Flexural Study on Non-Metallic (GFRP) Reinforced Concrete Flanged Beams

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Abstract

This study focuses on the flexural behaviour of reinforced concrete flanged beams reinforced with Non-Metallic (GFRP) reinforcements under Static Loading. The parameters considered for the study are M30 grade concrete, Non-Metallic reinforcements with two types of surface treatments and three different reinforcement ratios. The methodology adopted in this study are, firstly the preliminary laboratory tests to assess the basic properties of M30 Concrete, conventional Steel and non-metallic reinforcements and the results are presented. Secondly the experimental investigations of the flexural behaviour of flanged beams reinforced with non-metallic reinforcements under static loadings are compared with that of flanged beams reinforced with conventional steel reinforcements. A total of nine beams are cast, out of which three reinforced with conventional steel reinforcement and six reinforced with two types of surface treated non-metallic reinforcements having three different reinforcement ratios of under reinforced, balanced and over reinforced percentages of reinforcements with respect to cross section of beams are considered. The static load carrying capacities of conventional steel and GFRP reinforced flanged beams are then compared. Out of the two surface treated non-metallic reinforcements, the sand coated non-metallic reinforced beams had satisfactory performance and higher ultimate load than the conventional steel reinforced beams.

Key words: Flanged Beam, Non-Metallic Reinforcement, GFRP, Flexural Behaviour, Static Loading,

1. Introduction

Non-Metallic reinforcement frequently spelled as (FRP-Fibre Reinforced Polymer), Glass Fibre Reinforced Polymer (GFRP) is a common non-metallic composite material used for structural concrete members and rehabilitating the existing structures damaged due to the most common corrosion of conventional steel reinforcement. Non-Metallic reinforcements possess good properties for structural concrete application like light in weight, high performance, and high strength to weight ratio, high stiffness to weight ratio, high energy absorption, excellent corrosion resistance and fatigue damage resistance. It has been recommended in ACI codes [1-3]. FRP material finds its application in all fields. FRP material mainly made with the most common fibres like glass, carbon and aramid bonded together with resins and cements to produce rods, strands sheets, mats and pre-forms. But the pultruded rods and profiles like flat, angle, channel, “I”, and “T” sections are widely adopted in structural concrete applications. Because of well said qualities for structural concrete application non-metallic reinforcements has been accepted by many country codes and committee reports [4-6]. Their mechanical properties are highly dependent on the type of fibre, binding agents used as well as the method of processing and the shape [7]. Well established studies available for slabs [8], rectangular beams [9-12], columns [13], and beam column joints [14]. But flanged beams are the actual behaviuor in the structure, particularly in beams in severe environmental conditions has to be reinforced with non- metallic reinforcements are not explored so far. Therefore the present study discusses mainly the behaviour of concrete flanged beams internally reinforced with non-metallic (GFRP) reinforcements under static loading.

2. Materials

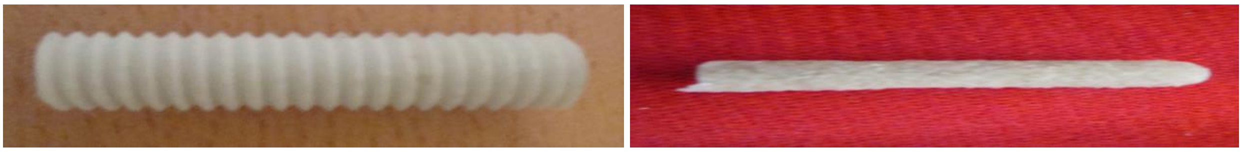
All the beams are cast using M30 grade of concrete based on mix design as per Indian standard codes [15-16]. The properties of concrete are listed in Table 1. The GFRP reinforcements used in this study are manufactured by pultruded process (Ercon Composite Industries Ltd., India; and Meena Fibre Glass Industry Ltd., India). GFRP reinforcements with two different types of surface treatments (Sand Coated - **F_S**, Threaded - **F_T**) are used. The GFRP reinforcements are shown in Figure 1, and the gripping arrangements for tensile test are shown in Figure 2. The mechanical properties of all the types of GFRP reinforcements are obtained from following tests prescribed as per ASTM Standards [17]. The various properties of reinforcements obtained through laboratory experiments and the results are presented in Table 2. The tensile test setup of GFRP reinforcements are shown in Figure 3, and the failure mode of GFRP reinforcement are shown in Figure 4. The stress- strain curve of conventional steel (**F_e**) and GFRP reinforcements are shown in Figure 5.

