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COMPRESSIVE STRENGTH ENHANCEMENT OF LOW STRENGTH CONCRETE SUBJECTED TO FREEZE-THAW EFFECT USING GFRP CONFINEMENT

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Abstract: Concrete is the most vital material for any kind of reinforced concrete structure. Very often it is likely to happen that, the specified required strength cannot be attained from the mixture because of improper mix design, inadequate compaction and several other uncertainty factors. Thus to improve the capacity of existing low strength concrete structures retrofitting is necessary with different external confining materials. An experimental investigation is made in this study to observe the effect of GFRP confinement on the compressive strength of concrete. Cylinders having GFRP confinement of different thickness are tested and improvement in their performance is observed under compression. Woven roving fiberglass as the reinforcing material and polyester resin as binding material are used to form GFRP. Cylinders subjected to freeze-thaw effect for a year and having a very low compressive strength are considered for this study. Results of the tests show that the GFRP confinement improves the compressive strength as much as 140% with the increase in the thickness of confining layer. Also the failure pattern of the concrete changes to more brittle type with increasing thickness of the GFRP layer.

1. INTRODUCTION

Concrete is one of the major role playing composite materials in the field of infrastructure development. It has a very good compression taking capability which makes it the most suitable material for construction of buildings, bridges, highways and runways. Reinforced with steel or any other reinforcing material, it forms different structural elements. In this fusion, concrete plays the role of taking major compressive loads while the reinforcements take most of the tensile loads. This compression taking capability of concrete can be significantly improved by adding a confinement effect that basically comes from the shear reinforcement in structural elements when it is designed properly. When structural members are designed with low shear demand or without considering the seismic requirements, concrete doesn't get the confinement from inadequate shear reinforcement.

Earlier before 1970, there was no strict provision for seismic code. Thus many of the bridges were built without considering the seismic effect and minimum requirements needed for withstanding the damage event of an earthquake. This deficiency in confinement can be resolved by adding external confinement using different techniques using steel tube and composite materials like GFRP and CFRP. Among these GFRP is cheap and most convenient for easy application. Thus the structures that need retrofitting and repairing works, can meet the shear requirements without demolishing.

The confinement also helps to improve the performance of low strength concrete that cannot meet the design strength because of improper mix design, curing and other environmental impacts like freeze-thaw effect.

Poorly detailed RC structural elements are vulnerable to loss of axial load carrying capacity at drift levels (2-3%) during a design level earthquake (Boys et al. 2008). Before 1970, the tie spacing of 300 mm was commonly used in the bridge piers. The inadequate lap splice length at the plastic hinge zone and inadequate transverse reinforcement in these piers were the most significant factors causing a lateral deficiency in resisting seismic force (Priestley and Seible 1995, Elsanadedy and Haroun 2005).

Passive confinement is one of the effective techniques for strengthening and has been popular and widely used all over the world. FRP wraps are the most common materials used to improve the ductility capacity of vulnerable piers (Chai et al. 1991, Norris et al. 1997, Elsanadedy and Haroun 2005). Several researchers like Elsanadedy and Haroun, Gallardo-Zafra and Kawashima conducted experimental investigation on the effectiveness of passive confinement using FRP composites. While other studies attempted to describe analytically the constitutive behavior and stress-strain model of concrete confined with FRP (Spoelstra and Monti 1999, Fam and Rizkalla 2001, Chun and Park 2002, Marques et al. 2004, Binici 2005, Youssef et al. 2007, Teng et al. 2007).

This paper describes the methods and results from the investigation carried on the effect of GFRP confinement on the compressive strength of concrete. Market available materials were used to form low cost GFRP. Cylinders having compressive strength of 22 MPa were wrapped with different layers of GFRP following standard method and tested under compression. Results from these tests shows that the compressive strength of concrete can be improved more than 100% with the GFRP confinement. But, the failure mode changes with increased thickness of GFRP.

