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Flexural Behaviour of Sand Coated GFRP Reinforced Flanged Beams

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Abstract- Non metallic reinforcements are emerged as an excellent alternative material to the conventional steel bars in the construction industry in recent times. Among this FRP bars like reinforcements are being used internally in the concrete members instead of steel bars because of its higher tensile strength and durability. Hence, this study mainly focuses on the flexural behaviour of reinforced concrete flanged beams reinforced with Glass Fibre Reinforced Polymer (GFRP) reinforcements under Static Loading. Firstly, the preliminary laboratory tests to assess the basic properties of Normal Strength Concrete (NSC), Steel and sand coated GFRP reinforcements and the results are presented. Secondly, the experimental investigations of the flexural behaviour of flanged beams reinforced with sand coated GFRP reinforcements under static loadings are compared with that of flanged beams reinforced with conventional steel reinforcements. A total of six beams are cast out of which three reinforced with conventional steel reinforcement and remaining three reinforced with sand coated surface treated GFRP Reinforcements, three different reinforcement ratios of 0.82%,1.24% and 2.06% are considered. The static load carrying capacities of conventional steel and sand coated GFRP reinforced flanged beams are then compared. The sand coated GFRP reinforced beams had a good agreement with the conventional steel reinforced beams.

Keywords- *Flanged beam, Glass Fibre Reinforced Polymer (GFRP), Flexural Behaviour, static Loading, Sand coated.*

I. INTRODUCTION

Composite materials offer an excellent alternative for multitude of uses, primarily because of their high performance and light weight qualities. Today, their potential is being harnessed in many ways. Advanced composite materials have many desirable properties, such as high performance, high strength to weight ratio, high stiffness to weight ratio, high energy absorption, outstanding corrosion resistance and fatigue damage resistance. Fibre reinforced polymer (FRP) composites have emerged as an evolutionary link along with conventional building materials such as steel, concrete, aluminium and wood. FRP bars are produced from varieties of fibres, e.g., carbon, glass, aramid, boron, alumina, polyvinyl alcohol and silicon carbide which are available in rowing, strands and chopped formats. These fibres are usually bonded together with the help of such binding agents as resins and cements and are used to produce rods, strands, sheets and mats. These find very large application in load bearing structures, repair and rehabilitation of existing structures. Their mechanical properties are highly dependent on the type of binding agents used as well as the method of processing and the shape. They behave as linearly elastic up to failure (ACI 440R-96 1996; ACI 4401R-01 2001; ACI Committee 440 XR 2007**;** Benmokrane 2001; ISIS Canada Design Manual 2001; Nanni 1993). Well established studies available for slabs, rectangular beams, columns, beam column joints (Aiello 2000; Houssam 2000; Abdalla 2002; Ashour 2005; Benmokrane 1995; Bank C Lawrence 2006: Sivagamasundari 2008; Barris 2009; Chabib Kassem 2011; Deiveegan 2011, Jagadeesan Saravanan 2011). But flanged beams with non-metallic reinforcements are not explored so far. Therefore the present study mainly discusses the behaviour of concrete flanged beams internally reinforced with GFRP reinforcements under static loading.

II. MATERIALS

All the beams are designed and cast using NSC of 20 MPa based on mix design as per IS 10262-2009 and IS 456 - 2000. The properties of concrete are listed in Table 1. The sand coated GFRP reinforcements (Fs) used in this study are manufactured by pultruded process (Ercon Composite Industries Ltd., India; and Hydro S&S Industry Ltd., India). The GFRP reinforcement is shown in Figure 1, and the gripping arrangement for tensile test is shown in Figure 2. The mechanical properties of all the types of GFRP reinforcements are obtained from following tests prescribed as per ASTM Standards (ASTM-D 3916-84). The various properties of reinforcements obtained through laboratory experiments and the results are presented in Table 2. The tensile test setup of GFRP reinforcements is shown in Figure 3, and the failure mode of GFRP reinforcement are shown in Figure 4. The stress- strain curve of conventional steel and GFRP reinforcement are shown in Figure 5.

