International Journal of ChemTech Research
CODEN (USA): IJCRGG ISSN: 0974-4290
Vol.8, No.2, pp 635-642, 2015

Static Behaviour of Concrete Beams Reinforced in Shear with GFRP Bars

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Abstract: Corrosion being a great drawback in steel, even though using of steel bars as reinforcement in concrete structures has not been reduced since there is no alternative replacement. Glass fibre reinforced polymer (GFRP) bars are now being considered as a replacement for steel in concrete beams. Due to insufficient study, there is no clear view for using GFRP as reinforcement in concrete beams. In this study two concrete mixes were considered, one as conventional mix (M25) and the other as high strength mix (M50). A high range water reducing admixture (HRWRA) is used in both the mixes which showed better compressive strength and tensile strength than the mixes without admixture. Both the mixes had test parameters like longitudinal steel and GFRP bars, with shear reinforcements as steel and GFRP. Totally 6 beams were tested using a two point loading system and the flexural behaviour was observed. The results showed that GFRP when used as transverse reinforcement showed high initial stiffness when compared to steel. The theoretical values are finally compared with the test results and discussed.
Keywords: Compressive strength, Tensile strength, Flexural behaviour, GFRP rods, HRWRA.

Introduction

Corrosion is inevitable in concrete structures reinforced with steel and creates a reason for engineers to find an alternate replacement for steel. Corrosion in concrete structures is due to concrete carbonation. When the service life of a structure starts the steel surface is formed with a passive layer due to concrete pore water's high alkalinity which has pH above 12. As the service life starts to increase there is decrease in alkalinity in the layer formed because of concrete carbonation, followed by oxygen, aggressive agents and moisture to penetrate through the concrete. So to clear the likelihood of steel corrosion and not to compromise with the strength it provides as a reinforcing material, fibre reinforced polymer (FRP) reinforcing bars can be used instead. Of late Glass fibre reinforced polymer (GFRP) bars are adopted as reinforcements in concrete structures like columns, beams, slabs and in underwater construction. Apart from the non-corrosive property GFRP also holds nonmagnetic properties, resistance against salt water, unaffected by acid rain and most chemicals and has various applications. Due to these properties it can be handled in extreme conditions where steel reinforcement has inadmissible serviceability issues. When compared to its strength to weight ratio, steel is less. In present times, they are applied in repairing and rehabilitation of concrete structures for increasing its strength. The methods include warping of GFRP sheets around the damaged zone in layers using epoxy resins as bonding agents. Using of these bars as replacements for steel is a very challenging practice since the properties of these bars varies with that of steel and many design guidelines have been proposed by ACI committee, Canadian standard association (CSA) and Japan society of civil engineers (JSCE).But there are no separate Indian standard codes for the design of GFRP reinforced concrete structures. It should be taken into account that the use of GFRP bars plays a prominent role in avoiding corrosion in structures.

Using of bonded FRP bars are transversal reinforcement in L-shaped beams showed improved ultimate torsional strength, unit angle of twist, maximum stirrup strain, adequate torsional deformability index, toughness and major concrete crack width[1].GFRP bars as near surface mounted (NSM) showed 23% to 53% increase in ultimate moment over beams without NSM GFRP bars[2].NSM GFRP bars overall showed 23% to 53%increase in ultimate moment over the normal beams. Moment–deflection response up to the peak moment was dominated by the epoxy type influence[3].Thebeams with lesser shear span to-effective depth ratios showed higher ultimate capacity and the shear capacity is lower compared to RC beams[4].The test results of eight beams with GFRP or steel with amount of reinforcement and ratio to GFRP to steel as test criterions, concluded that the use of GFRP and steel in combination showed good results in flexure with increasing stiffness with the effective reinforcement ratio [5]. Assessment of the shear capacity of GFRP reinforced beams and reported that strains and deflections are greater in concrete beams fortified with FRP bars than steel[6]. Test carried out on 12 beams with different depth and GFRP reinforcement ratios and observed flexural failure in under reinforced beams and shear failure in over reinforced beams[7].Dynamic free vibration tests of beam with NSM GFR Prods and confirmed that the effects of damage due to bending tests in strengthened beam with NSM GFR Prods are lesser of non-strengthened beam[8].

Experimental Program

The experiment includes testing of 6 prototype beams under static loading of two different concrete grades, M25 and M50. Two point loading system was used to test all the beams. The strength of concrete was found for both mixes with and without HRWRA. The mix with better results was considered for beams. The parameters considered for beams were GFRP as longitudinal reinforcement along with steel as shear reinforcement and GFRP as both longitudinal and shear reinforcement along with two control beams, one for each concrete grade. The width, depth and length of the beam were 100mm, 150mm and 1200mm respectively. All the beams were cast and cured for 28 days.