2. RELEVANCE OF THE RESEARCH

This study guides enhancing compressive strength of concrete with improper mix design, inadequate curing and deterioration because of environmental effects like freezing and thawing. The performance of structures made of low strength concrete can be improved by enhancing the compression carrying capacity of concrete using GFRP confinement. Also, the capacity of non-seismically designed structural elements can be significantly improved by applying this kind of external confinement.

3. DETAILS OF THE EXPERIMENT

3.1 Selection of Specimens

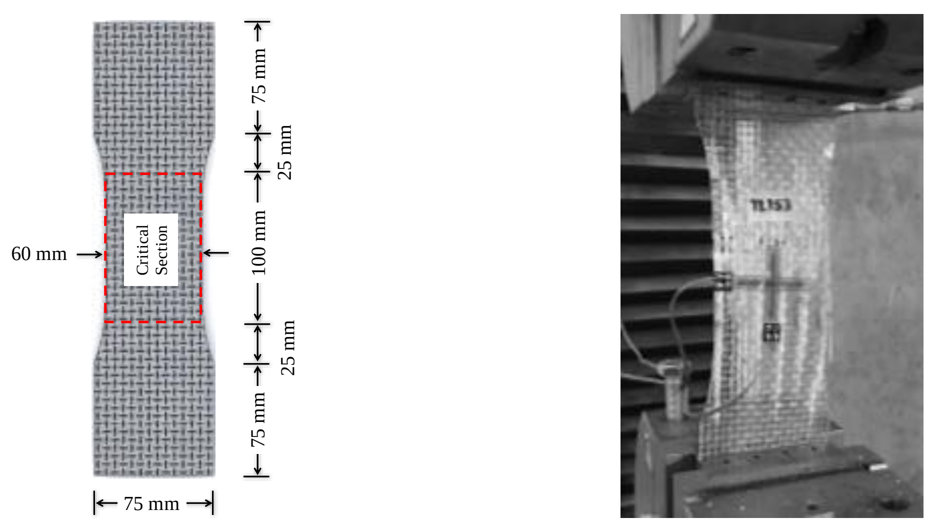
Cylinders deteriorated because of freeze-thaw effect were chosen to carry out the investigation on the effect of GFRP confinement on low strength concrete. These cylinders were placed in open environment for a year and significantly lost their strength. Their compressive strength reduced to 22 MPa from designed 35 MPa because of freeze-thaw effect during winter. Cracks were formed on the surface of the cylinders. This group of cylinders represents the practical condition where required compressive strength cannot be achieved because of improper mix design, curing and environmental conditions.

3.2 Preparation of Polymer Matrix and GFRP

Aropol K 1951-22 polyester resin as a binder material and CSM 1.5 OC woven fabric glass fiber as reinforcing material are used to form GFRP matrix. Luperox DDM-9 from Arkema Inc., a Methyl Ethyl Ketone Peroxide, is used as a catalyst for the resin for curing. 1:1 ratio (w/w) is used for fabric and resin. The amount of catalyst used was 1.5% of the resin (w/w) which lies between 1.5-2% as specified by the producer. The lower end of the amount of catalyst is used to ensure a slow rate of reaction so that the matrix get enough curing time. The prepared matrix was cured for 48 hrs before they were used for preparing test sample of tension and bond test.

3.3 Tensile Strength Test of GFRP

The GFRP plates once cured are cut into specific dimension using water-jet machine for coupon test. Fig. 1(a) shows the dimensions of coupons made for tensile strength test. Coupons were made with two different thickness i.e. one layer and two layers and their strength and modulus of elasticity were calculated according CSA S806. Fig. 1(b) shows the failure of a coupon under tensile test.



(a) (b)

Fig. 1. GFRP Coupons for **(a)** tensile test **(b)** coupon after tensile failure

3.4 Application of GFRP on Cylinders

The prepared cylinders were confined with different thickness of GFRP by applying one, two and three layers of GFRP on them. Fig. 2 illustrates the standard procedure used to confine the specimens. Each cylinder was first coated with a prime layer of epoxy to ensure the fibre would bond to the concrete. The fibre was covered with epoxy glue and then wrapped around the specimen. A grooved roller was used to press the fibre against the concrete for a good bond. When more than one layer was applied, the above operation was repeated, with a 150 mm overlap between final two adjacent layers (Aire et al. 2010).