Figure 1. Sand Coated GFRP Reinforcement

TABLE I. PROPERTIES OF CONCRETE

Description	*M 20 grade*
Design Mix Ratio	1:1.76:3.14
W/C Ratio	0.45
Average Compressive Strength of Concrete Cubes (MPa)	28.75
Modulus of Elasticity (MPa)	26,575

TABLE II. PROPERTIES OF REINFORCEMENTS

Properties	*Steel (F_e)*	*Sand Coated GFRP (F_s)*
Yield strength (MPa)	490	690
Longitudinal elastic modulus (GPa)	218	69.0
Compressive strength (MPa)	572	334
Strain	0.014	0.029
Poisson’s ratio	0.26	0.22

Figure 2. GFRP Reinforcement with End Anchorages for Tensile Test

Figure 3. GFRP Reinforcement under Tension Test

Figure 4. Tensile Failure Mode of GFRP Reinforcement

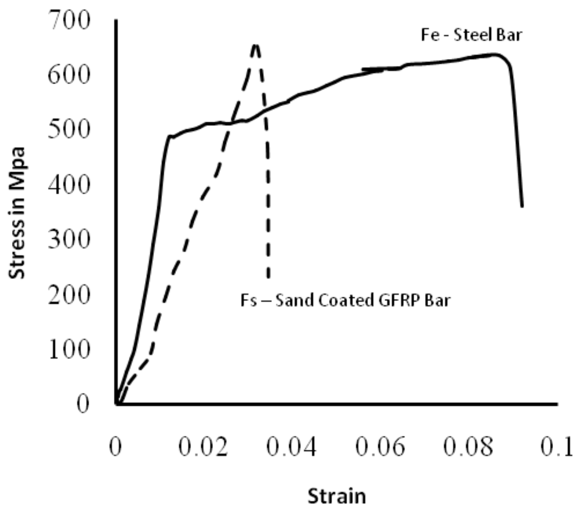
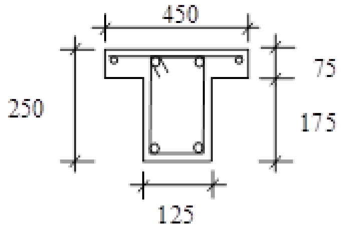


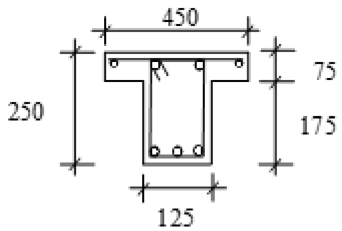
Figure 5. Stress-Strain Curve for Steel and GFRP Reinforcements

III. EXPERIMENTAL TEST SETUP AND INSTRUMENTATION

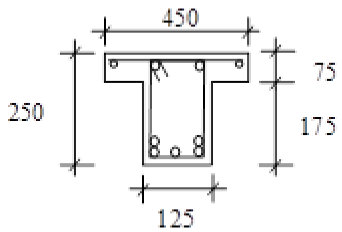
The testing program consists of six beams that are subjected to static loading. Load frame of capacity 50 tonnes is used for testing the beam specimens. Beams are supported with following end condition; i.e. one end of the beam rests on roller support and the other end rests on hinged support. Two point loading (line loads) system is used with the help of spreader beams. Thick rubber or neoprene pads are kept under the spreader beams to avoid local effects. The support end levels of the beams are maintained properly by spirit levels. The static loads are applied with the help of hydraulic jack manually (250 kN capacity) and are monitored by proving ring. The deflections or deformations of the beams are measured by dial gauges, LVDTs and Demec gauges. Dial gauges are fixed at centre, one-third load points and at supports. To measure strains with help of Demec gauges, a standard gauge distance is required and it is done with the help of brass pellets pasted at a known distance at top, bottom and centre fibres on the face of the beam. Apart from these, LVDTs of range 0-100 mm are used at mid span and at one-third load points to monitor vertical deflections. The load is gradually applied with an increment of 2.5 kN up to the failure of the beams. The crack widths are measured periodically by using crack width detection microscope. The beams with various reinforcement ratios are shown in Figure 6. The varying parameters including type of reinforcements, grade of concrete and reinforcement ratios considered in this study are given in Table 3. The test set up is shown in Figure 7. The testing of beams is shown in Figure 8.



