Int. J. Struct. & Civil Engg. Res. 2013

International Journal of Structural and Civil Engineering Research

ISSN 2319 – 6009 www.ijscer.com
Vol. 2, No. 2, May 2013

Research Paper

COMPRESSIVE BEHAVIOR OF CONCRETE CYLINDERS CONFINED WITH GLASS AND CARBON FIBRE REINFORCED POLYMERS

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External wrapping with Fibre Reinforced Polymers (FRP) has been increasing in recent years for strengthening and retrofitting of concrete and steel structures. Hence an attempt has been made to investigate the compressive behavior of concrete specimens (cylinders) strengthened with FRPs. The parameters varied in this investigation were wrapping materials (which include glass and carbon fibre reinforced polymers), number of plies (single and double plies), orientation of fibres (along the length and circumference of the specimens) and curing period (wrapping after 7 and 28 days of water curing). The experimental result shows that the specimens wrapped with carbon fibre reinforced polymers have higher compressive strength than the specimens wrapped with glass fibre reinforced polymers in both single and double plies for wrapping after 7 and 28 days of water curing.

Keywords: CFRP, GFRP, Epoxy, Compressive strength

INTRODUCTION

Traditional retrofitting techniques that use steel and cementitious materials do not always offer the most appropriate solutions. Whereas, retrofitting with FRP may provide a more economical and technically superior alternative to the traditional techniques in many situations. FRP composite materials posses superior mechanical properties, it includes corrosion resistance, impact resistance, excellent durability, high strength-to-weight ratio, light in weight, versatility, ease of installation, electromagnetic neutrality, excellent fatigue behavior, fire resistance, creep, stiffness and geometry than traditional reinforcing materials such as steel and cementitious materials, and can result in less labor-intensive and less equipment intensive retrofitting work. In recent years, many investigations have addressed the externally bonded fibre reinforced polymer composites for strengthening of concrete structures. Teng and Lam (2002) conducted an experimental study on FRP-confined concrete in elliptical columns. Test results indicate that the confining FRP becomes increasingly less effective as the section

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becomes more elliptical, substantial strength gains from FRP confinement can still be achieved even for strongly elliptical sections. Lamanna *et al*. (2004) carried out an experimental work on split tensile strengthening of reinforced concrete specimens by mechanically attaching fibre-reinforced polymer strips. It has been observed that mechanically attached FRP strips showed a greater ductility than the specimen strengthened with a bonded FRP strip. Sen and Mullins (2007) studied the application of FRP composites for underwater piles repair. They suggested that the bi-directional material should be preferred over uni-directional material and carbon fibre over glass fibre. Purushotham Reddy *et al*. (2009) studied the retrofitting of RC Piles using GFRP Composites. The authors concluded that the axial and lateral load carrying capacity of the GFRP retrofitted pile increases with the conventional pile. Sangeetha and Sumathi (2010) investigated the behavior of Glass fibre wrapped concrete columns under uniaxial compression. The study concluded that confinement increased the strength of the concrete columns loaded axially.

MATERIALS AND METHODS

Material Properties

The characteristic compressive strength of concrete used for the study was 30 MPa. The mix ratio adopted was 1: 1.204: 2.755: 0.385 (cement: Fine aggregate: Coarse aggregate: Water). The compressive strength of concrete cubes after 28 days water curing was 43.92 MPa.

Preparation and Casting of Specimens

The specimens were prepared by casting them in steel moulds with a size of 150 mm in diameter and 300 mm in length. The interior of the steel mould was applied a liberal coat of lubricating oil to prevent concrete from adhering to the mould. The designed concrete mix was filled into the moulds in layers. Adequate compaction was carried out using table vibrator to avoid honey combing. After one day of casting, specimens were demoulded and immersed in water for curing.

Properties of Fibre Reinforced Polymers

Glass and carbon fibre reinforced polymers were used in the study. Properties of GFRP and CFRP materials are given in the Table 1.

Table 1: Properties of FRP Materials

Properties	CFRP	GFRP	
	Unidirectional	Unidirectional	Bidirectional
Weight of fibre	200 g/m^2	920 g/m^2	750 g/m^2
Fibre thickness	0.3 mm	0.90 mm	0.6 mm
Nominal thickness per layer	0.5 mm	1.5 mm	1 mm
Primary fibre tensile strength	3500 N/mm^2	3400 N/mm^2	3400 N/mm^2
Tensile Modulus	285000 N/mm^2	73000 N/mm^2	73000 N/mm^2

Wrapping with FRP

The cured specimens were prepared for wrapping with FRPs. The surfaces of the specimens were ground with an emery sheet to remove loose and deleterious material from the surface. Then, FRP wrapping was done by the epoxy adhesive. The wrapped surfaces were gently pressed with a rubber roller to ensure proper adhesion between the layers and proper distribution of resin.

