125; (d) SBSB125; (e) SBB125

E. Comparison between Experimental and Predicted Shear Strength

The shear strength of the BFRP RC-beams were predicted using the shear design provisions of the ACI 440.1R (ACI 2006), CSA S806 (CSA 2012), ISIS 2007 and the shear strength equation based on the modified compression field theory (MCFT) developed by Hoult et al. (2008). Table VII shows a summary of the shear strength prediction equations for the shear capacity in concrete and the shear capacity in FRP stirrups. The ratio of experimental to predicted shear strength values was calculated for each specimen in the database. The results are shown in Table VIII. It can be seen that all of the design methods provide conservative predictions of the shear strengths of the tested beams (V_{exp} / V_{pred} > 1). The experimentally obtained shear strength is more than all predicted values.

TABLE VII

SHEAR CAPACITY PREDICTION METHODS FOR CONCRETE REINFORCED WITH FRP [7]

Prediction methods	**Shear capacity in concrete. V_c (N)**	**Shear capacity in FRP stirrups, V_s (N)**
ACI 440.1R (2006)	$V_s = \frac{2}{5}\sqrt{f'c}bc$ Where $c = kd$ $k = \sqrt{2\rho_f n_f (\rho_f n_f)^2} - \rho_f n_f$	$V_S = \frac{A_{fv} f_{fv} d}{s}$ Where $f_{fv} = 0.004 E_f \leq f_{fb}$
CSA S806 (2012)	$V_C = 0.05\lambda k_m k_r k_a \sqrt[3]{f'c}bd$ for $d \leq 300mm$ $0.11\phi\sqrt{f'c}\text{bd} \leq V_c \leq 0.2\phi\sqrt{f'c}\text{bd}$ $f'c \leq 60\ MPa\ ;\ k_m = \sqrt{V_f d / M_f}$ $k_r = 1 + \sqrt[3]{E_f \rho_f}$ $k_a = (2.5 V_f d) / M_f$ for $a/d < 2.5$	$V_s = \frac{A_{fv} f_{fv} d_v}{s} cot\theta$ $\theta = 30 + 7000\epsilon_x$ $\epsilon_x = \frac{M_f / d_v + V_f + 0.5 N_f}{2 E_f A_f}$ $d_v = 0.9d\ or\ 0.72h$
ISIS (2007)	$V_c = 0.2\lambda\sqrt{f'c}bd\sqrt{\frac{E_f}{E_s}}$	$V_s = \frac{A_{fv} f_{fv} d_v}{s} cot\theta$ $f_{fv} = E_{fv};\ d_v = 0.9d$ $\epsilon_{ff_v} = 0.001\sqrt{\frac{f'_c \rho_{fl} E_{fl}}{\rho_{fv} E_{fv}}}\left[1 + 2\left(\frac{\sigma_v}{f'_c}\right)\right] \leq 0.0025$
MCFT (Hoult et al. 2008)	$V_c = \frac{0.30}{0.5 + (1000\epsilon_x + 0.15)^{0.7}} \frac{1300}{(1000 + s_{xe})} \sqrt{f'c} b d_v$ $\epsilon_x = \frac{(M_f / d_v) + V_f}{2 E_f A_f}$ $s_{xe} = \frac{31.5d}{16 + a_g} \geq 0.77d$	$V_s = \frac{A_{fv} f_{fv} d_v}{s} cot\theta$

TABLE VIII

EXPERIMENTAL AND PREDICTED RESULTS

Beam	Test Result (MPa)	FRP design codes and theory							
		ACI 440.1-06		CSA S806-12		ISIS-07		MCFT (Hoult et al. 2008)	
		Predicted (MPa)	Test/Predicted	Predicted (MPa)	Test/Predicted	Predicted (MPa)	Test/Predicted	Predicted (MPa)	Test/Predicted
SBS125	0.89	0.47	1.89	0.7	1.27	0.64	1.39	0.58	1.53
SBSB125	0.92	0.46	2	0.68	1.35	0.62	1.48	0.57	1.61
SBB 125	0.95	0.45	2.04	0.67	1.42	0.61	1.56	0.56	1.7

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CONCLUSIONS

The shear behaviour of concrete beams reinforced with BFRP longitudinal bars and with steel and BFRP shear reinforcement has been presented in this study. Fifteen beams were tested for shear strength. The beams were reinforced with same BFRP reinforcement ratios and same shear span to depth ratios. The following conclusions can be made from this study:

1. The load carrying capacity of BFRP reinforced beams is more than the conventional beams.

2. Shear capacity of SBB125 is more than the other BFRP reinforced beams.

3. Crack pattern is different in all beams and for BFRP RC beams shear cracks are detected mainly, they are seen at the supports. After the release of load the flexural cracks formed are suddenly disappeared and the shear cracks are diminishing proving the elastic property of basalt rebars. This property is useful for the construction of structures in the earthquake prone areas

4. Deflection of the beam increases with the replacement of steel with BFRP. It can take more loads without much deflection.

5. The experimentally obtained values are more than the predicted values by design codes and theory. All of the design methods provide conservative predictions of the shear strengths of the tested beams ($V_{exp} / V_{pred} > 1$).

The shear failure can be eliminated by using more shear reinforcements at the supports. Shear capacity can be increased by using shear reinforcements having smaller diameter and also by using more longitudinal reinforcements.

NOTATIONS

A = area of longitudinal reinforcement (mm^2);
a_g = aggregate size (mm);
b = width of cross section (mm);
d = distance from extreme fiber in compression to centre of reinforcement (mm);
d_v = effective shear depth (taken as the greater of 0.9d or 0.72h) ;
E = modulus of elasticity of longitudinal FRP reinforcement (MPa) ;
E_s = modulus of elasticity of longitudinal steel reinforcement (MPa ;
f'_c = concrete compressive strength (MPa);
f_u = ultimate tensile stress in longitudinal reinforcement (MPa);
M_f = factored moment applied (kNm);
N_f = factored axial load applied (kN);
s_{ze} = crack spacing (mm) ;
V_c = shear strength of concrete (kN);
V_{exp} = experimental shear force (kN);
V_f = factored shear force (kN);
V_s = shear strength of transverse reinforcement (kN);
λ = factor for concrete density (taken ¼ 1 in this study);

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