(a) (b) (c) (d) (e)

Fig. 2. Standard method of GFRP confinement application: **(a)** Priming; **(b)** Applying epoxy on glass fibers; **(c)** wrapping the first layer of GFRP around the specimens; **(d)** Pressing with a grooved roller; **(e)** Applying last layer of epoxy.

3.5 Test for Compressive Strength

The control cylinders and GFRP confined cylinders were tested according to CSA A23.2-9C. 100 mm X 200 mm concrete cylinders with strain gauges attached on them were tested under compressive load. The rate of loading applied was 2 kN/sec upto the maximum capacity. After reaching the maximum load, displacement controlled loading was applied with a rate of 2 mm/min to get the post peak behaviour. Fig. 3 shows failure of control and confined cylinders.

(a) (b)

Fig. 3. Test of cylinders under compression **(a)** degraded cylinder **(b)** GFRP confined cylinder

4. RESULTS

4.1 Tensile Properties of GFRP

CSA S806 Coupons for tensile test are tested in Instron test machine with a loading rate of 20 kN/sec. The test results for 1 and 2 layers of GFRP are shown in Fig. 4. The resin starts to fail and the fibers start to take complete tensile load at around 50 MPa. Also two layers of GFRP show higher tensile modulus and strength as the no of fiber is doubled for two layers but the thickness is not. The tensile strength of GFRP was found to be 270 MPa with a tensile modulus of 13.5 GPa for 1 layer and 16.5 GPa for 2 layers.

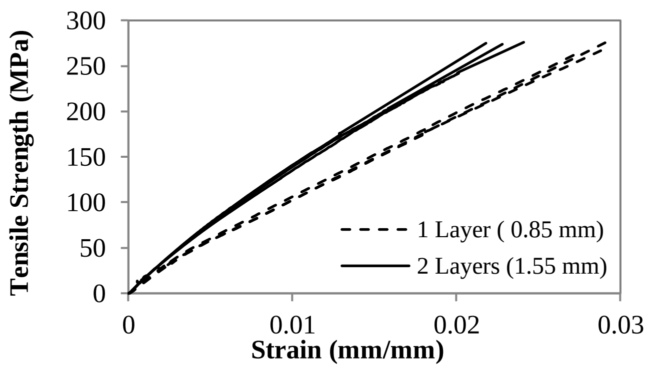


Fig. 4. Stress-Strain curve for two different thickness of GFRP

4.2 Compressive Properties of GFRP Confined Cylinders

Fig. 5 shows the effect of GFRP confinement with varying thickness on the compressive strength of concrete. It is found that, the compression carrying capacity of concrete increases with increased no of layer (i.e. thickness). Confinement also improves the strain capacity of concrete which can be up to 0.04 for 3 layers of tested confinement. Also, the maximum strength is achieved at maximum strain applied on concrete.

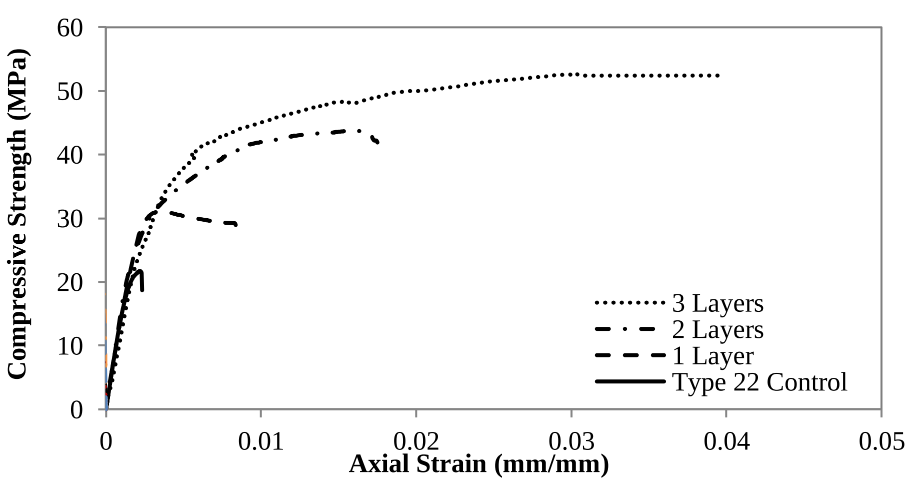


Fig. 5. Effect of GFRP layers on the compressive strength of low strength concrete