(a)



(b)

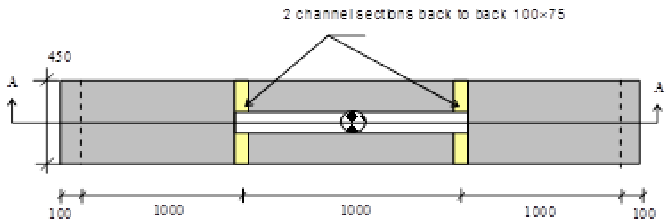


(c)

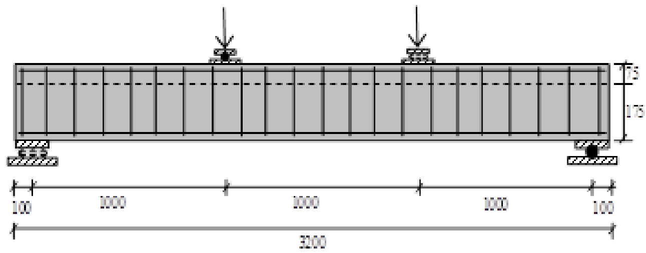
Figure 6. Reinforcement Details of Specimens: a) 2-Y12 top and bottom, 8Y stirrups 2L-150c/c ; b) 2-Y12 top and 3-Y12 bottom, 8Y stirrups 2L-150c/c c) 2-Y12 top and 5-Y12 bottom, 8Y stirrups 2L-150c/c

TABLE III. VARIOUS PARAMETERS INVOLVED IN BEAM SPECIMENS

Parameters	*Description*	*Designation*
Types of reinforcements	Conventional steel	*Fe*
	Sand coated GFRP	*Fs*
Grades of concrete	M20	*m*
Reinforcement ratios	0.82%	ρ_1
	1.24%	ρ_2
	2.06%	ρ_3



(Top view)



(All dimensions are in mm)

Figure 7. Schematic Diagram of Experimental Test Setup

Figure 8. Flexure Test of Flanged Beams under Static Loading Condition

IV. RESULTS AND DISCUSSION

All the six flanged beams are tested and observed various parameters. The results obtained from all the beams are presented in Table 4. The typical crack patterns of beam specimens are shown in Figure 9. The results are depicted in the form of graphs are shown in Figures 10 to 12. The first crack load, the ultimate static load and ultimate deflection for various beams are compared and are presented in the form of bar charts are shown in Figures 13 to 15.

TABLE IV. EXPERIMENTAL RESULTS OF THE FLANGED BEAM SPECIMENS

Sl. No.	Designation of Beams	Ultimate Load P_u (kN)	First Crack Load P_{cr} (kN)	Ultimate Deflection δ (mm)
1	$BmF_e\rho_1$	62.5	27.50	52.0
2	$BmFs\rho_1$	82.0	20.0	77.5
3	$BmF_e\rho_2$	82.5	12.5	44.0
4	$BmFs\rho_2$	95.0	17.5	68.0
5	$BmF_e\rho_3$	102.5	25.0	22.0
6	$BmFs\rho_3$	132.5	20.0	40.0

(a)

(b)

Figure 9. (a) Steel Beam, (b) Sand Coated GFRP Beam Typical Crack Patterns of Beam Specimens