Table 1 Properties of Concrete

Description	M 30 grade (m)
Design Mix Ratio	1:1.55:2.86
W/C Ratio	0.40
Average Compressive Strength of Concrete Cubes (MPa)	39.5
Modulus of Elasticity (MPa)	33,071

Table 2 Properties of Reinforcements

Properties	Steel (Fe)	Sand Coated GFRP (F_S)	Threaded GFRP (F_T)
Yield Strength (MPa)	490	690	625
Longitudinal Elastic Modulus (GPa)	218	69.0	61.0
Compressive Strength (MPa)	572	334	317
Strain	0.014	0.029	0.031
Poisson's ratio	0.26	0.22	0.215



(a) Threaded GFRP **(b) Sand Coated GFRP**

Figure 1 Type of GFRP Reinforcements

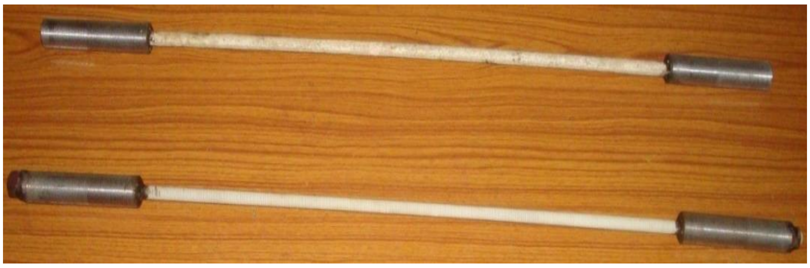
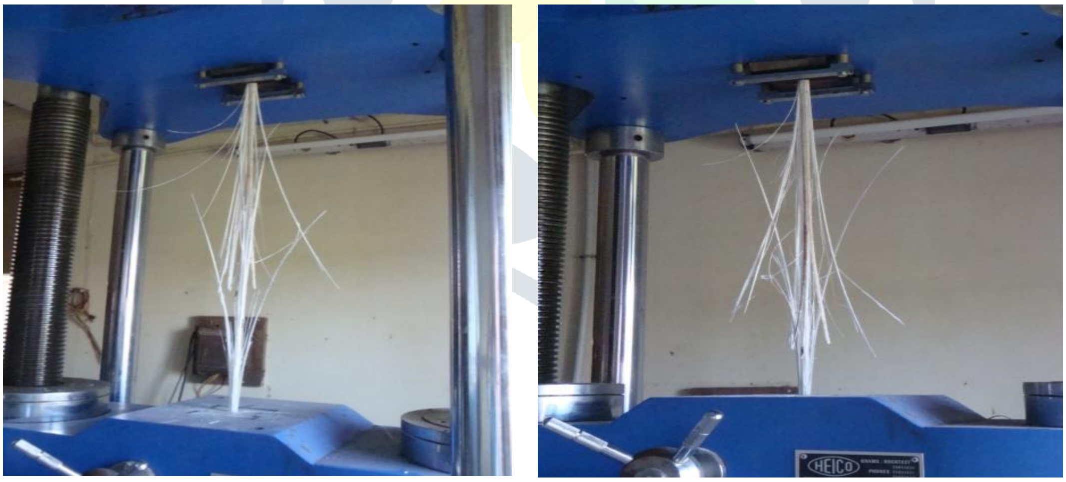


Figure 2 GFRP Reinforcements with End Anchorages for Tensile Test

(a) Threaded GFRP Rod **(b) Sand Coated GFRP Rod**

Figure 3 GFRP Reinforcements under Tension Test



(a) Threaded GFRP Rod **(b) Sand Coated GFRP Rod**

Fig. 4 Tensile Failure Mode of GFRP Reinforcements

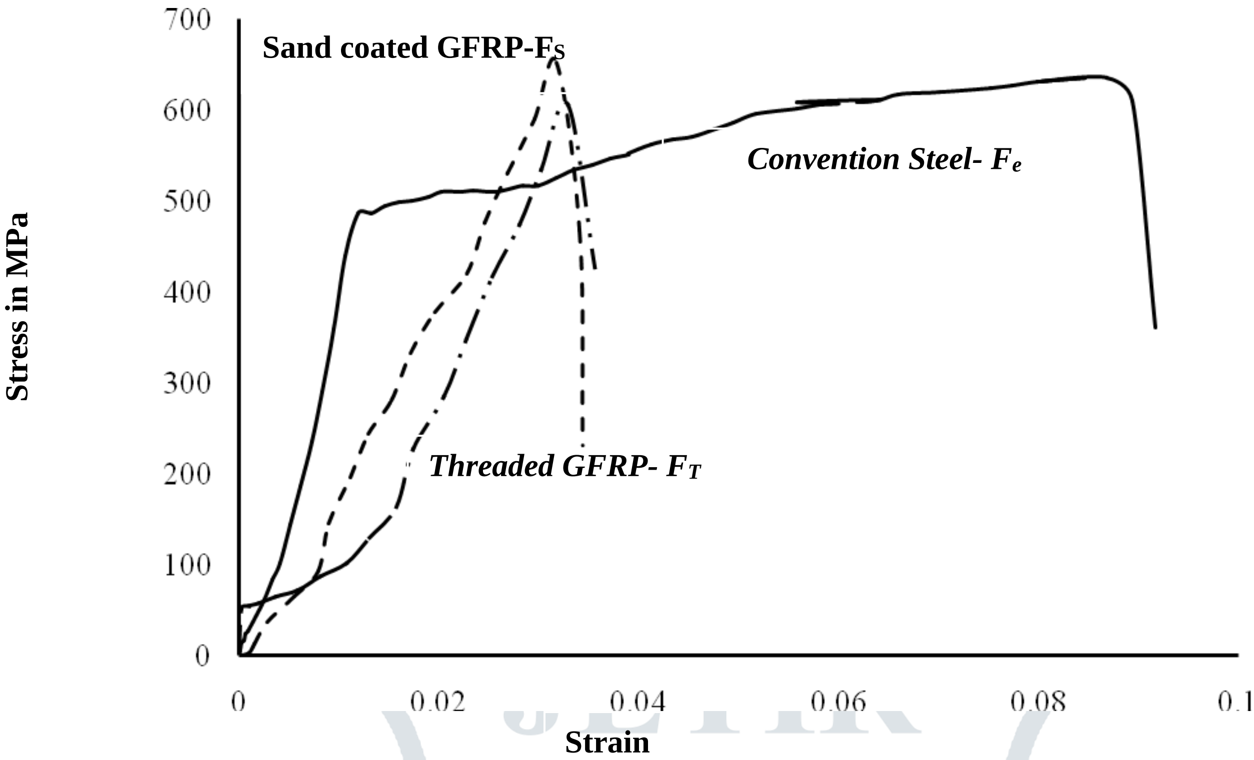
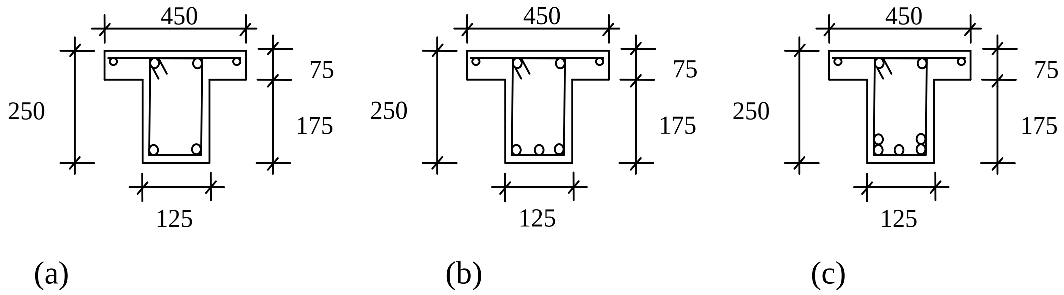