Material properties:

a) Cement: Ordinary Portland cement of 43 gradeconfirming to IS 8112:1989[9]of locally available RAMCO cement which comprises good quality. The chemical configuration of cement was found using XRF analysis and has the following properties

Table 1: Physical and chemical composition of ordinary Portland cement (OPC)

Description	**Composition**
Physical Properties	
Color	Grey
Specific gravity	3.15
Specific surface area (cm-	3540
Chemical Composition	
CaO (%)	62.8
SiO_2 (%)	20.3
Al_2O_3 (%)	5.4
Fe_2O_3 (%)	3.9
MgO (%)	2.7
Na_2O (%)	0.14
K_2O (%)	62.8

b) Fine aggregate: For fine aggregates, uncrushed locally available natural river sand of maximum size 4.75 mm with a fineness modulus of 3.35 and specific gravity of 2.65 usingIS 2386(Part III):1963[10] was used.

c) Coarse aggregate: The size of the coarse aggregates used ranges between 12.5 mm to 20 mm of specific gravity 2.74 using IS 2386(Part III):1963. The properties of coarse aggregate are given in Table 2.

Table 2. Properties of coarse aggregate

Aggregate properties	Results
Impact value	17.18
Crushing value	21.46
Water absorption	1.56
Abrasion value	24.4

d) Admixtures: Super-plasticizer:CONPLAST SP430 (G) complies with IS: 9103:1999[11] and BS: 5075 (Part 3) and ASTM-C-494[12] type 'F' having a specific gravity of 1.2 was used as a high range water reducing agent.Air entrainment ofApprox. 1% additional (As per Manufacturers manual)

e) Water:Ordinary potable tap water was used for mixing and curing.

f) Reinforcement: Steel bars of Fe 415 grade and sand coated GFRP bars were used for main reinforcement and stirrups. GFRP bars used were prepared by pultrusion process with E-glass fibres and vinyl ester resin. The direct tensile test results showed elastic modulus, yield stress and yield strain for steel bars used in the experiment were 210 GPa, 512 GPa and 0.0028 respectively. As for the steel used in shear reinforcement, the values were found to be 164 GPa, 433MPa and 0.0028 as the modulus, yield stress and yield strain respectively. The manufacturer provided the specification for mechanical properties of GFRP bars.The properties of both longitudinal and transverse GFRP bars are given in the **Table 3.**

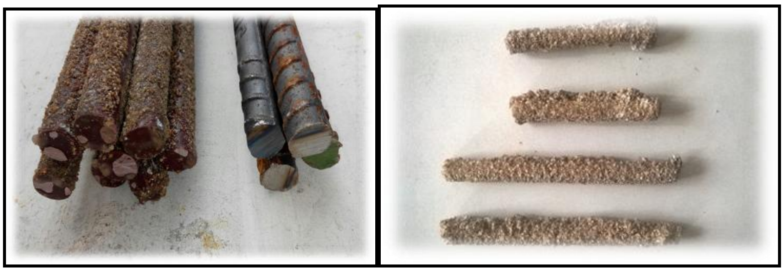

Fig.1 GFRP and Steel bars

Table 3: Mechanical properties of GFRP bars

Diameter (mm)	Elastic modulus (GPa)	Tensile strength (MPa)	Ultimate strain (%)
16	56.45	913	1.6
8	53.21	872	1.87

Concrete:

a) Mix proportions: Design of Concrete mix was in accordance with IS 10262:2009[13] and IS 456:2000[14] two concrete grade mix was designed, namely M25 and M50. The proportions of the materials by weight were 1:1.58:2.9 and 1:1.04:2.13 for M25 and M50 respectively. The w/c ratio was maintained as 0.4 for M25 and 0.3 for M50. The specimens such as cubes and cylinders were cast for each grade with and without chemical admixtures.

b) Specimen casting and testing: 100mm cube specimens and 100mm diameter and 200mm height cylinder specimens were cast as per IS 516:1959[15] for finding the compressive strength and tensile strength of concrete. The compressive strength of various mixes was found out at 7 and 28 days of curing and Split Tensile Strength and Flexural Strength were found out at 28 days. The normalized compressive strength and tensile strength of M25 grade and M50 grade concrete is shown inTable 4.

