FLEXURAL RESPONSE OF FRC BEAMS WITH EXTERNAL GFRP LAMINATES

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Abstract

This study presents the experimental results of steel fibre reinforced concrete beams with externally bonded glass fibre reinforced polymer laminates with a view to study their strength and ductility. Three types of beams were tested in the laboratory. Three fibre reinforced concrete beams were used as reference beams. Six fibre reinforced concrete beams were provided with externally bonded GFRP laminates. One concrete beam was left virgin without any fibre reinforcement and external GFRP laminates. All the beams were tested until failure. The variables considered included volume fraction of fibre reinforcement and stiffness of Glass fibre reinforced polymer laminates. The static responses of all the beams were evaluated in terms of strength, stiffness and ductility. The experimental results show that the beams provided with steel fibres and externally bonded glass fibre reinforced polymer laminates exhibit improved performance in all the aspects over the beams with internal fibre reinforcement.

Keywords: RC; GFRP; FRP; SFRC; Ductility;

I. INTRODUCTION

The applications of fibre reinforced polymer laminates have been widely used in repair and rehabilitation of concrete structures. However, the interfacial fracture that happens along the FRP-concrete bonding interface significantly limits the strengthening performance of FRP laminates. From the experiment researches so for carried out, it is found that interfacial debonding in most cases initiates where a localized flexural crack forms in the concrete. Then it develops further within the adhesive resin (or) the interfacial concrete adjacent to the bonding interface in the plain concrete structures. Because of this the strengthening performance of FRP laminates cannot be achieved sufficiently. A practical and effective solution, which has adopted to bring concrete itself better performance, is to incorporate a small amount of short fibres into the concrete. Various types of short fibres such as natural fibres, steel fibres, glass fibres and poly propylene fibres are used. Several methods have been devised and adopted for the years for imparting ductility to concrete structures. One such method involves introduction of micro-reinforcement into concrete. With the passage of time, a novel method of using ultra-thin fibre reinforced polymer wraps/laminates has been adopted for the purpose. FRP wraps/laminates can be installed at specific locations on the structural members to obtain maximum efficiency. Ductility is a structural design requirement in most design codes. In steel reinforced concrete structures, ductility is defined as the ratio of ultimate deformation to yield deformation. The most important aspect of ductility is a precaution of structural failure. Ductile structure can provide an advanced warning before failure. Attari.N., et al.[1] in their study they have concluded that the strengthening laminates GFRP and CFRP noticeably increases the ultimate load capacity and stiffness of the beams and it is an effective method to enhance theirs ductility. Alfarabi et al.[2] tested concrete beams strengthened using different patterns of GFRP plates. They recommended the use of I-jackets to eliminate plate separation and diagonal tension failure and to avoid significant decrease in ductility. In another study, they examined the feasibility of using different shapes of GFRP plates for shear strengthening; plates, wings and I-jacket patterns were tested. It was concluded that only the I-jacket shape converted the mode failure to flexural mode. Swamy et al.[3] studied the ductility of beams strengthened with FRP plates. It was concluded that the ductility of these beams can be improved using innovative design techniques that minimize the relative bond slip between the plates and the beam. F.Ceroni[4] studied the performance of RC beams strengthened with FRP materials. He used CFRP laminates for strengthening the RC beams. He concluded that use of CFRP laminates increases the load carrying capacity but the ductility has reduced due to brittle failure caused by the occurrence of end debonding of FRP reinforcement. T.El-Amoury et al.[5] carried out the seismic rehabilitation of beam-column joint using GFRP sheets. The authors concluded that GFRP jacketing for rehabilitation of beam-column joint maintained the concrete integrity by confinement and significantly improved the ductility and load carrying capacity of the rehabilitated joint. Huanzi wang et al.[6] studied the ductility characteristics of fibre reinforced concrete beams reinforced with FRP rebar. They concluded that addition of polypropylene fibre has been proved to be an effective way to enhance the ductility of FRP reinforced system. From the literature review, it can be found that the premature debonding of FRP laminates will affect the strength and ductility of the RC beams. Many of the researchers have concentrated only on the load carrying capacity. Some of them have recommended CFRP or GFRP sheets with two or three or more number of layers for effective strengthening. CFRP strengthened RC beams showed improved flexural strength but not ductility. It can also be found that some researchers used poly propylene fibre along with steel fibres and also they used CFRP for strengthening purpose. Using of short fibres can increase the load carrying capacity of the structural member but service life of a structural member when subjected to disaster (or) accident cannot be improved by using short fibres. Many researchers have concentred only on the flexural and shear behaviour of the FRP strengthened beams. Based on all the above criteria an attempt has hence been made to provide an effective method of strengthening RC beams by introducing short steel fibres and bonding of GFRP laminates to the tension face of the beam. The main objective was is to study the ductility behaviour of concrete beams with short steel fibres of different volume fractions and strengthening the FRC beams with GFRP laminates with different thickness. Three types of concrete beams were casted and tested, which are conventional RC beams for reference, steel fibre reinforced concrete beams with three volume fractions (0.5%, 1.0% & 1.5%) and the beams with SF and UDC GFRP laminate with different thickness (3mm & 5mm).

