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EXPERIMENTAL INVESTIGATION ON FLEXURAL BEHAVIOR OF CONCRETE BEAM WITH GLASS FIBRE REINFORCED POLYMER REBAR AS INTERNAL REINFORCEMENT

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ABSTRACT

An experimental investigation was carried out to study the flexural behaviour of concrete beams reinforced with Glass fiber reinforced polymers (GFRP) bars. The use of GFRP bars in reinforced concrete structures has emerged as an alternative to traditional reinforced concrete by enhancing the strong performance with limited ductility over concrete beam. In this, present study the results and comparative discussion is carried on an experimental programme concerning concrete beam reinforced with both steel bars, GFRP bars and partially under varying concrete grade and diameter of GFRP bars. In order, to observe the better ductile and strong performance on reinforced concrete beam. This paper investigate the flexural behavior of concrete beam reinforced with steel bars and GFRP bars under two-point loading designed based on code of IS 456: 2000 and ACI 440-1R. The parameters inspected in this study are flexural behaviour, load- deflection, crack pattern and width.

Key words: Reinforcement, GFRP bars, Partial, Two point loading, Flexural, Load-deflection, Crack.

INTRODUCTION

Reinforced concrete beam are one of the most important structural components which can intake load primarily by resisting bending. Usually, steel bars are used as a reinforcement which offers a tensile strength and ductility. Where steel reinforcement is usually, corrodes rapidly under aggressive environments. In order to avoid such issues over concrete structures Fiber Reinforced Polymers (FRP) bars is introduced as internal reinforcement in flexural member has emerged as an alternative solution. Since, it has light weight, good fatigue properties, and high stiffness to weight ratio. Barris et al investigated

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the serviceability and ultimate limit states using flexural behaviour of GFRP reinforced concrete beam and their results are compared to code predictions[1]. Maher A. Adam has produced GFRP bars using available raw materials in laboratory and reinforced in concrete beam and their deflection behaviour and ultimate load carrying capacity is inspected[2]. H. Y. Leung has reported an analytical model is generated on concrete section reinforced with steel bars and FRP bars and their failure modes are discussed[3]. Saleh Harmed has presented the comparison made between numerical and experimental load-deflection relationship of concrete beam reinforced with GFRP bars[4]. Viktor et al describes comparative analysis on GFRP reinforced concrete beams by computing the tension-stiffening relation and corresponding deformation[5]. The main aim of this study is to inspect flexural behaviour of beam reinforced with steel bars, GFRP bars both GFRP and Steel composite which offers strong performance and ductility under varying compressive strength of concrete and varying diameter of GFRP bars. Thus, comparisons are made between some results including strain, load-deflection and crack pattern and crack width.

EXPERIMENTAL

A total of ten beams were designed with an adequate amount of longitudinal and shear reinforcement using code provision and tested using two-point loading by crushing of beam in the central zone. Details of material, test setup and instrumentation are described below.

Materials

Steel bars

The steel bars incorporated in beam section are Fe 415. Where, its yield strength of 415N/mm^2 as per IS 1786. Tensile strength is more than 10% of the proof stress but not less than 485 N/mm^2.

GFRP Bars

GFRP bars are manufactured by a pultrusion process with 75% of glass fiber composition. These bars are available with outer diameter from 4 to 20 mm with evenly distributed spiral relief of any construction length based on requirement as shown in Fig. 1. Since, the fixture has more fiber content it has good physical, chemical and strength characteristics which is compared with steel bar and summarized in Table 1. Where, GFRP bar is 4 times lighter than steel reinforcement with equal strength characteristics, which significantly reduces transportation costs for shipping, loading and unloading, as well as operating expenses at the construction site**.**

Table 1: Material properties

Characteristics	Steel bar	GFRP bar
Tensile strength	400 mPa	1250 mPa
Elastic modulus	200000 mPa	55000 mPa
Lengthening	>14%	2.3%
Density (t/m^3)	7.850	2.170
Corrosion stability	Corrode	Non-corrode
Heat conductivity	Calorific	Non-calorific
Electric conductivity	Conductor	Dielectric

Fig. 1: GFRP Bar

Beam specimens

The experimental programme is preceded based on the beam specimen designed and casted based on required codal provision. Five pairs of GFRP reinforced concrete beams are designed and casted in M30 and M40 grade which is shown in Fig. 2 below.