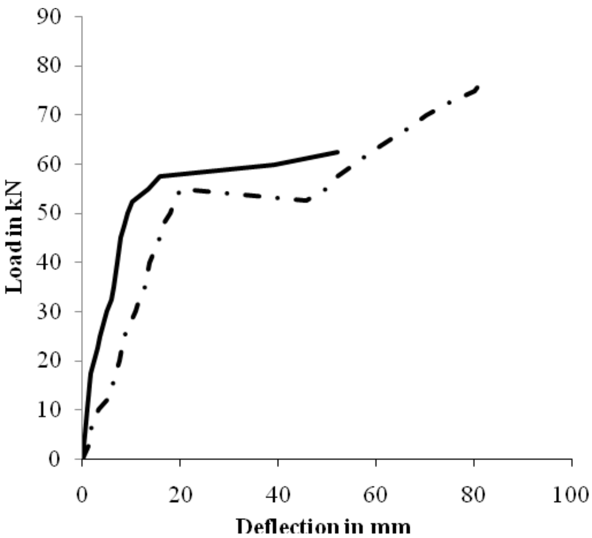


Figure 10. Load versus Deflection of Beams (Series 1)

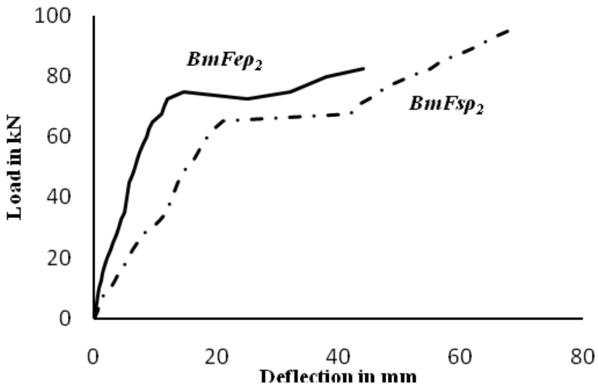


Figure 11. Load versus Deflection of Beams (Series 2)

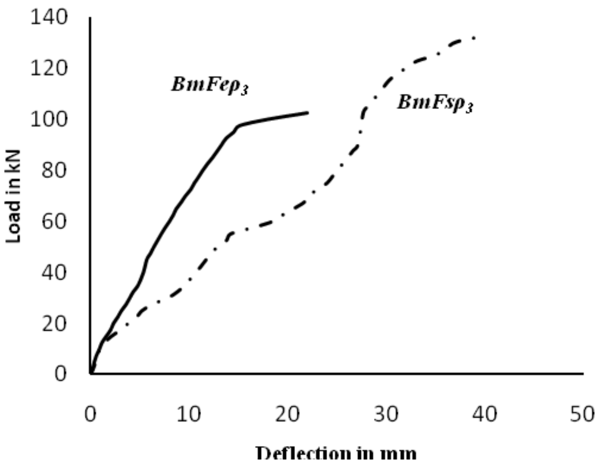


Figure 12. Load versus Deflection of Beams (Series 3)

