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Flexural Behaviour of Flanged Beams Internally Reinforced with Non-Metallic (GFRP) Reinforcements

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Abstract: *Fibre Reinforced Polymer (FRP) composites are being used as reinforcements in concrete structures now a days. The FRP reinforcements can be replaced the conventional steel bars in structural elements and found superior because of its higher tensile strength and durability. Hence this study focuses mainly 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 threaded GFRP reinforcements and the results are presented. Secondly, the experimental investigations of the flexural behaviour of flanged beams reinforced with threaded 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 another three reinforced with threaded types of 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 threaded GFRP reinforced flanged beams are then compared. The threaded 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,*

I. Introduction

Fibre Reinforced Polymer (FRP) materials are well recognized as a vital constituent of the modern concrete structures. The superiority of the FRP materials, in comparison with other conventional building materials like timber, steel and reinforced concrete, lies in its improved structural performance, in terms of stability, stiffness, strength (including improved resistance to fatigue loading) and durability (ACI 440R-96 1996[1];. Nanni 2000[2]). Other factors include convenience in mass production with high quality control and relative economy. The most commonly used fibres in the production of FRP are glass, carbon and aramid. 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, mats and pultruded profiles. 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 4401R-01 2001[3]; ACI Committee 440 XR 2007[4]**;** ISIS Canada Design Manual 2001[5]). Well established studies available for slabs, rectangular beams, columns, beam column joints (Bank C Lawrence 2006[6]: Sivagamasundari 2008[7]; Deiveegan 2011[8], Jagadeesan Saravanan 2011[9]). But flanged beams with FRP reinforcements are not explored so far. Therefore the present study discusses mainly the behaviour of concrete flanged beams internally reinforced with threaded GFRP reinforcements under static loading.

II. Materials

All the beams are designed cast using NSC of 20 MPa based on mix design as per IS: 10262-2009[10] and IS: 456-2000[11]. The properties of concrete are listed in Table 1. The threaded GFRP reinforcements used in this study are manufactured by pultruded process (Hydro S&S Industry Ltd., India). The threaded GFRP reinforcement (Ft) is shown in Figure 1, and the gripping arrangement for tensile test is shown in Figure 2. The mechanical properties of threaded GFRP reinforcement are obtained from following tests prescribed as per ASTM Standards (ASTM-D 3916-84[12]). The various properties of reinforcements obtained through laboratory experiments and the results are presented in Table 2. The tensile test setup of GFRP reinforcement 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 threaded GFRP reinforcements are shown in Figure 5.

Table 1 Properties of Concrete

Description	**M 20 grade (m)**
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)	26575

Table 2 Properties of Reinforcements

Properties	**Steel (Fe)**	**Threaded GFRP (F_T)**
Yield strength (MPa)	490	625
Longitudinal elastic modulus (GPa)	218	61.0
Compressive strength (MPa)	572	317
Strain	0.014	0.031
Poisson's ratio	0.26	0.215

