

Strengthening of Reinforced Concrete Beams using Glass Fibre Reinforced Polymer Laminate

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Abstract— Strengthening of structures using Fibre Reinforced Polymer (FRP) shows better promise for extending the life span of structures. The advantages of using FRP include light weight, ease of installation, minimal labour costs and site constraints, high strength-to-weight and durability. Fibre reinforced polymer application is a very effective way to repair and strengthen structures that have become structurally weak over their life span. The objective of this work is to evaluate the structural behaviour of reinforced concrete beams with externally bonded FRP reinforcement. Two different grades (M15, M25) of reinforced concrete beams were casted and curing is done for a period of 28 days. Reinforced concrete beams of two different grades bonded with Glass Fibre Reinforced Polymer (GFRP) laminate of varying (0.50 mm, 1.00 mm) thickness were used. Totally six rectangular beams of 1600 mm×100 mm×200 mm size were cast. Two beams were used as reference beams for both grades and the remaining beams were provided with GFRP laminates. The variable considered for the study is thickness of GFRP laminate. The study parameters of this investigation included yield load, ultimate load, yield deflection and ultimate deflection of the test beams. The performance of FRP wrapped beams was compared with that of unwrapped beam. The test results were showed that the beams strengthened with GFRP laminates exhibited better performance.

Key words: Self Compaction Concrete, Marble Dust, Fly Ash

I. INTRODUCTION

Reorganization, change of use or re-planning of industrial buildings might cause changes of structural systems as well as higher life loads so that we have to rehabilitate or upgrade those structural systems. The maintenance, rehabilitation and upgrading of structural members, is perhaps one of the most crucial problems in civil engineering applications. Moreover, a large number of structures constructed in the past using the older design codes in different parts of the world are structurally unsafe according to the new design codes. Since replacement of such deficient elements of structures incurs a huge amount of public money and time, strengthening has become the acceptable way of improving their load carrying capacity and extending their service lives. Infrastructure decay caused by premature deterioration of buildings and structures has lead to the investigation of several processes for repairing or strengthening purposes. One of the challenges in strengthening of concrete structures is selection of a strengthening method that will enhance the strength and serviceability of the structure while addressing limitations such as constructability, building operations, and budget.

II. LITERATURE REVIEW

Teng. et al. (2002) presented a finite element study for interfacial stresses in reinforced concrete beams strengthened with a bonded soffit plate. They validated the finite element results with the predictions of the approximate analytical solution by Smith and Teng. The authors varied parameters such as thickness of adhesive layer, the elasticity modulus of adhesive layer, the thickness of soffit plate. They concluded that the interfacial stresses were found to increase with a reduction in adhesive thickness and an increase in adhesive elastic modulus, plate thickness/elasticity modulus. They have used fine mesh for analyzing the point of stress singularity in a plated RC beam.

Chen and Teng (2003) developed a simple, accurate and rational design model for the shear capacity of FRP strengthened beams which fail mainly by FRP debonding. The authors validated their model against experimental data collected from the existing literature. Their model explicitly recognizes the non-uniform stress distribution in the FRP along a shear crack as determined by the bond strength between FRP strips and concrete. The design proposal developed by them can be directly used for practical design.

Francois Buyle-Bodin (2004) examined the performance of rectangular simply supported reinforced concrete beams with externally bonded reinforcement made of carbon fibre reinforced polymer plates. The author studied the load-carrying capacity of CFRP beams by delaying end peel failure. The author prevented the brittle failure by use of clamps at the ends of the beam, bonding of lateral perpendicular or inclined strips and U-wrapping of shear spans with carbon fibre textile. The author concluded that the lateral bonding of CFRP strips and U-wrapping using carbon fibre textile controls the debonding cracks and delay the premature end failure of the beams. The load carrying capacity is enhanced, and the ductility is increased.