Table 4. Compressive strength and Split tensile strength

Description	Compressive strength		Tensile strength	
	M25	M50	M25	M50
Without admixture	28.4 MPa	59.7MPa	2.04 MPa	4.27MPa
With admixture	32.1 MPa	64.2 MPa	2.16 MPa	4.44 MPa

Test matrix and Specimen preparation:

Totally 6 prototype beams were cast with cross sectional dimensions of width 100mm and depth 150mm for a length of 1200mm.The longitudinal bars were of 16mm diameter and the stirrups were of 8mm diameter with minimum spacing of 100mm increasing towards the centre. The concrete mix used for casting beams were with Superplasticizer content as it showed better results. The specimen ID for beams are given in **Table 5** along with the type of reinforcements used. The letter C in the Specimen ID indicates control beam, letter G represents GFRP used as longitudinal reinforcement and letter GS represents GFRP bars used as longitudinal as well as transverse reinforcement. Group I contains three specimens including a control specimen (M25-C) and two GFRP specimens (M25-G and M25-GS) with concrete grade of M25. Similarly Group II contains three specimens of but are of M50 grade concrete.

Table 5.Test matrix

Group	Specimen ID	Longitudinal reinforcement	Transverse reinforcement
I	M25-C	Steel	Steel
	M25-G	GFRP	Steel
	M25-GS	GFRP	GFRP
II	M50-C	Steel	Steel
	M50-G	GFRP	Steel
	M50-GS	GFRP	GFRP

Fig.2 Beam Prototypes

Test setup:

The test setup includes two point loading using a single point loading system by which the loads are transferred equally to the two points using a spreader beam and two rollers. Dial gauges are placed in the bottom of the beam at the mid-point to find the deflection. Demecs are placed on the surface of the beam to find the surface strains which are placed at a distance of 100mm from one another. The strains at these points are found using a mechanical strain gauge. The crack patterns are noted on both sides of the beams at particular intervals. The gauge length between the load points is 333.33 mm and 100 mm are left on both sides of the beam at the supports. All the specimens were capped for uniform loading prior testing. The control of load over the test was 10 kN/min. Automatic data acquisition system was used to record the load, strain and axial displacement which in turn connected to the computer.

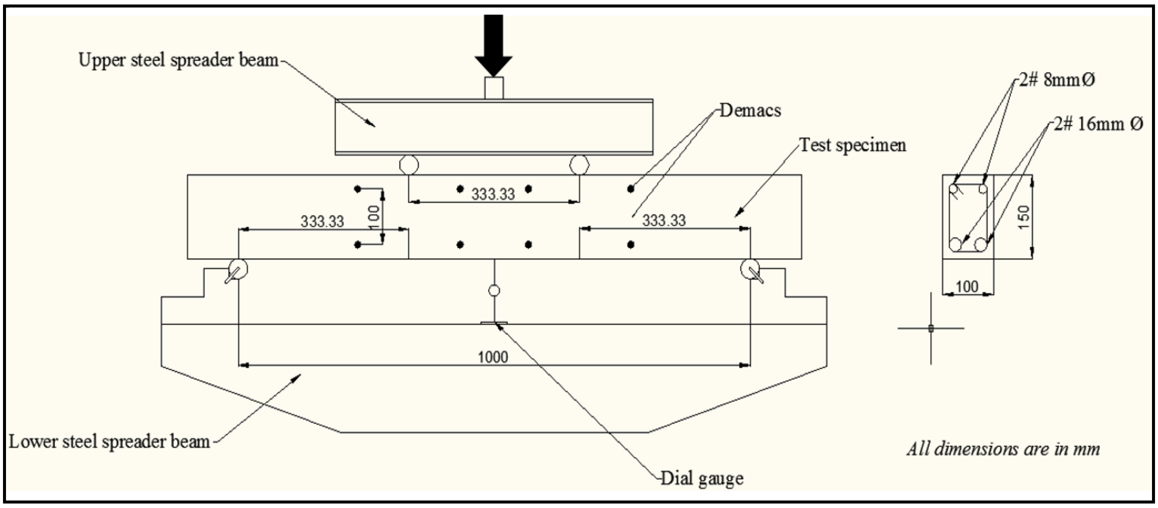

Fig.3 Test setup and reinforcement details

Experimental Results and Discussions

Load Deflection Behaviour

The load vs displacement for Group I (referFig.4) specimens clearly shows M25-C has lesser displacement at peak load whereas M25-G showed greater deflection than M25-C at its peak load. But in the case of Group II (refer Fig.5) the control specimen showed greater displacement at its peak load when correlated with GFRP reinforced specimen.