Fig. 1 Threaded GFRP Reinforcement

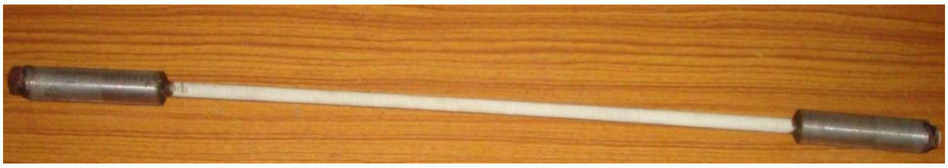


Fig. 2 GFRP Reinforcements with End Anchorages for Tensile Test

Fig. 3 GFRP reinforcement under Tension test

Fig. 4 Tensile Failure Mode of GFRP Reinforcement

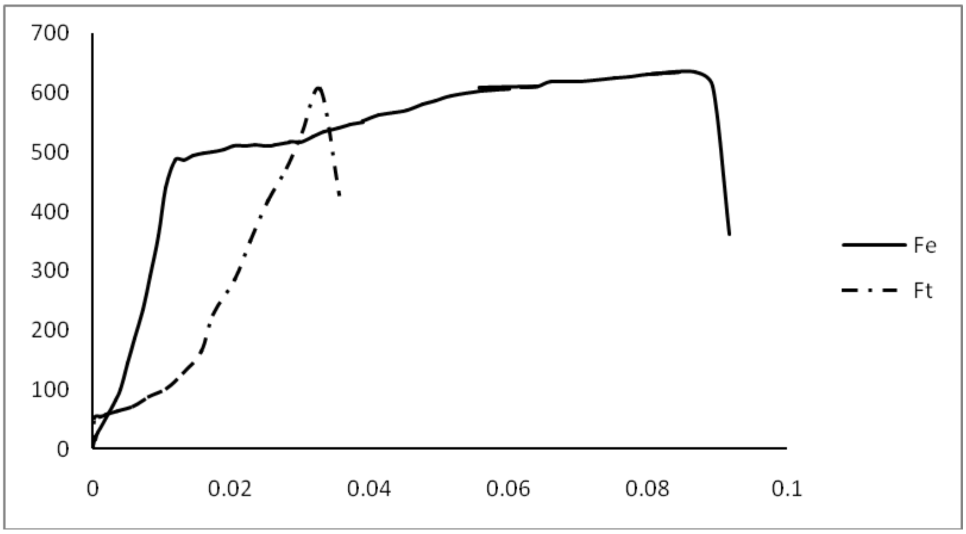
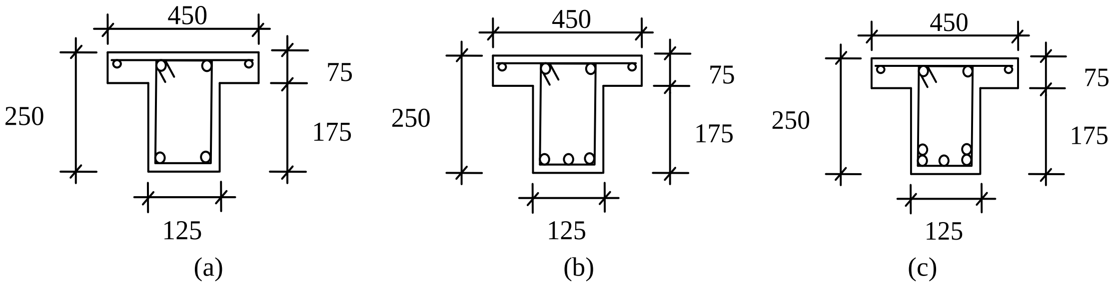


Fig.5 Stress-Strain Curve for Steel and GFRP Reinforcements

III. Experimental Test Setup And Instrumentation

The testing programme 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 were 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.

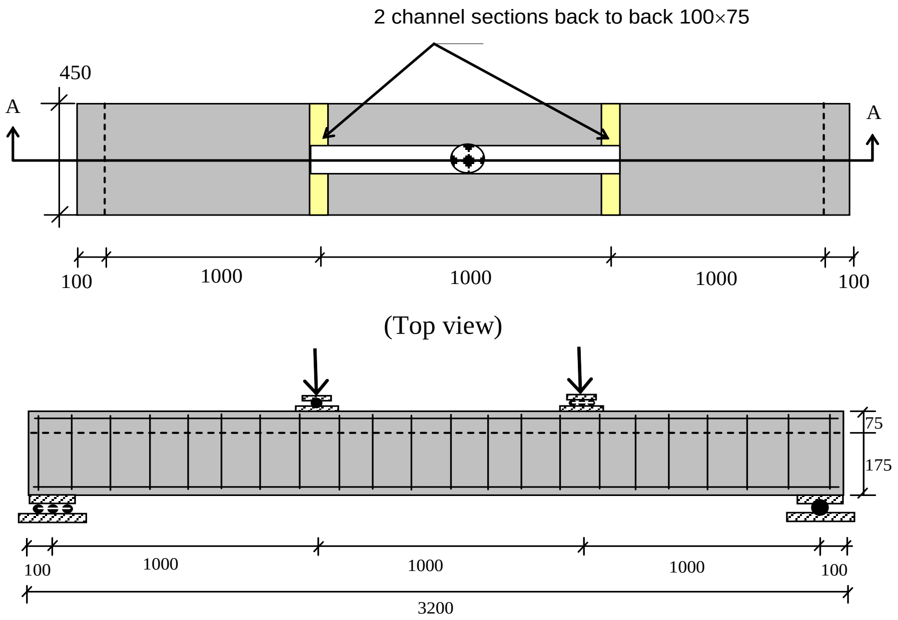


Reinforcements Details: a) 2-Y12 top and bottom, 8Y stirrups 2L-150c/c ; b) 3-Y12 top and 2-Y12 bottom, 8Y stirrups 2L-150c/c c) 2-Y12 top and 5-Y12 bottom, 8Y stirrups 2L-150c/c