EXPERIMENTAL INVESTIGATION

The test is performed in accordance with IS 516:1959. A standard test cylinder of 300 mm length and 150 mm diameter is placed vertically between the loading surfaces of compression testing machine. The compression load is applied vertically and uniformly until the failure of the cylinder. Experimental investigation has been conducted on 66 specimens. Three specimens were tested for each test and the average of three values was taken for further study. Out of the 66 specimens, six reference specimens were tested after 7 and 28 days curing without any wrapping and the remaining 60 specimens were wrapped with GFRP and CFRP mat of varying configuration with different layers. FRP wrapped concrete cylinders are shown in Figure 1. Compressive failure of FRP wrapped cylinders are shown in Figures 2 to 4.

Figure 1: FRP Wrapped Concrete Cylinders

Figure 2: Failure of Unidirectional GFRP Wrapped Cylinders Along the Circumference

Figure 3: Failure of Unidirectional CFRP Wrapped Cylinders Along the Circumference

Figure 4: Failure of Unidirectional CFRP Wrapped Cylinders Along the Circumference

EXPERIMENTAL RESULTS AND INVESTIGATION

7 and 28 days cured specimens were wrapped with glass and carbon fibre reinforced polymers with single and 2 plies. Unidirectional glass and carbon fibre reinforced polymers were wrapped along the length and circumference of the specimen. In addition to this bidirectional glass fibre reinforced polymers also used for this study. Table 2 shows the results of tested specimens.

Table 2: Results of Tested Specimens

S. No.	Specimen Descriptions	Number of Specimens (Specimens)	Period of Curing (days)	Number of Plies	Compressive Strength (N/mm^2)
1	Unconfined Specimens	3	7	0	23.91
		3	28	0	34.94
2	Specimens wrapped with	3	7	1	32.36
	unidirectional GFRP	3	28	1	42.70
	along the length of the	3	7	2	43.91
	specimen	3	28	2	53.12
3	Specimens wrapped	3	7	1	37.48
	with unidirectional	3	28	1	48.07
	GFRP along the circumference	3	7	2	52.12
	of the specimen	3	28	2	59.98
4	Specimens wrapped	3	7	1	34.15
	with bidirectional GFRP	3	28	1	46.23
		3	7	2	51.42
		3	28	2	58.84
5	Specimens wrapped with	3	7	1	36.24
	unidirectional CFRP along	3	28	1	44.74
	the length of the specimen	3	7	2	52.24
		3	28	2	60.24
6	Specimens wrapped with	3	7	1	48.10
	unidirectional CFRP along the	3	28	1	57.51
	circumference of the specimen	3	28	2	79.96
		3	7	2	73.11

Effect of FRP Wrapping Materials

To determine the effect of FRP wrapping materials on the compressive strength of concrete, the specimens were wrapped with glass and carbon fibre reinforced polymers. The experimental results shows that the specimens wrapped with carbon fibre reinforced polymers has higher compressive strength than the specimens wrapped with glass fibre reinforced polymers. This is due to the high tensile strength of carbon fibres than glass fibres. Figures 5 and 6 shows the variation of compressive strength for specimens wrapped with glass and carbon fibre reinforced polymers.

Figure 5: 28 Days Cured Specimens Wrapped With Unidirectional GFRP and CFRP Mat Along the Length of Specimen

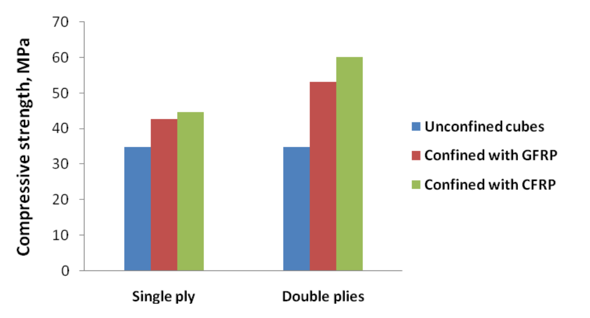
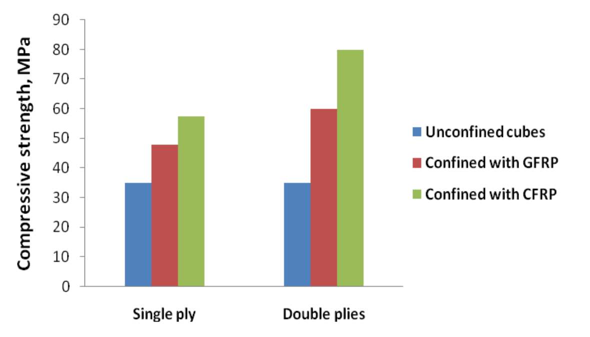