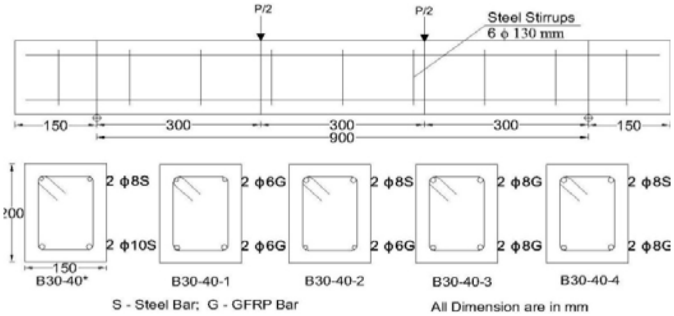

Fig. 1: Reinforcement details

The total length of the beam is 1200 mm, with a rectangular cross section of width 150 mm and depth 200 mm. The steel reinforced beams are designed based on IS 456: 2000 and GFRP bar reinforced beams are designed based on ACI 440. 1R. Hence, Total eight beams specimens were designed as simple span, with an adequate amount of longitudinal and shear reinforcement to fail by either tensile failure by rupture of GFRP bars or crushing of concrete in the central zone. Additionally, two beams were designed with similar amount of steel reinforcement based on IS 456:2000 codal provision as a control beam for comparison purposes. GFRP and steel bars are compositely designed in beam specimen by replacing the foremost failure zone in both full GFRP reinforced beam as per ACI code and full steel reinforced beam as per IS code. Thus, composite of steel and GFRP bar in beam section is convinced. These beam specimens were compared based on varying compressive strength of the concrete and varying diameter of GFRP bar. Compressive strength of concrete M30 and M40 is examined by trail mix and strength of concrete cube and cylinder are inspected after 28 days of curing. The shear span in reinforced with sufficient steel stirrups over five pairs of specimen to avoid shear failure (6 mm @ 130 mm). In order to hold the stirrups hanger bars of 2   8 mm provided. Beam designation is identified as B-xy-dD, where B stands for beam, xy stands for the compressive strength of the concrete and dD stands for top-bottom reinforcement diameter. Geometric and reinforcement details of the beam are given in Table 2 below.

Table 2: Details of test specimens

Designation	Top - Reinf.	Bottom - Reinf.	Stirrups
B30 *	**2 # 8 mm steel**	**2 # 10 mm steel**	**6 @ 130 mm**
B30 – 6G6G	2 # 6 mm GFRP	2 # 6 mm GFRP	6 @ 130 mm
B30 – 8S6G	2 # 8 mm steel	2 # 6 mm GFRP	6 @ 130 mm
B30 – 8G8G	2 # 8 mm GFRP	2 # 8 mm GFRP	6 @ 130 mm
B30 – 8S8G	2 # 8 mm steel	2 # 8 mm GFRP	6 @ 130 mm
B40 *	**2 # 8 mm steel**	**2 # 10 mm steel**	6 @ 130 mm
B40 – 6G6G	2 # 6 mm GFRP	2 # 6 mm GFRP	6 @ 130 mm
B40 – 8S6G	2 # 8 mm steel	2 # 6 mm GFRP	6 @ 130 mm
B40 – 8G8G	2 # 8 mm GFRP	2 # 8 mm GFRP	6 @ 130 mm
B40 – 8S8G	2 # 8 mm steel	2 # 8 mm GFRP	6 @ 130 mm

Experimental setup and investigation

The experimental beams with nominal length of 900 mm and the distance between loads applied being 300 mm were loaded by two point loading. Each specimen was supported on roller assemblies with knife edges in order to locate the exact supporting point. Fig. 3 shows the test setup and instrumentations for tested specimen.

Fig. 2: Experimental setup

The load was applied over beam specimen of around 4 kN were applied and after each increment the behaviour of beam is inspected over concerning several parameters like, deflection, strain, crack patter and crack width was recorded and analyzed. In order to measure the deflection based on the load applied three linear variable differential transformers (LVDT) were used to record the deflection were one is fixed at mid-section of the beam specimen and other two LVDT is fixed at two loading points. Mechanical strain over beam specimen is calculated using demec gauge and demec points over a gauge length of 200 mm. Thus, corresponding strains were recorded for every load increment of 4 kN. Over, the increment of load the width of crack is measured for every cycle of load increment using optical magnifier with an accuracy of 0.05 mm and their corresponding pattern were recorded.

RESULTS AND DISCUSSION

In this section, the most significant results are presented and compared with different beam specimen using several theoretical approaches. During the test, the beams were observed visually until the first crack appeared and corresponding loads was recorded. The first cracking load was also verified from the load deflection and load strain relationships. Table 3 provides a summary of the key experimental results for all beam specimens. The average initial cracking load of beam series of B30 and B40 were tabulated. The cracking load is directly related to concrete tensile strength which, in turn, is a function of compressive strength, increasing the concrete compressive strength is expected to yield higher cracking loads.

