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Flexural Behaviour of Concrete Slab Reinforced Withbasalt and Steel Rebars

S.Ramamoorthy[1]kl.Muthuramu[2]l.K. Rex[3]
[1]*Associate Professor& Head, Dept. of Civil Engg.*
Agni College of Technology, Chennai – 600 025, Tamilnadu, India
Corresponding author e-mail: ramamoorthy.cvl@act.edu.in
[2]*Professor and Principal*
Shanmuganathan EngineeringCollege, Pudukottai - 622507, Tamilnadu, India
[3]*Associate Professor & Head, Dept. of Civil Engg.*
Surya Group of Institutions, Vikravandi – 605 652, Tamilnadu, India

Abstract: *Theresearch study presents the results of an experimental investigation thatwas carried out toevaluate the performance characteristics of concrete slabs reinforced with Basalt Fiber Reinforced Plastic (BFRP) rods. The fundamental objective of this investigation was to experimentally determine the load-deflection behaviour of the concrete slab reinforced with basalt rod and compare it with concrete slab reinforced with conventional steel rebars.Slabsusing M30 grade concrete of size 1000mm x 1000mm and100mm thick were cast. The slabswere tested for 28 days curing strength under static flexural loading. The loads were applied through a high accuracy load cell with a load sensitive of 0.1Tonnes and mid span deflection was measured using dial gauges of least count 0.01mm. The study parameters includedload-deflection behaviour, crack patterns and modes of failures of the specimens.Theslabs had considerable cracking and large deflections before ultimate failure. The concrete slabsfailed primarily in flexure.From the experimental investigations, it was inferred that slabs with basalt rebars hadadequate load carrying capacitywithstanding high deflections and therefore they could be effectively used as alternative reinforcement in flexural members of concrete.*
Keywords: *BFRP, cracks, flexure, load-deflection, steel rebar*

I. Introduction

One of the major problems the construction industry faces today is corrosion ofreinforcing steel, which profusely plays a vital role in the life and durability of concrete structures. Basaltrebars can effectively counter this problem due to the properties like inhibiting corrosion, hightensile strength, low young's modulus, lightweight and resist electrical conductivity. This rebar consists of 80% fibers and has a tensile strength three times that ofthe steel rebar normally used in building construction. It is made by utilizing a resin (epoxy)binder [1]. Currently many FRP rebars (made of E-glass fiber and thermosetting resin) lack sufficient durability under extreme environments. The material costs of these bars are also costly and are not resistant to alkalis [2-3]. Nevertheless, basalt rebars do not possess these disadvantages and can be effectively used in various applications such as highway barriers, offshore structures and bridge decks.

The key aspect of this research work is the detailed study of non-corrosive basalt fiberrebar.

Basalt rebar having full resistance against corrosion may be a potential source of use as an alternative reinforcement in concrete members/structures subjected to environmental attack [13].

Basalt fiber composite rebars have the potential to replace steel in reinforced concretestructures exposed to salt water, ocean climate, etc and wherever the corrosion problem exists.Other advantages of the basalt rebar are that its weight is one-third of the weight of steeland the thermal expansion coefficient is very close to that of concrete. The high mechanicalperformance to price ratio of basalt fiber composite rebar, combined with corrosion resistance toalkaline attack are further reasons, for replacing steel in concrete by basalt fiber compositerebars.

There is no published information available on the flexural behaviour of concrete slab reinforced with basalt fiber compositerebar and therefore there is a need for this research.This investigation was undertaken to evaluate the performance of concrete slabsreinforced with the basalt fiber composite rebars. The following were the objectives ofthe research.

o To determine the ultimate failing load
o To study the load-deflection behaviour
o To study the crack patterns

II. Experimental Programme

2.1 Test Materials

In this study, the materials used, tests conducted on themto determine its properties and their results were discussed. The cement used was Ordinary Portland Cement (OPC) 43 grade with specific gravity = 3.15 conforming to IS 8112:2013. Natural river sand with specific gravity = 2.65, fineness modulus = 3.91, water absorption = 1.0% andparticle size distribution = grading zone II was usedin this work conforming to IS 2386 (Part 1): 1963. Crushed stone angular aggregate of maximum size 20 mm with specific gravity = 2.88, fineness modulus = 6.99, water absorption = 0.6% was used in this work conforming to IS 2386 (Part 1): 1963. Potable water conforming to IS 10500: 2012was used for mixing of concrete making materials.Basalt Fibre Reinforced Polymer (BFRP) - basalt rebarshown in Fig. 1 was used as reinforcement in concrete slabspecimens and its properties are given in Table 1 to 4.