Figure 5 Stress-Strain Curve for Steel and GFRP Reinforcements

3. Experimental Test Setup and Instrumentation

The testing programme consists of nine beams that are subjected to static loading. 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 effect of area of reinforcements provided in RC beams is depending upon the percentage of reinforcement provided as under reinforced, balanced and over reinforced sections. In this study, the first series beam consists of 0.82% (ρ_1), the second series consists of 1.24% (ρ_2) and the third series consists of 2.06% (ρ_3) with respect to under reinforced, almost balanced and over reinforced sections. The test set up is shown in Figure 7. 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 testing of beams is shown in Figure 8.

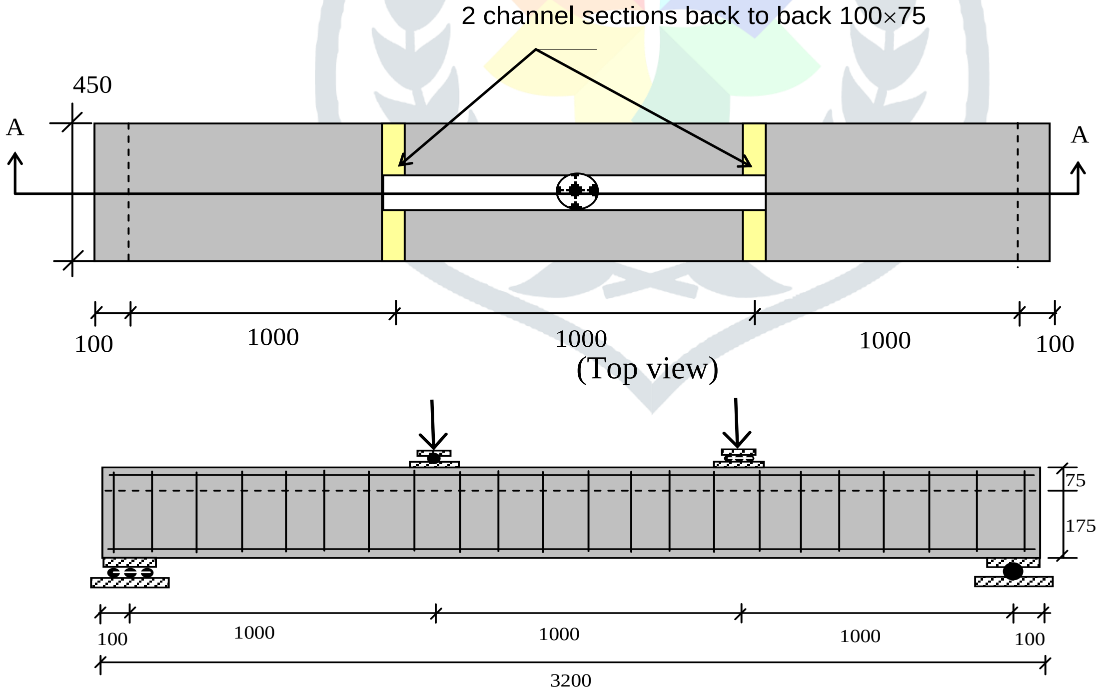


Reinforcements Details: a) 2-Y12 top and bottom, 8Y stirrups 2L-150c/c ; b) 2-Y12 top and 3-Y12 bottom, 8Y stirrups 2L-150c/c c) 2-Y12 top and 5-Y12 bottom, 8Y stirrups 2L-150c/c