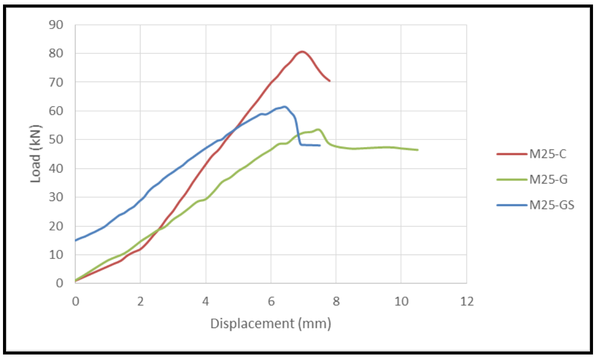

Fig.4 Load vs displacement (Group I)

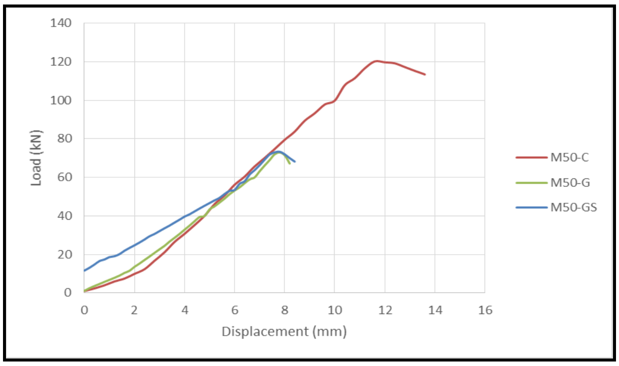

Fig.5 Load vs Displacement (Group II)

Stiffness

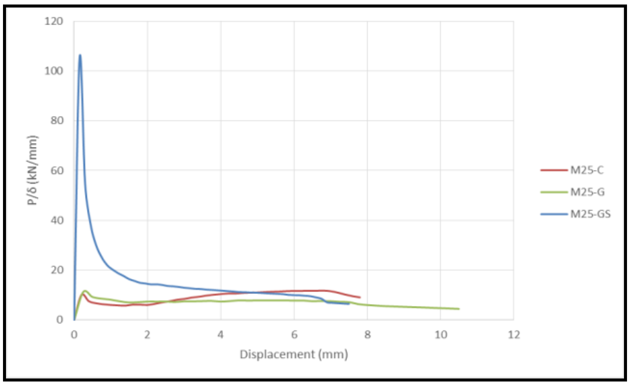

Fig.6 Stiffness (Group I)

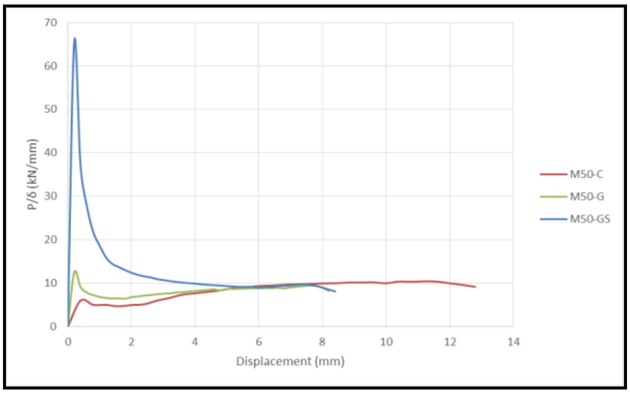

Fig.7 Stiffness (Group II)

Both the specimens which comprises of GFRP bar as longitudinal reinforcement as well as transverse reinforcement (M25-GS and M50-GS) showed very high initial stiffness when compared to steel and GFRP as longitudinal reinforcement with steel stirrups(refer Fig.6 and Fig.7). When comparing M25-C and M50-C with that of M25-G and M50-G respectively, the beams with GFRP showed greater stiffness. As the displacement increases the stiffness gradually decreases for M25-G whereas the stiffness increases up-to a certain point for M25-C(refer Fig.4). But for M50-G and M50-C, both show gradual increase in stiffness as the displacement increases (refer Fig.7).

Crack Pattern and Spacing

The crack patterns for Group I test specimens shows that the no. of flexural cracks are same for all the beams whereas the shear cracks in M25-C are more when compared to M25-GS which in turn is greater than M25-G. For Group II test specimens the number of flexural cracks in M50-C are double than that of M50-G and M50-GS. The shear cracks for Group II specimens were found to be more for M50-C than M50-GS and M50-G. The number of shear and flexural cracks are listed in Fig.9.