Fig.1 Basalt Fibre Reinforced Polymer (BFRP) Rods

Table 1 Physical Properties of BFRP

Diameter	Wt.per40'	ShearStrength	UltimateTensile Strength	TensileModulus	ElongationatBreak
mm	lbs	MPa	MPa	GPa	%
8 mm	3.7	201	1200	57	2.24
10 mm	4.85	208	1160	56	1.95
12 mm	9.47	219	1155	55	1.88
16 mm	18.37	225	1120	52	1.31

Table 2 Chemical Properties of BFRP

SiO_2	53%
Al_2O_3	17%
Fe_2O_3	10%
CaO	8.5%
MgO	4.5%
Na_2O	3.3%
K_2O	1.5%
TiO_2	1.4%
Others	0.8%
Note: Rebar is 80% Basalt, 20%Epoxy,Dacron,and Sand	

Table 3 Thermal Properties of BFRP

Service Temperature	270-650°C
SofteningTemperature	1050°C
Thermal Conductivity	0.035 W/m°K
Tensile StrengthRetained, 200°C	95%
After Exposureto Heat, 400°C	82%
Weight Loss,boiled 3 hr,2NHCl	2.2%
Weight Loss,boiled 3 hr,2NNaOH	6.0%

Table 4 Comparison of Material Properties of Basalt Rod and Steel Rebar

Properties		BasaltRod		SteelRebar	
		Publishedvalues	Test values	Published values	Test values
Weight	kg/m^3	1900-2100	1909	7800-7900	-
Tensilestrength	MPa	700	1143	450	525
Young'smodulus	GPa	40	52	210	206
Poisson'sratio		-	-4	0.30	-
Elongation	%	1.8	-	18	-
Coefficient ofthermalexpansion	10^6%c	9-12	-	11.7	-
Residual strength of bars subjected to heat	%	@20°c-100% @200°c-100% @400°c-100% @600°c-100%	-	-	@20°c-100% @200°c-18% @400°c-42% @600°c-18%

The concrete mix design was performed according to IS 10262: 2009 and the quantities of the mix proportion were cement content = 413 kg/m^3, fine aggregate = 698.94 kg/m^3, coarse aggregate = 1192.70kg/m^3 and water (w/c ratio of 0.45) = 200.25 kg/m^3. The final concrete mix proportion was = 1:1.69:2.88. The slab specimenswere then cast, demoulded after 24 hours, kept under curingfor a period of 28 days and tested.

2.2 Test Plan

The experimental programme was conducted to compare the flexural performance of concrete slabsreinforced with basalt rod to that of conventional steel rebar.The experimental work consisted of casting slabsof size1000mmx1000mm and 100mm thick.The grade of concrete and steel used was M30 and Fe415 respectively. The study parameters included load-deflection behaviour, failure load and crack patterns. Theslabswere tested for flexuralstrength in a loading frame of 100 tonscapacity until failure. The reinforcement details of test slabsare furnished in Table 5 and the sequence of casting to curing of slab specimens are shown through Figs.2 to 5.

Table5Details ofSlab Specimens

Slab ID	Slab Size	Typeof Reinforcement	MainReinforcement	DistributionReinforcement
S1	1000x1000x100	SteelRebar	8φ @150mm c/c	8φ @150mm c/c
S2	1000x1000x100	Basalt Rebar	8φ @150mm c/c	8φ @150mm c/c

2.3 Test Procedure

Simply supported RCC slabs were subjected to pure flexural failure by subjecting them to central point load test. The slabs used in this study were 1000mm x 1000mm in size with a thickness of 100mm. Basalt and steel rebars of 8mm diameter were used as main and distribution reinforcements at spacing of 150mm c/c. These slabs were tested for flexural strength in Universal Testing Machine of capacity 100 tonnes. The loads were monitored through a high accuracy load cell with a load sensitive of 0.1tonnes. For this case, mid span deflection was measured using dial gauges of least count 0.01mm. The parameters such as initial cracking load, ultimate load and the deflected shape of the specimens were noted.The details of the test set-up and instrumentation is shown in Fig. 6.