Figure 6 Reinforcement Details of Specimens

Table 3. Various Parameters involved in Beam Specimens

Parameters	Description	Designation
Types of reinforcements	Conventional steel	*Fe*
	Sand coated GFRP	*Fs*
	Threaded GFRP	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)

Figure 7 Experimental Test Setup

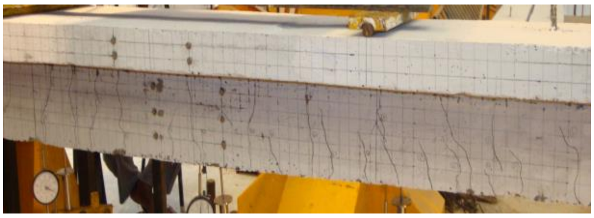
Figure 8 Flexure Test of Flanged Beams under Static Loading Condition

4. Results and Discussion

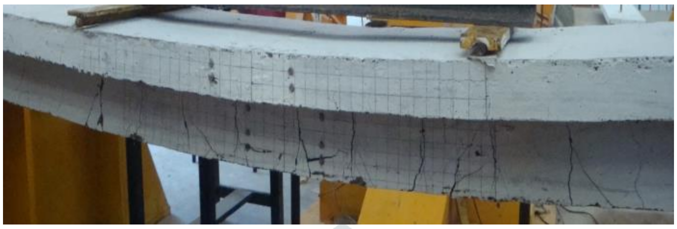
All the nine flanged beams are tested under flexure and observed various parameters. The results obtained for all the beam specimens are presented in Table 4. The typical crack patterns of beam specimens are shown in Figure 9. The results are depicted in the form of graphs are shown in Figures 10 to 15. 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 16 to 20.

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 δ_u (mm)	Ultimate Moment M_u (kN-m)	Curvature ϕ (x 10^{-3} radians)
1	***BmF**$_e\rho_1$*	71.00	30.0	46.00	35.00	4.09
2	***BmFs** ρ_1*	90.00	22.5	65.00	45.00	5.78
3	***BmF**$_T\rho_1$*	33.00	10.0	16.00	16.50	1.42
4	***BmF**$_e\rho_2$*	90.00	27.5	42.00	45.00	3.73
5	***BmFs** ρ_2*	100.50	22.0	44.00	50.25	3.91
6	***BmF**$_T\rho_2$*	39.50	12.0	26.00	19.75	2.31
7	***BmF**$_e\rho_3$*	115.00	30.0	22.00	57.50	1.96
8	***BmFs** ρ_3*	139.00	26.0	38.50	69.50	3.42
9	***BmF**$_T\rho_3$*	53.00	12.0	23.95	26.50	2.13