Table 3: Loading result

Beam Series	Cracking Load (kN)	Ultimate Load (kN)
B30 *	32	95
B30 – 6G6G	16	96
B30 – 8S6G	24	10
B30 – 8G8G	32	140
B30 – 8S8G	32	160
B40 *	34	108
B40 – 6G6G	20	104
B40 – 8S6G	28	126
B40 – 8G8G	32	156
B40 – 8S8G	40	180

Crack pattern

The cracks patterns for beam series B30 and B40 are depicted in Fig. 4, generally, the first cracks were vertical flexural cracks which arise at the tension zone. From, that corresponding new cracks will be formed over the shear span. At higher loading stages, the rate of formation of new cracks significantly decreases. Moreover, the existing cracks grow wider over the compression zone especially, the first formed cracks, and splitting to small short cracks adjacent to the main GFRP bars. It was observed that the cracks located adjacent and near the vertical stirrups. From, the crack pattern examination it is observed that control beam of different grades has high number cracks than the GFRP reinforced beam and crack width is not developed more. Whereas, GFRP bar reinforced beam has very few cracks but, these cracks grow wider as much as possible. Among, this cracking behaviour the beam reinforced with both steel and GFRP bars had considerable crack and limited crack widening.

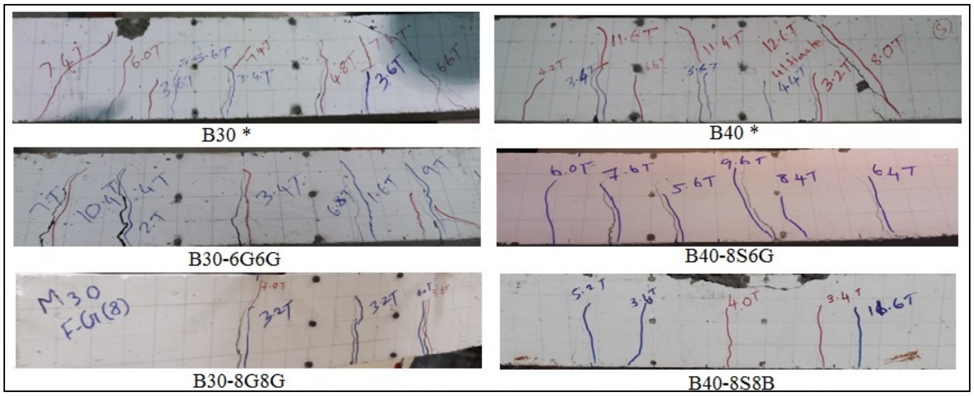

Fig. 3: Crack pattern

Crack width

The experimental crack width at the flexural zone was measured by an optical micrometer at sequenced load steps. Fig. 5 below reveals that the concrete beam reinforced with GFRP bar and steel bar tends to reduce the crack width compared to beam specimen reinforced with GFRP has observed with high crack width since, GFRP has high modulus of elasticity compared to steel bar.

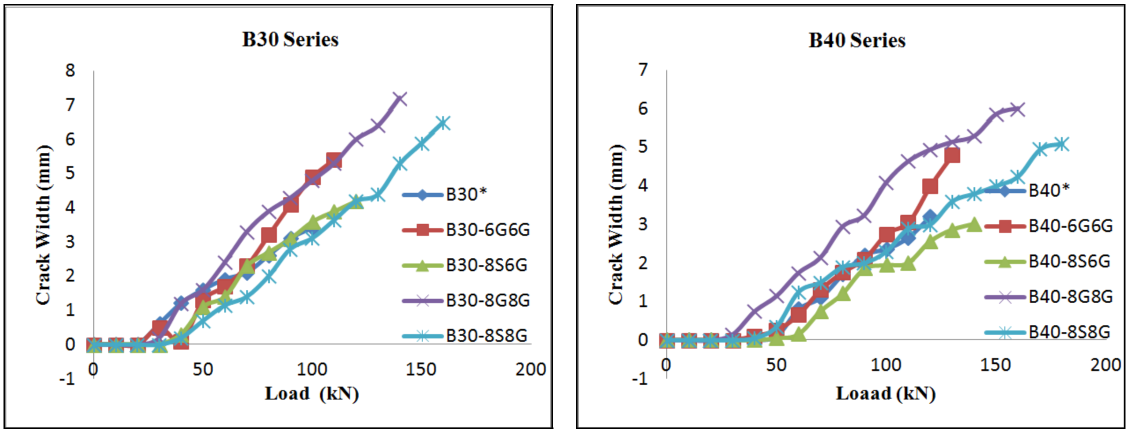

Fig. 5: Crack width for beam Series B30 and B40

It is also found that increasing the compressive strength of concrete over beam specimen has considerably reduces the crack width over loading. Most design codes specify a flexural crack width limit for steel reinforced concrete structures to protect the reinforcing bars from corrosion and to maintain the structure's aesthetic appearance. Unlike steel reinforcement, GFRP is corrosion resistant. Hence, it is permitted for higher crack width.