II. MATERIALS AND METHODS

All the beams were of same size as 150mm x 250mm x 3000mm. The details of tested beams and GFRP laminates used in this study are given in Table 1. All the beams were reinforced with 2 nos. of 12mm diameter bars in the tension face and two nos. of 10mm diameter bars were used as hanger bars. The shear links consisted of 8mm diameter two-legged stirrups @ 125mm c/c spacing. All the beams were tested in a 750 kN capacity loading frame. The beams were subjected to static four-point bending. The loads were applied in increments of 2.5kN. Dial gauges of 0.01 mm accuracy were used to measure deflections at the loading points and at mid-span. A microscope of 0.02 mm precision was used to measure the crack width. The experimental set-up adopted is shown in Fig.1. The steel fibres used in this study were Dramix steel fibres with hooked end of diameter 0.5mm and of length 30mm. The aspect of the steel fibre is 60. The density, young's modulus and tensile strength of the steel fibre is 7850kg/m^3, 2.1x10^5 N/mm^2 and 532 N/mm^2 respectively.

TABLE 1: Beam Details

Beam	Volume of Steel Fibre (%)	GFRP Thickness (mm)	Elastic Modulus of GFRP (N/mm^2)
B0	0	-	
B1	0.5	-	
B2	1.0	-	
B3	1.5	-	
B11	0.5	3	13965
B12	0.5	5	17365
B21	1.0	3	13965
B22	1.0	5	17365
B31	1.5	3	13965
B32	1.5	5	17365

Figure.1 Experimental Set-up

III. RESULTS AND DISCUSSION

The test results of all the beams are given in Table 2. The test results show that the load carrying capacity increased with increase in fibre content. The ultimate load was found to be 32% with 1.5% fibre content when compared to that of conventional concrete. The ultimate load carrying capacity of SFRC beams with 0.5%, 1.0% and 1.5% steel fibres improved by 14%, 20% and 32% respectively compared to the conventional RC beam. From the experimental results it can also be found that the first crack load of SFRC beams with 0.5%, 1.0% and 1.5% steel fibres increased by 10%, 20% and 36% respectively when compared to the conventional RC beam. The crack width of SFRC beams with 0.5%, 1.0% and 1.5% steel fibres got reduced at ultimate level by 6%, 16% and 29% respectively as compared to the conventional RC beam. From the test results, it can also be found that the SFRC beams with GFRP laminates exhibit an increase of 156% in ultimate load capacity over the conventional RC beams and of 96% over the SFRC beams. The fibre reinforced concrete beams with external GFRP laminates exhibit a decrease of 87% in ultimate deflection over the conventional RC beams and of 48% over the SFRC beams. The load-deflection behaviour of all the tested beams are shown in Fig.2. The comparisons of load at various stages of test of all the beams are shown in Fig.3. The fibre reinforced concrete beams with external GFRP laminates exhibit a decrease of 71% in crack width at ultimate load level with respect to the conventional RC beams. From the test results it can also be found that the load at which the formation of first crack of SFRC beams with 0.5%, 1.0% and 1.5% steel fibres increased by 10%, 20% and 36% as compared with conventional RC beam. Also GFRP strengthened SFRC beams increases the first crack load by 58% as compared with unstrengthened SFRC beams. The ductility details of all the tested beams were shown in Table.3. From the test results it can also be found that deflection ductility of SFRC beams with 0.5%, 1.0% and 1.5% steel fibres improved by 23%, 61% and 89% respectively compared to the conventional RC beam. The fibre reinforced concrete beams with external GFRP laminates exhibit an increase of 210% in deflection ductility over conventional RC beams and 65% over the SFRC beams. From the test results it can also be found that energy ductility of SFRC beams with 0.5%, 1.0% and 1.5% steel fibres improved by 15%, 66% and 94% respectively compared to the conventional RC beam. The fibre reinforced concrete beams with external GFRP laminates exhibit an increase of 95% in energy ductility over the SFRC beams. Ductility comparisons of all the tested beams are shown in Fig.4.