(a) Conventional Steel Beam **(b) Sand Coated GFRP Beam**



(b) Threaded GFRP Beam

Figure 9 Typical Crack patterns of Beam Specimens

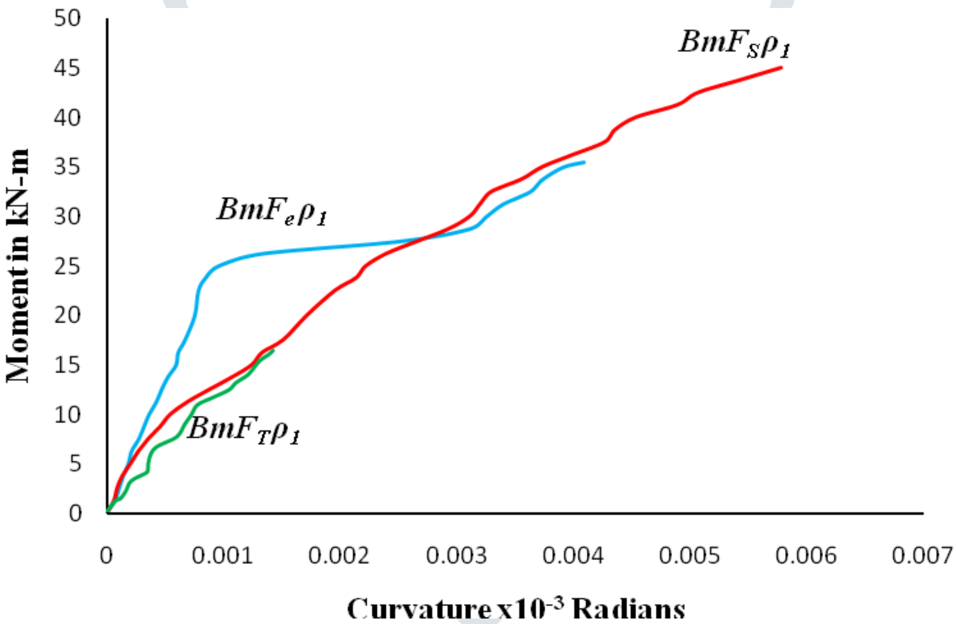


Figure 10 Moment versus Curvature of Beam Series 1

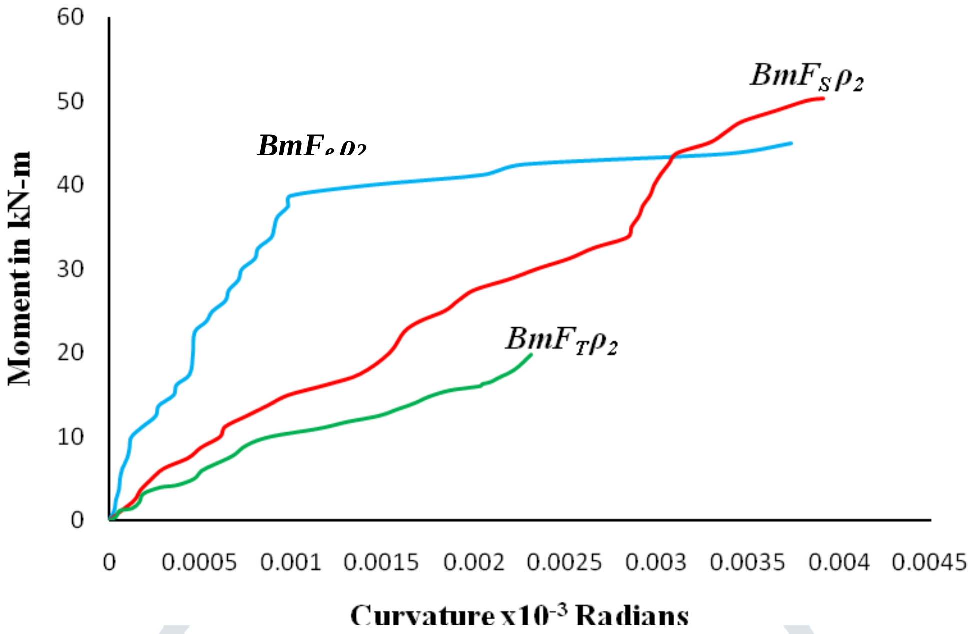


Figure 11 Moment versus Curvature of Beam Series 2

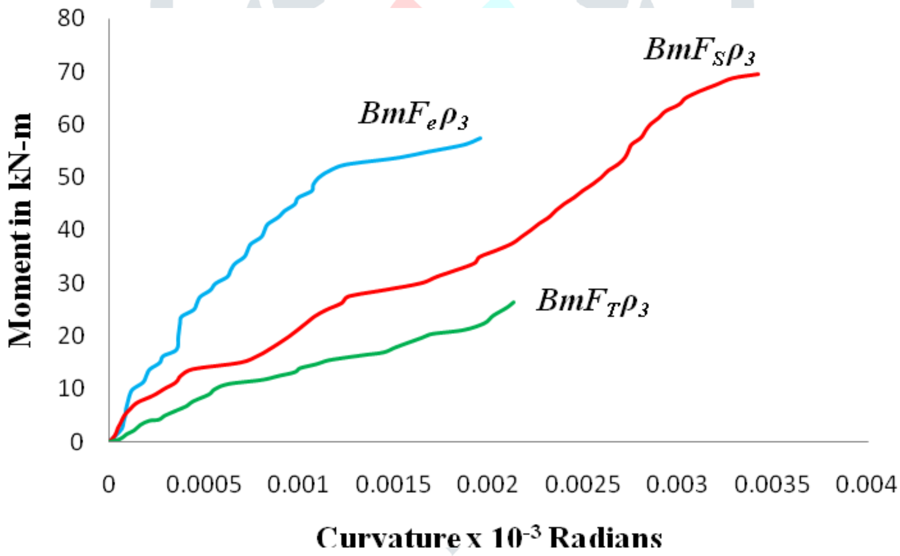


Figure 12 Moment versus Curvature of Beam Series 3

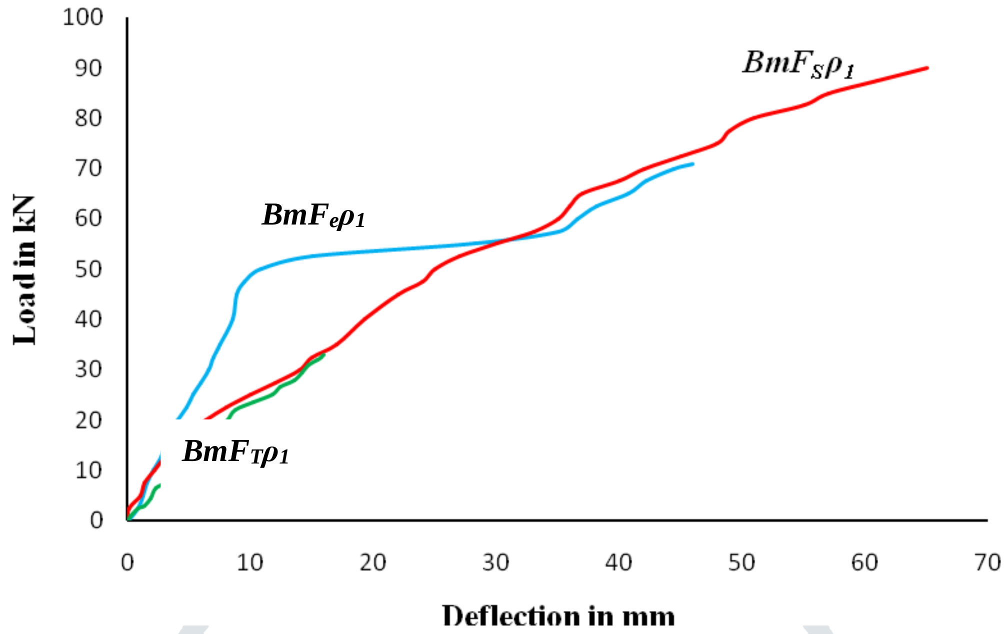


Figure 13 Load versus Deflection of Beam Series 1

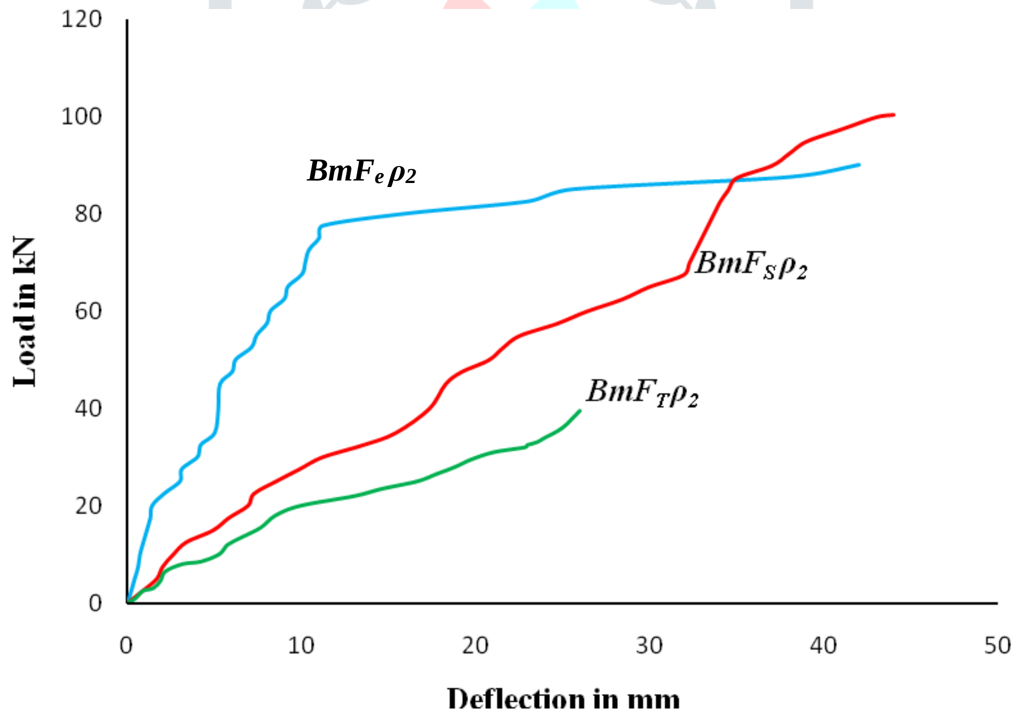


Figure 14 Load versus deflection of Beam Series 2

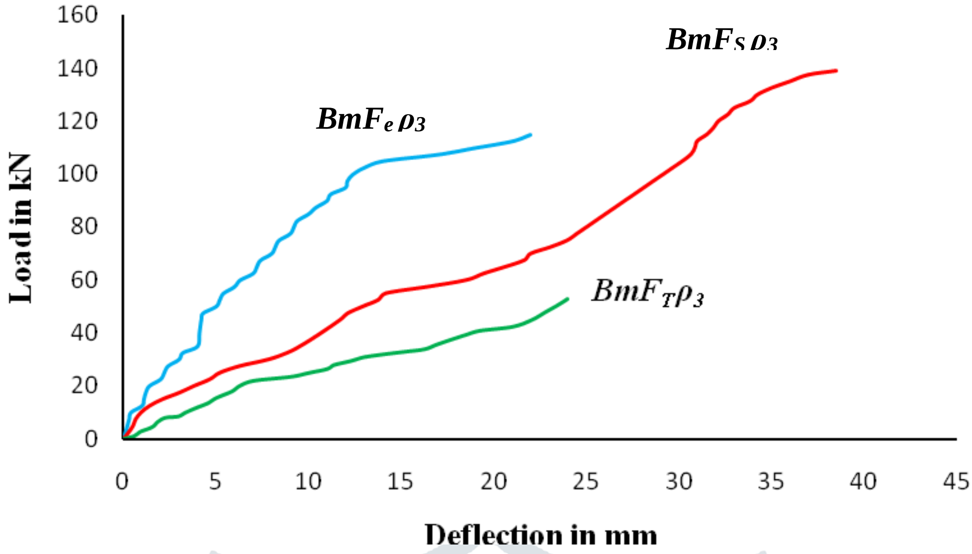


Figure 15 Load versus Deflection of Beam Series 3

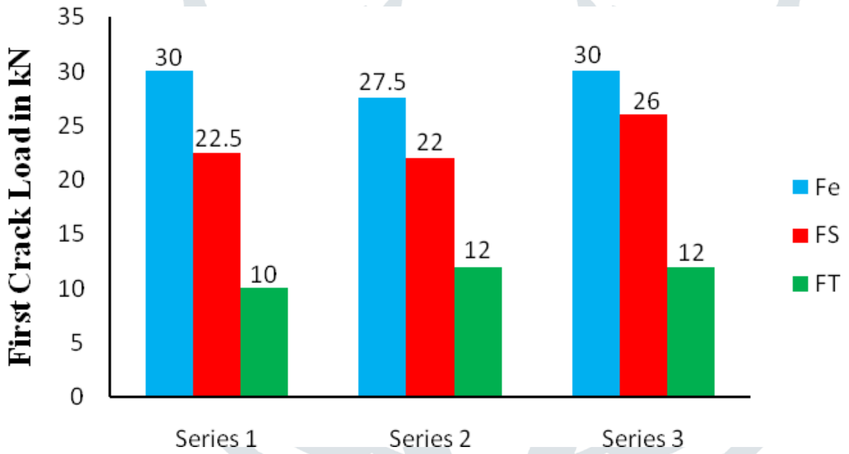


Figure 16 Comparison of First Crack load of All Beams

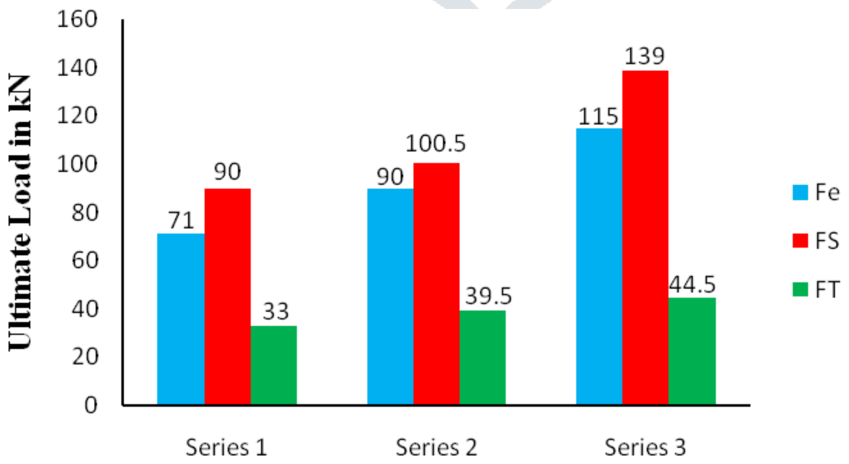


Figure 17 Comparison of Ultimate Load of All Beams

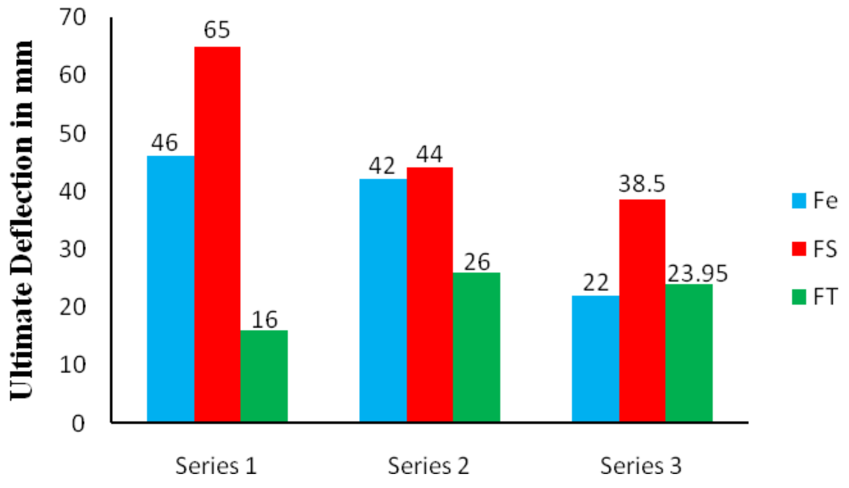


Figure 18 Comparison of Ultimate Deflection of All Beams

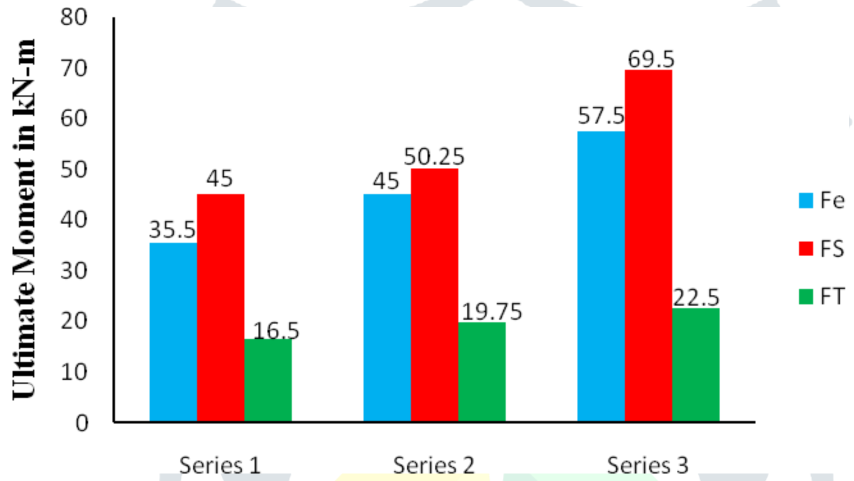


Figure 19 Comparison of Ultimate Moment of All Beams

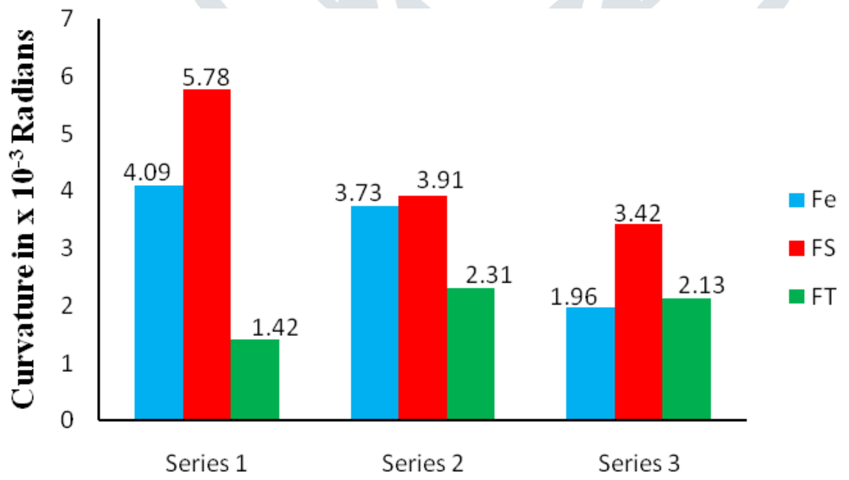


Figure 20 Comparison of Curvature of All Beams