Fig.6 Reinforcement Details of Specimens

Table 3. Various Parameters involved in Beam Specimens

Parameters	Description	Designation
Types of reinforcements	Conventional steel	***Fe***
	Threaded GFRP	$\boldsymbol{F_T}$
Grades of concrete	M20	***m***
Reinforcement ratios	0.82%	ρ_1
	1.24%	ρ_2
	2.06%	ρ_3



(All dimensions are in mm)
Fig.7 Experimental Test Setup

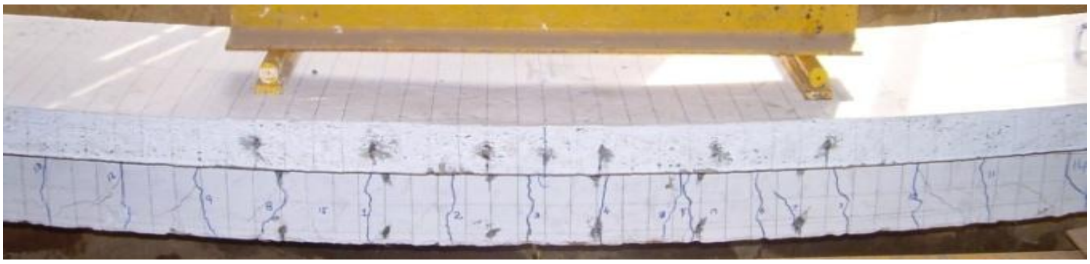
Fig.8 Flexure Test of Flanged Beams under Static Loading Condition

IV. Results And Discussion

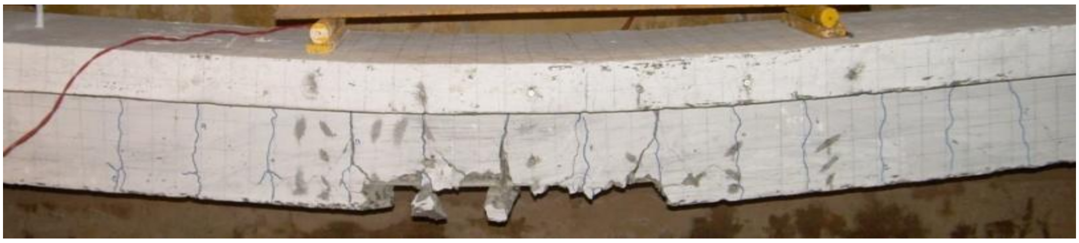
All the six flanged beams are tested and observed various parameters. The results obtained for all the beam specimens are presented in Table 4. The typical crack patterns of beam specimens are shown in Figure 9. The results are depicted in the form of graphs are shown in Figure 10 to 12. The first crack 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.4 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 □ (mm)**
1	$BmF_e\rho_1$	62.5	27.5	52.0
2	$BmF_T\rho_1$	29.5	7.5	17.15
3	$BmF_e\rho_2$	82.5	12.5	44.0
4	$BmF_T\rho_2$	33.0	8.25	18.15
5	$BmF_e\rho_3$	102.5	25.0	22.0
6	$BmF_T\rho_3$	51.5	11.75	32.5