TABLE: 2 Test Results of Beams

Beam	First Crack load (kN)	Service Load (kN)	Yield Load (kN)	Ultimate Load (kN)	Crack Width at Ultimate stage (mm)
B0	24.53	31.72	34.34	47.58	0.72
B1	26.98	36.13	41.82	54.20	0.52
B2	29.43	38.09	44.15	57.14	0.50
B3	31.88	41.77	49.05	62.20	0.46
B11	36.79	55.20	61.31	82.80	0.42
B12	41.69	61.64	71.12	92.46	0.40
B21	42.18	64.91	71.12	97.36	0.37
B22	44.15	70.63	76.03	105.95	0.35
B31	46.60	71.94	73.58	107.91	0.33
B32	51.51	81.36	88.29	122.04	0.30

TABLE: 3 Ductility Details of tested Beams

Beam	Yield Load Deflection (mm)	Ultimate Load Deflection (mm)	Deflection Ductility	Energy Ductility
B0	13.15	38.85	2.95	4.96
B1	12.00	43.55	3.63	5.69
B2	10.90	51.65	4.74	8.25
B3	9.85	54.85	5.57	9.63
B11	12.85	68.10	5.30	9.81
B12	12.5	71.10	5.69	10.69
B21	11.95	81.50	6.82	11.61
B22	11.75	90.00	7.66	13.16
B31	11.38	94.00	8.26	16.63
B32	10.65	97.50	9.15	18.78