Load-deflection behavior

The experimental load to mid-span deflection curves and failure loads of the steel bars, GFRP bars and composite reinforced concrete beams are presented in Fig. 6. Each curve represents the deflection readings obtained from the LVDT at beam mid-span. The loads to mid-span deflection curves were bilinear for all GFRP reinforced beams and it shows the lesser deflection in compositely reinforced beam compared over the beam reinforced with full GFRP.

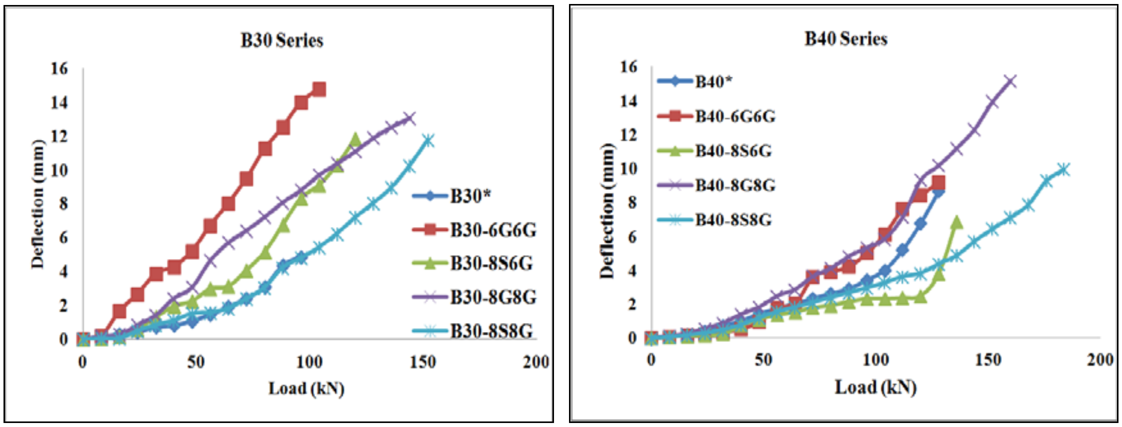

Fig. 6: Load-deflection behaviour for Beam Series B30 and B40

Strain distribution

A typical representation of the experimental load-concrete strain relation is shown in Fig. 7.

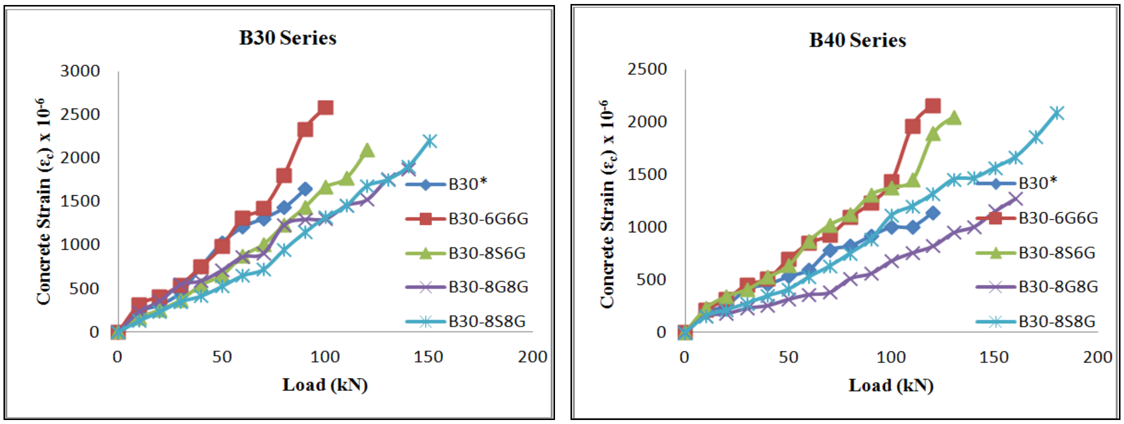

Fig. 7: Concrete strain for beam Series B30 and B40

A relatively small first linear branch, corresponding to the uncracked condition, is evident. In this first step of the test, the three experimental curves indicate similar behaviour with reduced values of strain. When cracking occurs, the differences among them increase rapidly. Strain over beam section is calculated by load increment of 4 kN. Where, strain from demec gauge is calculated from top and bottom zone of beam with a gauge length of 200mm from which average strain is calculated and plotted over the load.

CONCLUSION

Tests results on ten GFRP reinforced concrete beams are presented in this paper. The reinforcing bars had a relatively high modulus of elasticity and different reinforcement amounts and effective depth-to-height ratios were used. From experimental study it is observed that the results satisfy expectation. The beam specimen reinforced with both steel bar and GFRP bars as good flexural behaviour over other beam specimen. Since, GFRP bars offer high strength performance and a steel bar offers a good ductility which in turn observed that it has good behaviour over all parameter took in account like, load-deflection behaviour, strain distribution and crack pattern.

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