Fig.2 Fixing of Reinforcements

Fig.3Placing of Concrete

Fig.4Finishing of Concrete

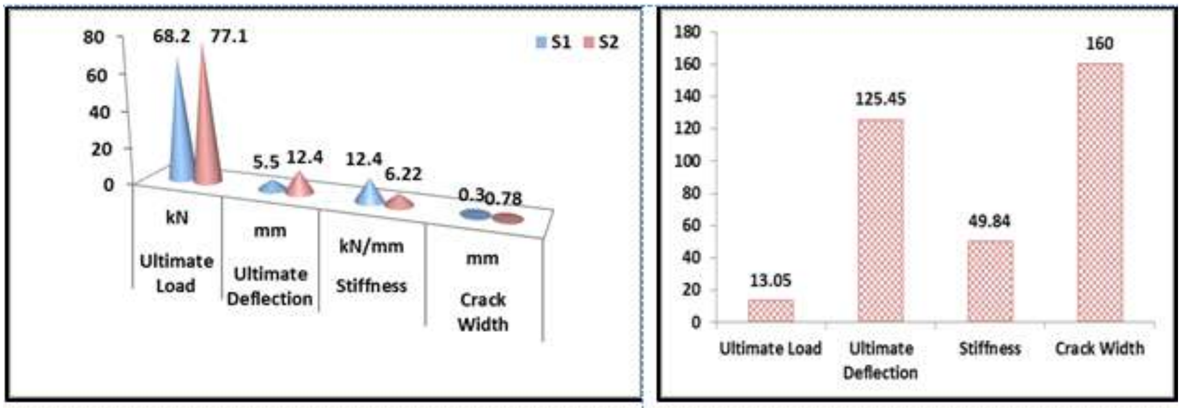
Fig.5Curing Process

III. Test Results And Discussion

The test results of slab subjected to static flexural loading are presented in Table 6 and Fig.7. The parameters considered for discussion are the failure load, deflection at ultimate load, stiffness, crackwidth and failure modes.

Table 6 Test Results of Slab Specimens

Slab ID	**Ultimate Load**	**Ultimate Deflection**	**Stiffness**	**Crack Width**	**Failure Mode**
	kN	**mm**	**kN/mm**	**mm**	
S1	68.20	5.50	12.4	0.30	Flexural failure
S2	77.10	12.40	6.22	0.78	Flexural failure
% Variation of S2 w.r.t S1	13.05	125.45	49.84	160	-