Figure 6: 28 Days Cured Specimens Wrapped with Unidirectional GFRP and CFRP Mat Along the Circumference of Specimen



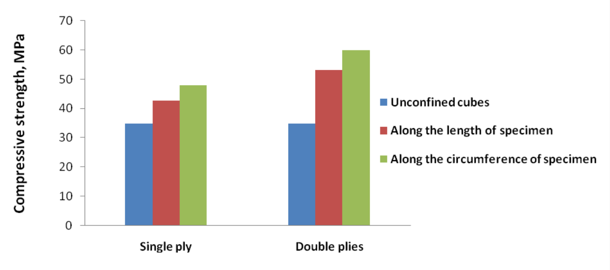
- The percentage increase in compressive strength of specimens (after 28 days curing) wrapped with unidirectional GFRP and CFRP mat along the length of the specimen were 22.21 and 28.05% for single ply and 52.03 and 72.41% for double plies respectively (Ref. Figure 5).
- The percentage increase in compressive strength of specimens (after 28 days curing) wrapped with unidirectional GFRP and CFRP mat along the circumference of the specimen were 37.58 and 64.60% for single ply and 71.67 and 128.85% for double plies respectively (Ref. Figure 6).

Effect of Fibre Orientation

To determine the effect of fibre orientation on the compressive strength of concrete specimens, the specimens were wrapped with unidirectional fibres along the circumference and length of the specimens. The experimental result shows that the orientation of the fibres along the circumference of the specimen has higher compressive strength than the orientation of the fibre along the length of the specimen for both CFRP and GFRP wrapping. This is due to the high tensile strength of fibres along its length. Figures 7 and 8 shows the variation of compressive strength for unidirectional GFRP and CFRP mat wrapped along the circumferential and length of the specimen.

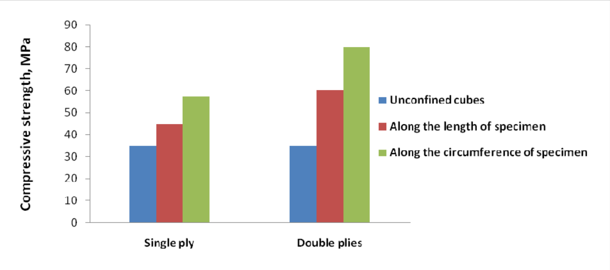
- The percentage increase in compressive strength of specimens (after 28 days curing) wrapped with unidirectional GFRP mat along the length and circumference of the specimens were 22.21 and 37.58% for single ply and 52.03 and 71.67 % for double plies respectively (Ref. Figure 7).

Figure 7: 28 Days Cured Specimens Wrapped With Unidirectional GFRP Mat



- The percentage increase in compressive strength of specimens (after 28 days curing) wrapped with unidirectional CFRP mat along the length and circumference of the specimens were 28.05 and 64.60% for single ply and 72.41 and 128.85% for double plies respectively (Ref. Figure 8).

Figure 8: 28 Days Cured Specimens Wrapped with Unidirectional CFRP Mat



Effect of Piles and Curing

To determine the effect of number of plies and curing on compressive strength of concrete specimens, the specimens were wrapped with fibre reinforced polymers of single and double plies after 7 and 28 days curing. The experimental result shows that the specimens wrapped with double plies have higher compressive strength than the specimens wrapped with single ply for both CFRP and GFRP wrapping after 7 and 28 days curing. This is due to the increase in the thickness of confinement and curing period before wrapping with CFRP and GFRP mat. Figures 9 to 11 shows the variation of compressive strength of specimens wrapped with single and double plies of GFRP and CFRP after 7 and 28 days curing.