Lin et al. (2005) presented an experimental study on strengthening reinforced concrete beams using pre-stressed glass fibre reinforced polymer (PGFRP). The ultimate loads and the deflections of strengthened RC beams using GFRP and PGFRP sheets were tested and compared. They reported that the beams strengthened with PGFRP sheets can withstand larger ultimate loads than beams with ordinary GFRP sheets. The deflections of the beams with PGFRP sheets are smaller than those of beams with GFRP sheets under the same external loads. The ductility of the over-strengthened beams was especially smaller.

Ginseppe Campione (2006) has studied on the influence of FRP wrapping techniques on the compressive behaviour of concrete prisms. The specimens were prism with square cross section externally wrapped with carbon fibre reinforced plastic sheets. The parameters analyzed were

local reinforcements at the corners and continuous layers, horizontal and vertical continuous strips, number of continuous layers, and length of the specimens. The author concluded that the test results showed a good agreement with an analytical model prepared to determine the maximum bearing capacity of compressed concrete members with square cross section and externally wrapped with FRP with different configuration.

Xiong et al. (2007) have tried to devise a way for preventing tension delamination of concrete cover at midspan of FRP strengthened beams by combining CFRP and GFRP sheets at midspan of a beam. They have used unidirectional carbon fibre reinforced polymer sheets on the tension face of the beams and bi-directional GFRP sheet wrapped on 3 sides of the beam continuously. The feasibility and potential advantages of the attempt are discussed. They have concluded that the hybrid CFRP-GFRP system could not only prevent the tension delamination of the bottom concrete cover, but also lead to a significant increase of deformation capacity of the strengthened beams at a very low cost compared to CFRP strengthening.

V.P.V. Ramana, T. Kant, S.E. Morton, P.K. Dutta, A. Mukherjee, Y.M. Desai: These authors have investigated and summarized the results of experimental and analytical studies on the flexural strengthening of reinforced concrete beams by the external bonding of high-strength, light-weight carbon fibre reinforced polymer composite (CFRPC) laminates to the tension face of the beam. Four sets of beams, three with different amounts of CFRPC reinforcement by changing the width of CFRPC laminate, and one without CFRPC were tested in four-point bending over a span of 900 mm. The tests were carried out under displacement control. At least one beam in a set was extensively instrumented to monitor strains and deflections over the entire range of loading till the failure of the beam. The increase in strength and stiffness provided by the bonded laminate was assessed by varying the width of laminate. The results indicate that the flexural strength of beams was significantly increased as the width of laminate increased. Theoretical analysis using a computer program based on strain compatibility is presented to predict the ultimate strength and moment deflection behavior of the beams. The comparison of the experimental results with theoretical values is also presented, along with an investigation of the beam failure modes.

Saleh H. Alsayed and Abdulrahman M. Al-Hozaimy: A total of 18 concrete beams were tested to study the influence of adding steel fibres (SF) on the ductility of the concrete beams reinforced with fibre reinforced plastic bars (FRP-beams). The main variables in the study were the type and volume fractions of the steel fibre. The study also investigated the accuracy of the modified analytical model to predict the flexural capacity of the FRP-beams. The results indicate that the energy ductility of FRP-beams is less than 50% of that of the respective concrete beams reinforced with steel bars (steel-beams). The results also reveal that the energy ductility of FRP-beams is directly related to the fibre content. In addition, the test results show that inclusion of 1% of hooked SF can improve the ductility of FRP-beams to be the same as that of the steel-beams. Furthermore, comparison between the predicted and measured flexural capacity of fibrous FRP-beams shows that the analytical model can predict the measured results within a reasonable accuracy.