A) Steel Beam



(a) Threaded GFRP Beam

(b) **Fig.9** Typical Crack Patterns of Beam Specimens

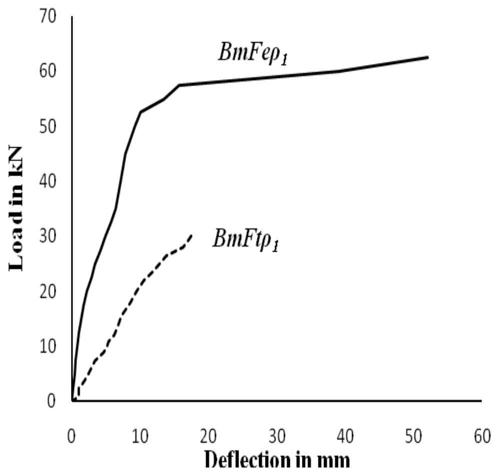


Fig.10 Load versus Deflection of Beams **(Series 1)**

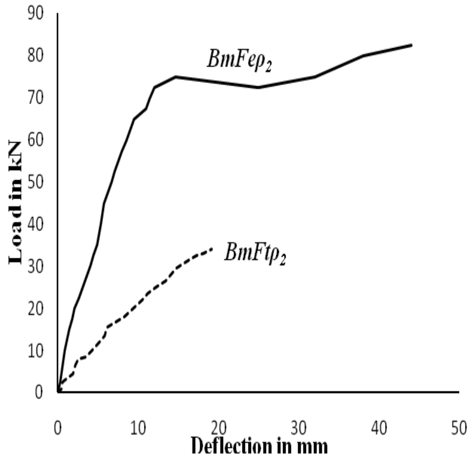


Fig.11 Load versus Deflection of Beams **(Series 2)**

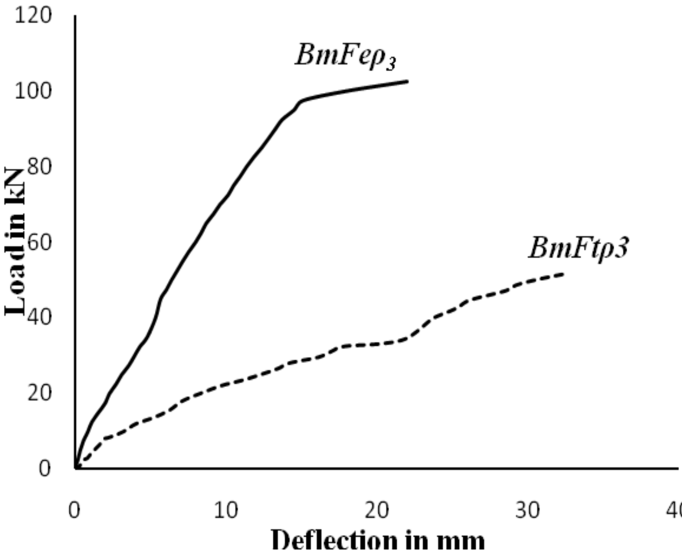


Fig.12 Load versus Deflection of Beams (Series 3)