The first crack load observed in sand coated GFRP beams shows a moderate load of 22.5 kN when compared to conventional steel as well as threaded GFRP reinforced under reinforced beams. The behaviour of conventional steel and sand coated GFRP reinforced beams are almost same in balanced and over reinforced beams, but the first crack appearance is too earlier in case of threaded GFRP beams because of the stress in concrete attained the modulus of rupture of the concrete.

The ultimate load carrying capacity of beams shows increasing trend when increase in the percentage of reinforcements in conventional steel and both GFRP reinforced beams.

The ultimate deflection of conventional steel as well as sand coated GFRP reinforced beams are showing decreasing trend while increasing the percentage of reinforcement, but threaded GFRP reinforced beams shows almost same value of ultimate deflection and the percentage of reinforcement is not reflected in the ultimate deflection of beams. When comparing the conventional steel and sand coated GFRP reinforced beams, the sand coated GFRP reinforced beams are showing a very high ultimate deflection (65 mm) 41.3% percentage higher than conventional steel reinforced beams, which is the most preferable condition for ductile structures.

5. Conclusion

The following conclusions are derived from the above experimental study

1. The first crack load observed in conventional steel (F_e) beams are 30 kN, 27.5 kN and 30 kN for beams having 0.82 %, 1.24 % and 2.06 % of reinforcement respectively.
2. The first crack load observed in sand coated GFRP (F_S) beams are 22.5 kN, 22 kN and 26 kN for beams having 0.82 %, 1.24 % and 2.06 % of reinforcement respectively.
3. The first crack load observed in threaded GFRP (F_T) beams are 10.0 kN, 12.0 kN and 12.0 kN for beams having 0.82 %, 1.24 % and 2.06 % of reinforcement respectively.
4. The first crack loads are almost observed in conventional steel and sand coated GFRP beams are showing almost same, but the threaded GFRP reinforced beams are having very lower first crack load since the stress in concrete exceeds its modulus of rupture at early stages of loading.
5. The ultimate load carrying capacity of steel as well as GFRP reinforced beams increases when increase in percentage of reinforcement.
6. The ultimate deflection observed in conventional steel and sand coated GFRP reinforced beams show reduction in deflection, when increase in percentage of reinforcement. In threaded GFRP reinforced beams the ultimate deflection is lower in all three series of beams. In addition it is very lower value in case of under reinforced conditions.
7. The performance of threaded GFRP reinforcements is poor when compared to sand coated GFRP beams with respect to ultimate load carrying capacity and ultimate deflections.
8. The ultimate load carrying capacity of series1 sand coated GFRP reinforced beam is 90 kN and the same in conventional steel reinforced beams is 71 kN. It shows 27% increase in sand coated GFRP reinforced beams compared to conventional steel reinforced beams.
9. The ultimate deflection observed in sand coated GFRP reinforced beams is 65 mm, which is higher than that observed in steel reinforced beams of 46 mm. It shows 41% increase in deflection in sand coated GFRP reinforced beams when compared to steel reinforced beams.
10. The sand coated GFRP reinforced beams are found superior when compared to conventional steel reinforced beams.

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