a. Test Results of Slab Specimens **b. % Variation of S2 compared to S1**

Fig. 7 Graphical Representation of Slab Test Results

3.1 Strength Behaviour

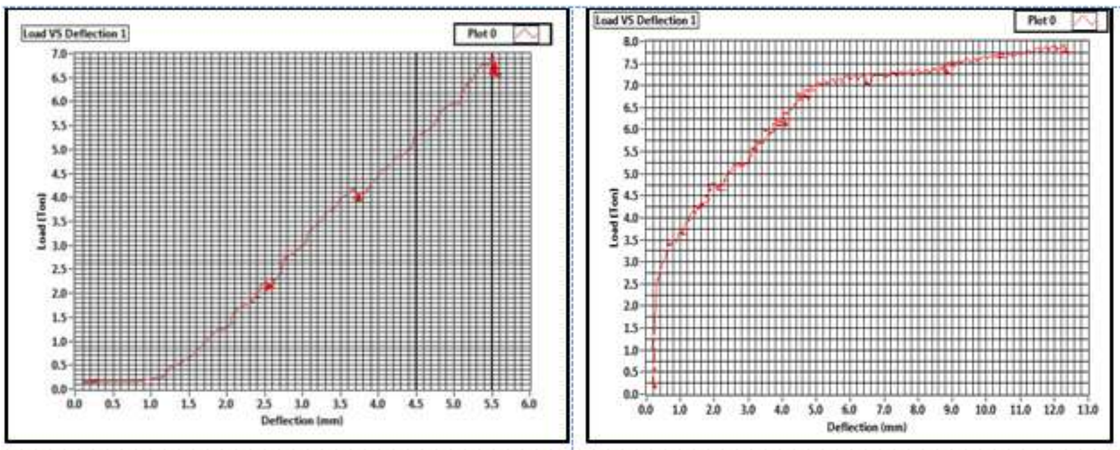
The reinforcement for the slabswas designed as per IS 456:2000 minimum reinforcement requirements. The diameter and spacing of reinforcements in both the directions were kept same inorder to achieve the two-way effect of bending. The strength capacities of the slabs using two different types of reinforcements under static load were recorded (Table 6) and its flexural behaviour under static load application was analysed. From the analysis of test results, it was observed that the slab with BFRP rebar sustained higher load than the slab with conventional rebar. Hence, the rate of increase in load carrying capacity of S2 is 13.05% more than S1. Since the failure of the BFRP slab occurred at a higher load-carrying rate, the deflection of the slab was also marginally higher than the slab with conventional rebar. Hence, the rate of increase in bending of S2 is 125.45% more than S1. The rate of variation in stiffness of slab S2 was 49.84% compared to slab S1 due to the effect of tension stiffening in reinforcement.

3.2 Load-Deflection Behaviour

The load-deflection response of the test specimens helps to identify major changes in their behaviour and load carrying mechanisms. Significant behavioural differences are expected since the slabs were reinforced with different types of reinforcements. The load-deflection curves show that all slabs behaved similarly in the uncracked stage. The early kink in the load-deflection curves signals the formation of first flexural cracks. The cracking loads and the corresponding deflections for all slabs were recorded. As the load increased, the cracks spread from inner to outer slab regions following the reinforcement layout.

In slab S1 (Fig.8a), first flexural cracks formed simultaneously in both directions. First yielding of steel reinforcement was observed at about 3.5mm deflection and yielding of bars spread to all faces at 5.5mm deflection.

In slab S2 (Fig.8b), first flexural cracks formed simultaneously in both directions. First yielding of steel reinforcement was observed at about 5.5mm deflection and yielding of bars spread to all faces at 12.5mm deflection.



a. Conventional Rebar Slab (S1) **b. BFRP Rebar Slab (S2)**

Fig. 8 Load-Deflection Behaviour

3.3 Cracksand Failure Modes

The configuration of the test slab specimens were designed to fail in bending. Tests indicated that flexural failure dominated. No indication of shear failure occurred in any of the test specimens. Crack widths (Fig.9)are average values from crack width measured in all four directions from the loading point. The crack width of slab S1 was about 0.30mm, which in slab S2 was two to three times greater. At a given load, cracks tend to be wider as the stiffness of the reinforcement decreases. For deflections lower than 4mm, the crack widths in the slab S1 were narrower and for greater deflections, slab S2 displayed wider cracks. The percentage increase in crack width of slab S2 was 160% than slab S1,which had resulted in an ultimate crack resistance property at higher loads.

Fig. 9 Crack Pattern of Slabs

IV. Conclusions

From the above experimental investigations on the slab specimens subjected to flexure, the following conclusions were drawn:

1. The increase in load carrying capacity of BFRP slab S2 was 13.05% higher than conventional reinforcement slab S1.
2.The increase in bending capacity of BFRP slab S2 was 125.45% higher than conventional reinforcement slab S1.
3. The rate of variation in stiffness of slab S2 was 49.84% than that of slab S1.
4. The crack resistance of slab S2 was higher by 160% that that of slab S1.

In overall, the slabs reinforced with BFRP rebars S2 exhibiting higher load carrying capacity with higher level of bending the thickness of slab shall be reduced to $1/3^{rd}$ of thickness required using conventionalsteel reinforcement. In addition, the density of BFRP rebars are much lesser than the conventional steel reinforcement and hence the self-weight of the concrete members shall be reduced considerably.The results of deflections indicate adequate ductility of the structural members. In general, the basalt rebars fits into an appropriate alternative equivalent to conventional steel reinforcements foruse in reinforced concrete structures.

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