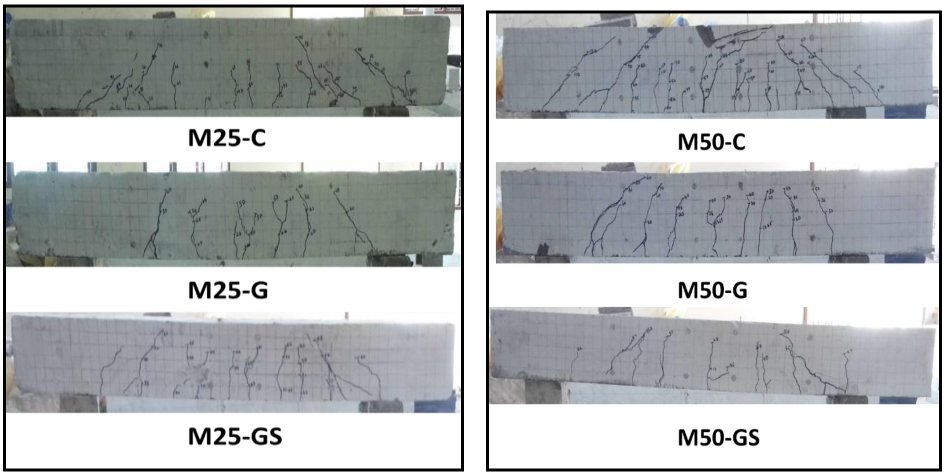

Fig.8 Tested beams

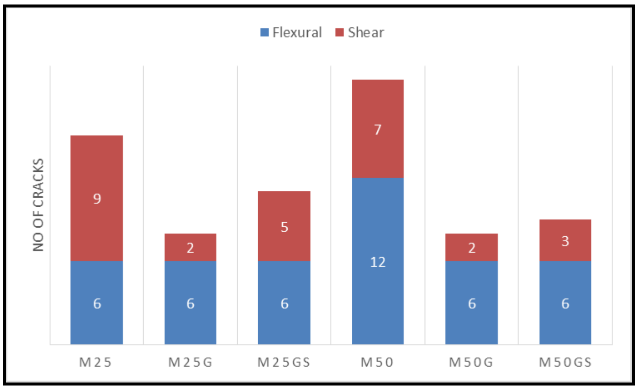

Fig.9 No. of cracks in flexure and shear

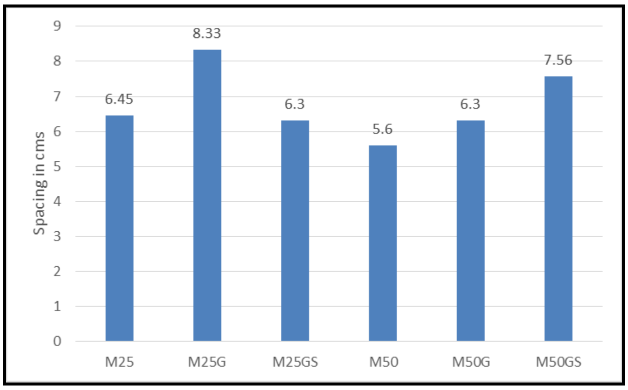

Fig.10 Average spacing between the cracks

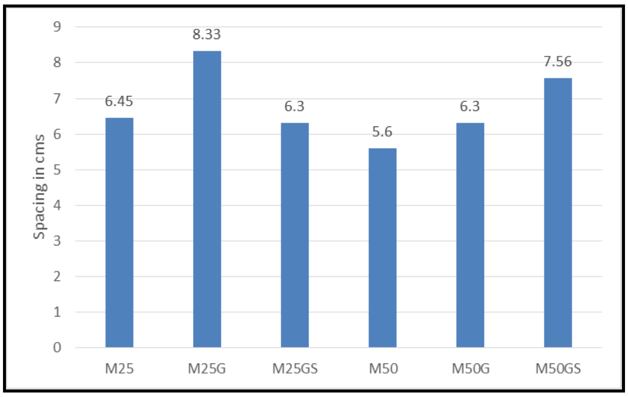

Fig.11 Average spacing between the cracks

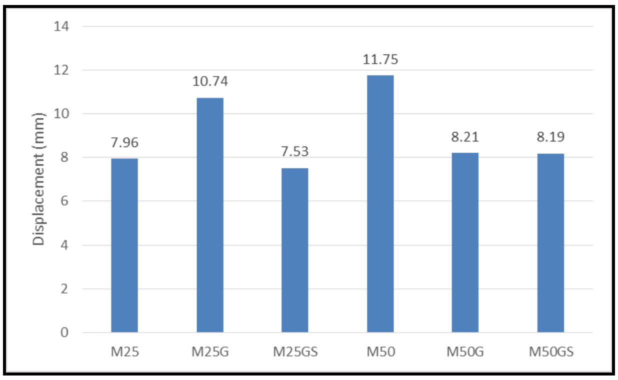

Fig.12 Maximum displacement of beams

The average crack pattern for M25-G was found to be more in Group I and M50-GS for Group II (see Fig.10).The average spacing between the cracks for Group I test specimens were more when compared to corresponding Group II specimens except for M25-GS and M50-GS, which was vice versa (see Fig.11). The maximum displacement for M25-G is more when compared to M25-C and M25-GS but for Group II, M50-C showed maximum displacement than that of the others (see Fig. 12).

Fig.13 and Fig.14 shows the first crack load and the peak load respectively. It shows that the first crack load is more for the control specimens when compared to GFRP reinforced beams. For Group I test matrix there is an average decrease of 23% in the first crack load when compared with control specimen, whereas for Group II there is only an average decrease of 8% from that of the reference specimen. The peak load is very high for M25-C and M50-C when compared with their respective test specimens. The mean increase in peak load for M25-C with that of M25-G and M25-GS is around 1.7 times. Similarly mean increase in peak load for M50-C with that of M50-G and M50-GS is around 1.64 times.

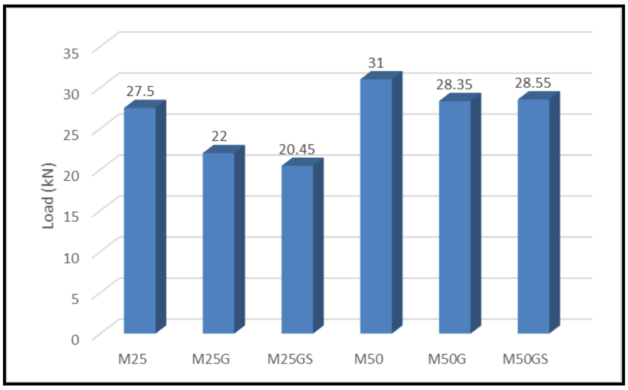