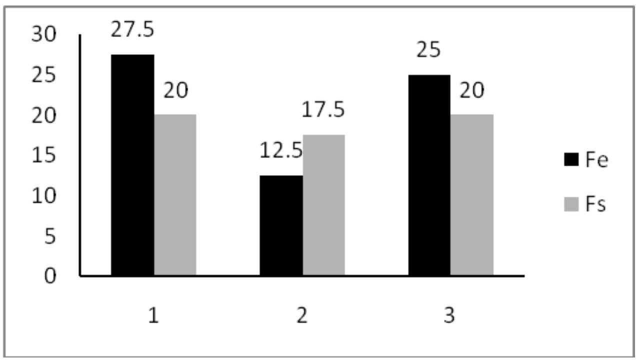


Figure 13. Comparison of First Crack Load for Various Beam Series

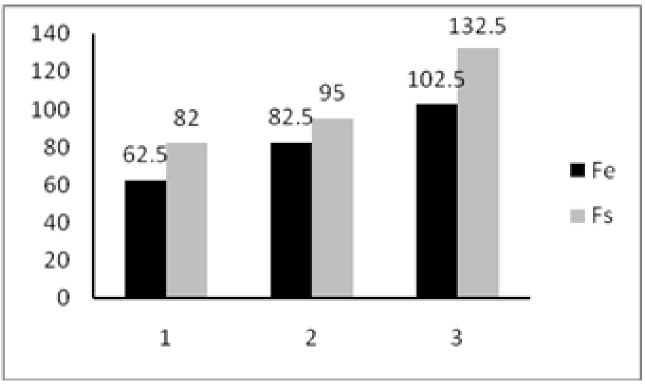


Figure 14. Comparison for Ultimate Load for Various Beam Series

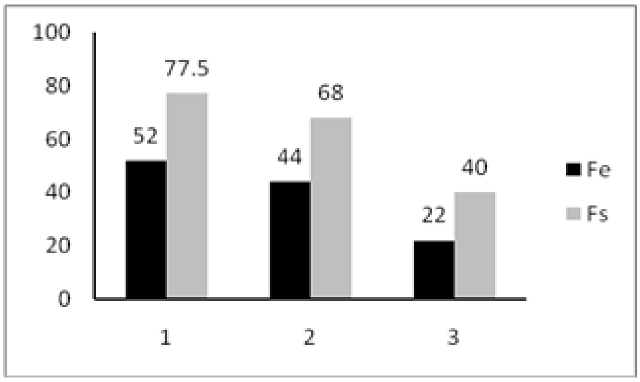


Figure 15. Comparison of Ultimate Deflection for Various Beam Series

The first crack load observed in series I and series III beams are showing the increase in first crack load in steel reinforced beams when compared to GFRP reinforced beams. At the same time the first crack load observed in series II beam showed that increase in first crack load for GFRP reinforced beams when compared with conventional steel beams. It shows that the effect of percentage of reinforcement in steel beams observed clearly of increasing first crack load at lower and higher reinforcement ratio beams. The effect of reinforcement ratio in GFRP beams for first crack load is negligible and indicates almost same amount of first crack load.

The ultimate load carrying capacity is increased with increasing in percentage of reinforcement, and the same is observed in all the three series beams of both conventional steel and GFRP reinforced beams.

The ultimate deflection observed in conventional steel beams with increasing percentage of reinforcement shows the reduction of ultimate deflection. The ultimate deflection observed in GFRP reinforced beams are having similar trend observed in steel beams.

Hence, it is concluded that sand coated GFRP reinforced beams performs better than conventional steel reinforced beams at ultimate load level in all series of beams. Also the ultimate deflection of sand coated GFRP beams (Series 1, Series 2 and Series 3 observes 49%, 54% and 81% respectively higher than that of steel reinforced beams.

V. CONCLUSION

The following conclusions are made from the above experimental study.

1. The first crack load observed in conventional steel reinforced beams are 27.5 kN, 12.5 kN and 25 kN for beams having 0.82%, 1.24% and 2.06% of reinforcement respectively.
2. The first crack load observed in sand coated GFRP reinforced beams are 20 kN, 17.5 kN and 20 kN for beams having 0.82 %, 1.24 % and 2.06 % of reinforcement respectively.
3. The first crack load of sand coated GFRP reinforced beams of series 2 shows 40% higher, whereas series 1 and series 3 beams shows 27% and 20% lower than that of corresponding steel reinforced beams.
4. The ultimate load carrying capacity of steel reinforced as well as GFRP reinforced beams shows increasing in load carrying capacity while increase in percentage of reinforcement.
5. The ultimate load of sand coated GFRP beams series 1, series 2 and series 3 are 31%, 15% and 29% respectively higher than that of steel reinforced beams.
6. The ultimate deflection observed in conventional steel reinforced beams shows reduction in deflection, when increase in percentage of reinforcement. The ultimate deflection observed in GFRP reinforced beams are showing similar trend as observed in steel reinforced beams.

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