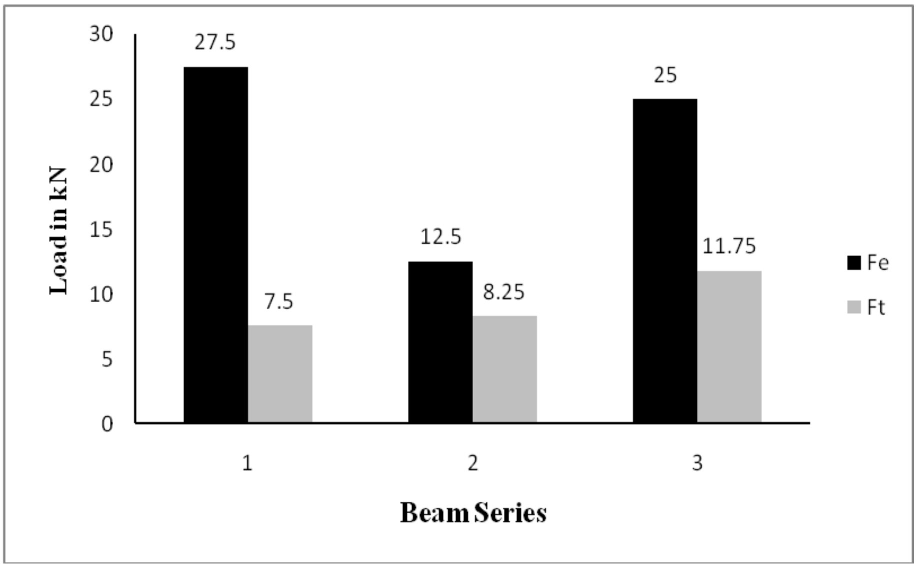


Fig.13 Comparison of First Crack Load for various Beam series

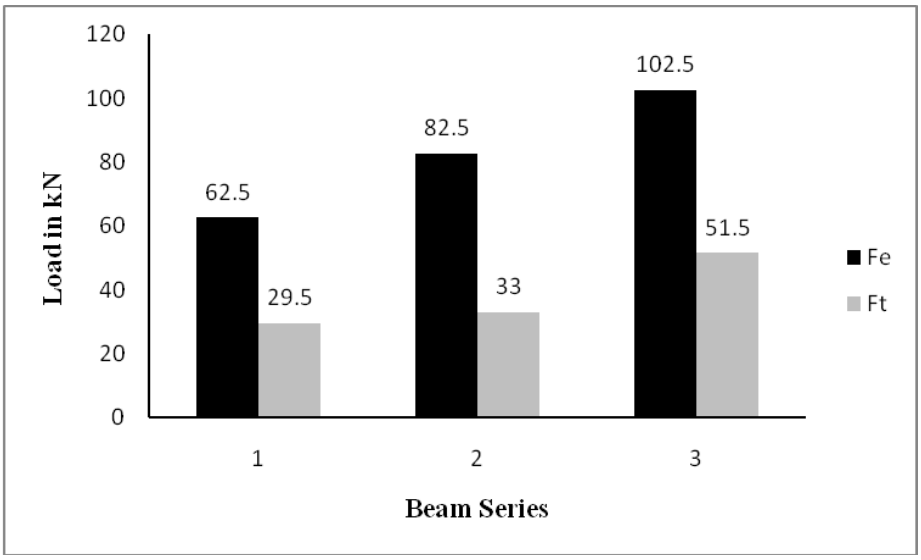


Fig.14 Comparison for Ultimate Load for Various Beam Series

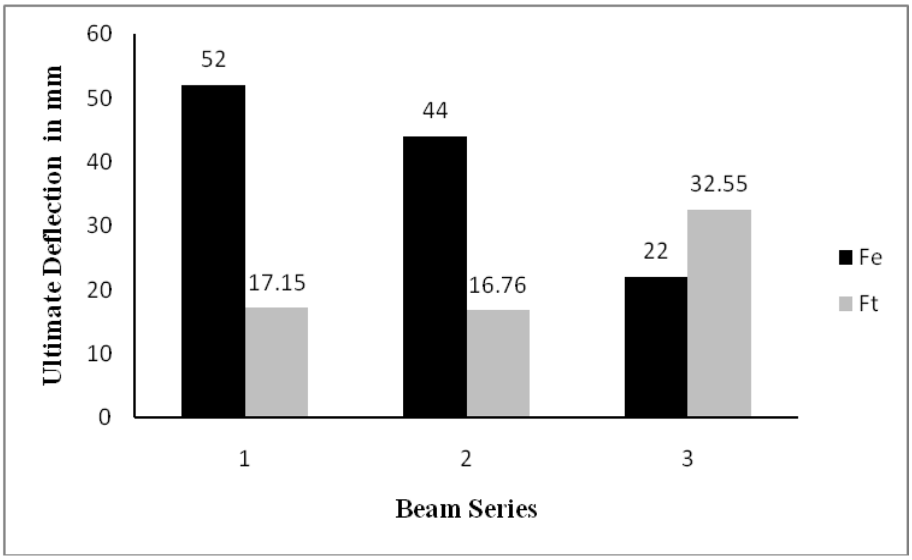


Fig.15 Comparison of Ultimate Deflection for Various Beam Series

The first crack load observed in GFRP reinforced beams of all series is lower when compared to conventional steel reinforced beams. The first crack load observed in steel reinforced beams of series 1and series 3 are almost same value (27.5 kN and 25 kN) but series 2 lower load value (12.5 kN).

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. Whereas the ultimate deflection observed in GFRP reinforced beams are having almost same amount of deflection in series 1 and series 2 beams and increased value in series 3 beams.

V. Conclusion

The following conclusions are made from the above experimental study.

1. The first crack load observed in conventional steel 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 threaded GFRP beams are 7.5 kN, 8.25 kN and 11.75 kN for beams having 0.82 %, 1.24 % and 2.06 % of reinforcement respectively.
3. The effect of GFRP reinforcement in first crack load has increased with increase in percentage of reinforcement.
4. The ultimate load carrying capacity in steel as well as threaded GFRP reinforced beams shows increasing in load carrying capacity when increase in percentage of reinforcement.
5. The ultimate deflection observed in conventional steel reinforced beams shows reduction in deflection, when increase in percentage of reinforcement. But at the same time there is increase in ultimate deflection of GFRP Reinforcement in higher reinforcement of beam (series 3) when compared to lower reinforcement of beam (series 1and series 2).

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