Fig.13 First crack load

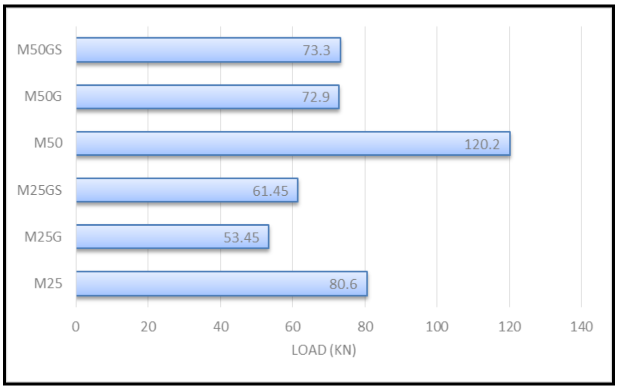

Fig.14 Peak load

Conclusion

Based on the experimental results the design guidelines for beams followed by IS methods are not sufficient for using GFRP bars as reinforcements and should be enumerated for convenient usage of fibres as reinforcing materials in concrete. The following results were observed in testing of the specimens:

a) The beams which are replaced with GFRP bars as longitudinal reinforcement showed flexural failure and beams replaced with GFRP bars as both longitudinal and transverse reinforcement showed shear failure.

b) For M25 grade beam, the maximum load carrying capacity were 33% and 23% less when compared to M25-C for M25-G and M25-GS respectively.

c) For M50 grade beam, the maximum load carrying capacity for M50-G and M50-GS were 39 % less than the M50-C.

d) It can be seen that GFRP bars when used as both longitudinal and transverse reinforcement showed better results than GFRP bars used as longitudinal reinforcements with steel as shear reinforcements, for conventional concrete.

e) As for high strength concrete both the GFRP replaced beams showed similar values except that the M50-GS beam showed greater initial stiffness than M50-G as well as M50-C.

Acknowledgement

The authors would like to thank to the authorities of SASTRA University, Thanjavur, for providing laboratory facilities and administrative assistance to perform the present research work in the School of Civil Engineering.

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