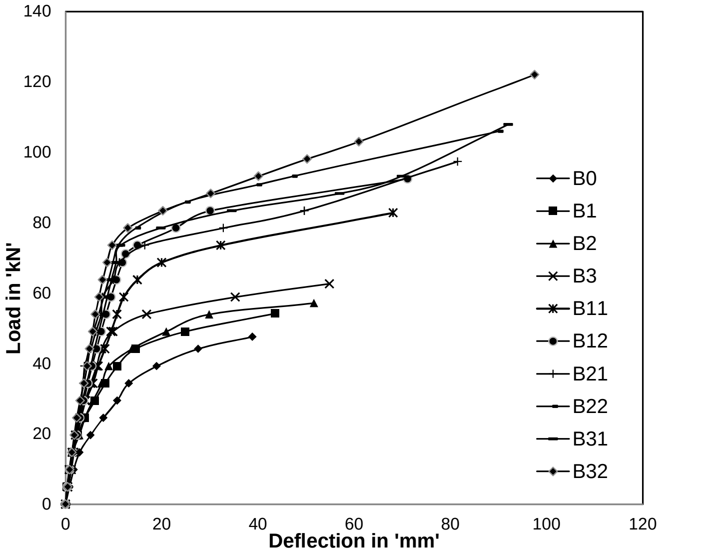

Figure.2 Load–Deflection behaviour of tested beams

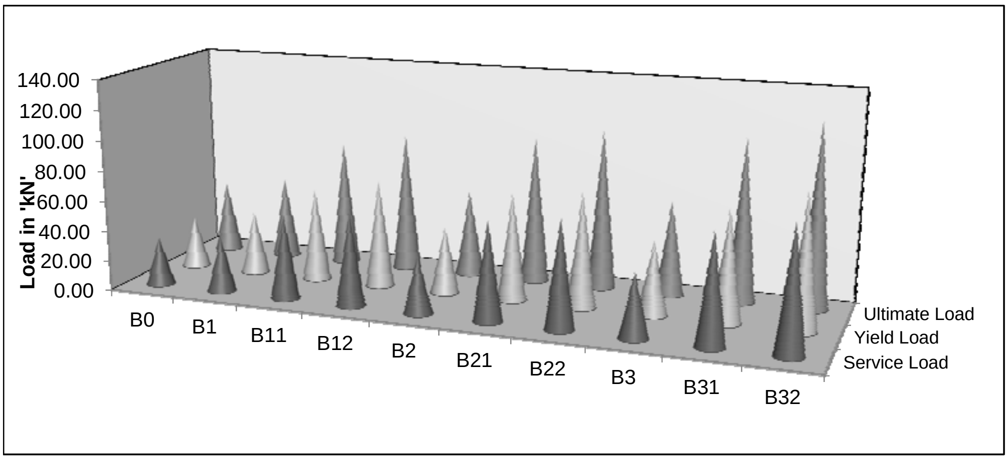

Figure.3 Load Comparison at various stages of tested beams

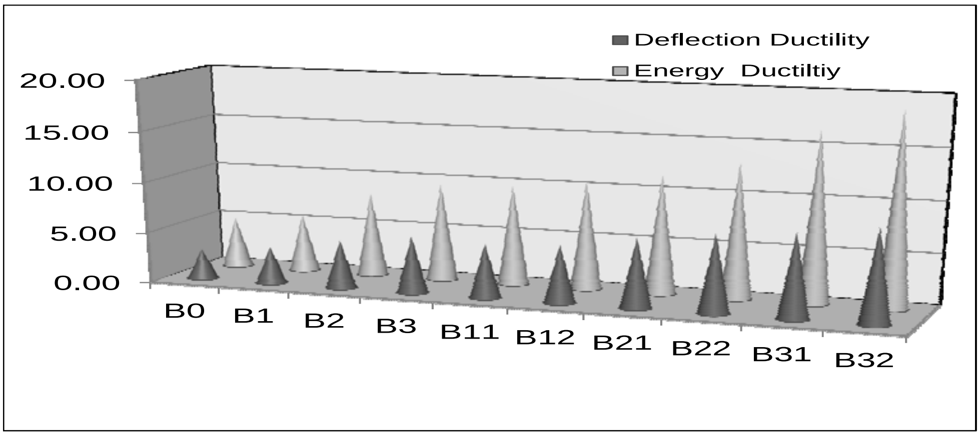

Figure.4 Ductility comparison of tested beams

IV. CONCLUSIONS

From the test results on steel fibre reinforced concrete beams strengthened with GFRP laminates, the following conclusions are drawn:

1. The SFRC beams with external GFRP laminates exhibit a maximum increase of 96% in ultimate load capacity with respect to the SFRC beams.

2**.** The SFRC beams with external GFRP laminates exhibit a decrease of deflection up to 48% with respect to the SFRC beams.

3. The SFRC beams with external GFRP laminates exhibit a decrease in crack width up to 25% in ultimate load capacity with respect to the SFRC beams.

4. The SFRC beams with external GFRP laminates exhibit an increase in deflection ductility up to 65% with respect to the SFRC beams.

6. The SFRC beams with external GFRP laminates exhibit an increase in energy ductility up to 95% with respect to the SFRC beams.

7. The SFRC beams with external GFRP laminates increases the first crack load by 58% as compared with unstrengthened SFRC beams.

8. All the beams with GFRP laminates experienced flexural failure.

9. None of the beams exhibited premature failure of the laminate.

V. REFERENCES

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