Figure 9: 28 Days Cured Specimens Wrapped with Unidirectional GFRP Mat

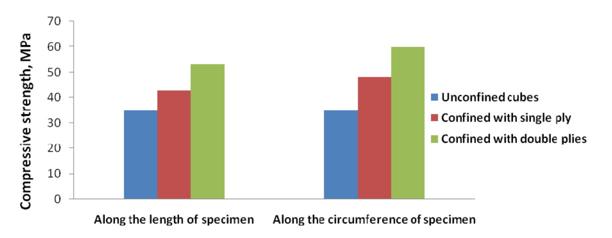


Figure 10: 28 Days Cured Specimens Wrapped with Unidirectional CFRP Mat

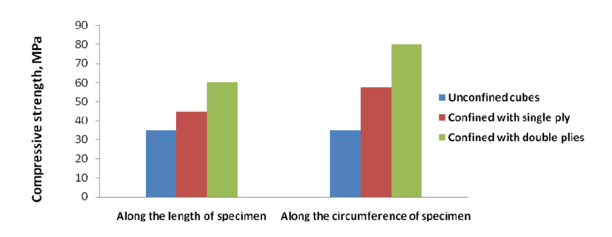
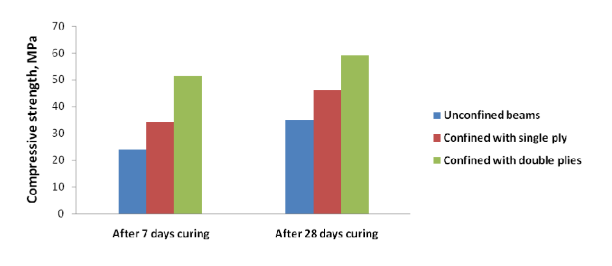


Figure 11: Specimens Wrapped with Bidirectional GFRP Mat



- The percentage increase in compressive strength of specimens (after 28 days curing) wrapped with single and double plies-unidirectional GFRP mat were 22.21 and 52.03% along the length of the specimen and 37.58 and 71.67% along the circumference of the specimen respectively (Ref. Figure 9).
- The percentage increase in compressive strength of specimens (after 28 days curing)

wrapped with single and double plies-unidirectional CFRP mat were 28.05 and 72.41% along the length of the specimen and 64.60 and 128.85% along the circumference of the specimen respectively (Ref. Figure 10).

· The percentage increase in compressive strength of specimens (after 28 days curing) wrapped with single and double plies-bidirectional GFRP mat were 32.31 and 68.40 % respectively (Ref. Figure 11).

AN EMPIRICAL MODEL FOR PREDICTING THE COMPRESSIVE STRENGTH OF FRP-CONFINED CONCRETE CYLINDERS

Experimental result shows that the compressive strength of FRP confined cylinders depends on grade of concrete, type of FRP material, fibre orientation, thickness of FRP layer and number of FRP layers. By considering all the factors, simple mathematical equation was arrived for compressive strength of FRP confined cylinders.

Compressive strength of FRP confined cylinders, $f = 1.165f_{ck} + k_1k_2tn$

where, f_{ck} = Characteristics compressive strength of concrete in N/mm^2

k_1 and k_2 are constants depends on type of FRP material and fibre orientation

Constant, k_1

Unidirectional GFRP mat, $k_1 = 5.765$

Bidirectional GFRP mat, $k_1 = 11.730$

Unidirectional CFRP mat, $k_1 = 23.400$

Constant, k_2

Unidirectional GFRP wrapping along the length, $k_2 = 1.000$

Unidirectional GFRP wrapping along the circumference, $k_2 = 1.471$

Unidirectional CFRP wrapping along the length, $k_2 = 1.000$

Unidirectional CFRP wrapping along the circumference, $k_2 = 1.926$

t is nominal thickness of FRP layer in mm

n is number of FRP layers.

CONCLUSION

The present study used 66 specimens, wrapped with unidirectional and bidirectional FRPs. Based on the experimental results, the following conclusions are made.

- Specimens wrapped with double plies have higher compressive strength than the specimens wrapped with single ply for both CFRP and GFRP wrapping. This is due to the increase in the thickness of CFRP and GFRP confinement.
- Compressive strength of 28 days cured specimens wrapped with both CFRP and GFRP mat has higher compressive strength than 7 days cured specimens wrapped with both CFRP and GFRP mat. This is due to the increase in the curing period before wrapping with CFRP and GFRP mat.
- Orientation of the fibres along the circumference of the specimens has higher compressive strength than the orientation of the fibre along the length of the specimens for both CFRP and GFRP wrapping. This is due to the high tensile strength of fibres along its length.

- Specimens wrapped with carbon fibre reinforced polymers have higher compressive strength than the specimens wrapped with glass fibre reinforced polymers. This is due to the high tensile strength of carbon fibres than glass fibres.

ACKNOWLEDGMENT

The authors wish to thank Fosroc Chemicals (India) Pvt. Ltd., for supply of fibre composites and epoxy used in this work.

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