Z.G. Guan and J.Z. Li: They have worked on Fibre reinforced concrete and stated that the Concrete sections strengthened with externally bonded FRP plates have a more complex load-deformation relationship due to the FRP's linear stress-strain relationship up to failure. Therefore, the conventional definitions of ductility indices, based on the assumption of the elastic-perfectly plastic load-deformation relationship, are inappropriate for evaluation of the ductility of FRP strengthened concrete sections. In this paper, a new definition for an effective ultimate deformation is proposed, synthetically considering the deformation status of the concrete, steel reinforcement and FRP plate. A new non dimensional index appropriate for the complex load-deformation relationships is presented. Compared to conventional indices, the new index gives more reasonable ductility results and can be equally applied to RC/PC sections strengthened with or without externally bonded FRP.

From the above information, it is thus clear that there lies a infinite scope of research in the field of retrofitting of concrete structures using externally bonded FRP composites. In the above section it has been shown how the structural strength and stiffness can be improved by externally bonded material. The worldwide interest in the technique reflects its potential benefits and also the current importance placed on economical rehabilitation and upgrading methods. Although the level of experience in the bonding technique of composite plates is limited, the investigations reported in this chapter have gone some way to illustrate its potential and to establish a basic technical understanding of short term and long term behaviour. Despite the growing number of field applications, there remain many material and structural implications that need to be addressed, in particular with regard to long term performance under loads.

III. EXPERIMENTAL INVESTIGATION

The testing of the ingredient materials of concrete such as cement, fine aggregates and coarse aggregates are carried out and results are presented below.

A. Cement

Ordinary Portland cement (OPC) – 53 grade (RAMCO Cement) was used for the investigation. It was tested for physical properties in accordance with Indian Standard specifications.

- Initial setting time - 80 min
- Final setting time - 600 min
- Specific gravity - 3.13

B. Fine Aggregates

The locally available good quality sand is used as fine aggregate and the following tests have been performed on fine aggregate.

- Specific Gravity: 2.60
- Fineness modulus: 2.27

C. Coarse Aggregates

The coarse aggregates used were locally available crushed granite stone. The tests conducted on coarse aggregate are:

- Sieve Analysis: maximum size 20mm
- Fineness modulus: 7.0
- Specific gravity: 2.69

D. Reinforcement

Steel used in beams is high yield strength deformed (HYSD) bars, yield strength of 415 N/mm². For each beam 2 no. of 8 mm diameter longitudinal reinforcement is adopted in bottom as well as 2 no. of 8 mm diameter longitudinal reinforcement is adopted in top for anchorage and 6mm diameter M.S bars are used as shear reinforcement. The steel bars used are free from dust, rust or any organic matter.

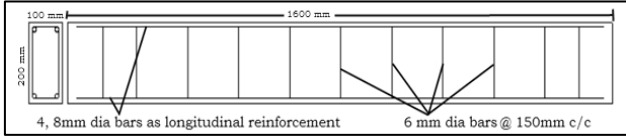


Fig. 1: Reinforcement details of SET I & SET II Beams

E. Chopped Strand Mat

Chopped strand mats are used primarily for hand lay-up, filament winding and press molding of FRP parts. Their many excellent characteristics have been used to provide superior performance in a broad range of end-use markets such as marine, transportation, recreation, construction, consumer and anti-Chopped Strand Mats Typical Laminate Properties corrosion.

F. Epoxy Resin

Fibres, since they cannot transmit loads from one to another, have limited use in engineering applications. When they are embedded in a matrix material, to form a composite, the matrix serves to bind the fibres together, transfer loads to the fibres, and damage due to handling. The matrix has a strong influence on several mechanical properties of the composite such as transverse modulus and strength, shear properties, and properties in compression.

G. Mix Proportion

Cement	Fine aggregate	Coarse aggregate	Water
320	598	1229	191.6
1	1.87	3.84	0.60

Table 1: Mix Proportion of M15

Cement	Fine aggregate	Coarse aggregate	water
384	546	1229	191.6
1	1.42	3.21	0.5

Table 2: Mix Proportion of M25

IV. RESULTS

Ultimate load results of SET I and SET II beams

S. No.	Description of beam	Beam Notation	Yield load(kN)	Ultimate load (kN)
1.	M15	B1	40	62
		B2	60	97.5
		B3	78	117
2.	M25	C1	60	75
		C2	77.5	105
		C3	98	125

Table 3: Ultimate load results of SET I and SET II beams

B1 (M15 0layer)		B2 (M15 1layer)		B3 (M15 2layers)	
Load (kN)	Deflection(mm)	Load (kN)	Deflection	Load (kN)	Deflection (mm)
0	0	0	0	0	0
10	0.17	20	0.8	20	0.78
20	0.64	40	1.95	40	1.9

30	1.4	50	2.55	55	2.95
40	2.4	60	3.6	60	3.18
45	2.61	65	4	64	3.5
50	3.33	72.5	4.4	67	3.9
55	4.09	75	4.8	72	4.25
60	4.56	77	5.25	78	4.67
62	5.2	80	5.8	80	5.05
		82.5	6.3	85	5.48
		85	6.92	95	5.98
		87.5	7.47	98	6.8
		90	8.03	102	7.05
		92.5	8.6	104	7.6
		95	9.2	106	8.2
		97.5	9.75	108	9.2
				110	10.3
				114	11.4
				117	12.9

Table 4: Results of M15 (B1, B2 and B3) Beams

C1 (M25 0layer)		C2 (M25 1layer)		C3 (M25 2layers)	
Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)
0	0	0	0	0	0
10	0.16	25	0.73	20	0.65
20	0.4	50	1.78	40	1.28
30	0.87	65	2.25	60	2.45
40	1.62	75	2.8	65	2.85
50	2.36	77.5	3.15	70	3.2
55	2.88	80	3.45	75	3.58
60	3.28	82.5	3.92	85	4
62	3.78	85	4.58	90	4.42
68	4.46	90	4.98	95	4.9
75	5.76	95	5.5	98	5.34
		100	6.52	101	5.82
		103	7.9	103	6.3
		105	9.63	105	6.8
				107	7.4
				110	7.98
				112	8.5
				115	9.05
				118	9.7
				125	10.7

Table 5: Results of M25 (C1, C2 and C3) Beams

V. CONCLUSION

In this experimental investigation the reinforced concrete beams strengthened by GFRP sheets are studied. Two sets of reinforced concrete (RC) beams, in SET I three M15 grade beams and in SET II three M25 grade beams were casted and tested. From the test results and calculated strength values, the following conclusions are drawn.

- 1) In controlled beams of different grades, the yield load carrying capacity of the beam C1 is 50% more than the beam B1 and the ultimate load carrying capacity of the beam C1 is 20.96% more than the beam B1.
- 2) In one layered beams of different sets, the yield load carrying capacity of the beam C2 is 29.16% more than the beam B2 and the ultimate load carrying capacity of the beam C2 is 7.69% more than the beam B2.
- 3) In two layered beams of different set, the yield load carrying capacity of the beam C3 is 25.64% more than the beam B3 and the ultimate load carrying capacity of the beam C3 is 6.83% more than the beam B3.

By comparing the beams of different sets with same layer thickness, the yield load carrying capacity is fairly increasing and the ultimate load carrying capacity is significantly increased.

The bonding between GFRP sheet and the concrete is intact up to the failure of the beam which clearly indicates the composite action due to GFRP sheet.

Restoring or upgrading the flexural strength of beams using GFRP sheet can result in increased flexural strength and stiffness with no visible cracks. Restoring the flexural strength of beams using GFRP is a highly effective technique.

VI. SCOPE FOR FUTURE WORK

It promises a great scope for future studies. Following areas are considered for future research:

- Strengthening of beam with different type of fibre reinforced polymer sheet like woven roving, Uni-directional mat and Carbon fibre reinforced polymer.
- Variation of beam dimension.
- Variation of thickness and for different grades of concrete.
- Strengthening of beam weak in shear and torsional strength.

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