4.3 Improvement of Compressive Strength

With increasing the no of GFRP layer, confinement on concrete can be increased which results in improvement of compression carrying capacity. This improvement is very significant for concrete that has a very low strength because of improper mix design and deterioration due to environmental effect. About 142.4% improvement in compressive strength was achieved in the experiment for 3 layers of GFRP which provides a confinement factor of about 2.42.

Table 1: Compressive strength improvement and confinement factor

No. of Layer	Compressive Strength* (MPa)	% Improvement	Confinement Factor
0	21.7	-	1
1	32.1	47.93	1.48
2	43.8	101.84	2.02
3	52.6	142.4	2.42

Table 1 shows the values for compressive strength and confinement effect for different no of layers. Fig. 6 shows that confinement factor is almost linearly proportional with the no of GFRP layer.

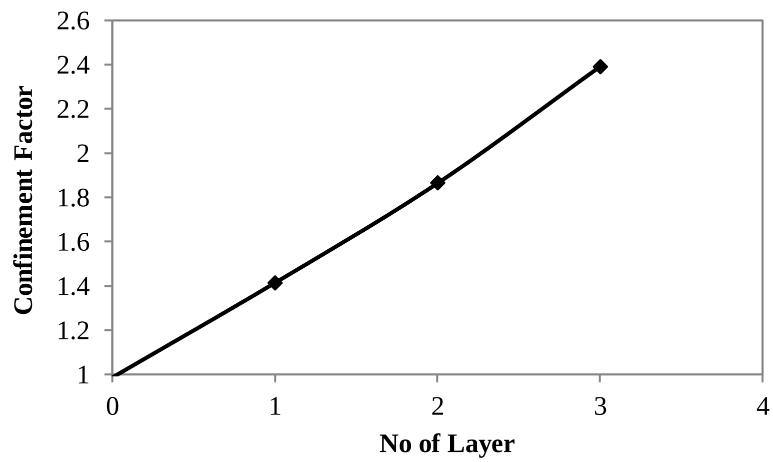


Fig. 6. Confinement Factor for different no of layers

4.4 Failure Mode

The thickness of GFRP layer has a significant role in the failure mode of the concrete. Gradual tearing of GFRP fibers were observed for 1 and 2 layers but a sudden failure with blast noise were observed for 3 layers of GFRP. Thus it can be concluded that, increased thickness of GFRP brings more brittle characteristic to the failure mode

5. CONCLUSIONS

A detailed experimental study has been conducted and presented in this paper on improving the compression carrying capacity of concrete using GFRP confinement. Material properties were tested prior to application of GFRP on cylinders. The following conclusions can be made from this study:

- GFRP with low tensile strength and modulus of elasticity can be used as a confining material for concrete.
- At initial stage of loading, both fibers and epoxy carry the load. Once the epoxy fails, fibers start taking the loads up to its strength.
- Multi-layer of GFRP show better mechanical properties than a single layer.
- Increasing the no of layer (i.e. thickness of GFRP) helps improving the confinement effect thus enhances the compression carrying capacity of low strength concrete. This keeps increasing with the increasing of layer no. But the failure mode changes to more brittle type for high no of layers.

References

Aire, C., Gettu, R., Casas, J. R., Marques, S., and Marques, D. 2010. Concrete laterally confined with fibre-reinforced polymers (FRP): experimental study and theoretical model. Journal of Construction Materials, 60(297): 19-31.

Binici, B. 2005. An analytical model for stress–strain behavior of confined concrete. Engineering Structures, 27(7): 1040–1051.

Boys, A., Bull, D., and Pampanin, S. 2008. Seismic performance assessment of inadequately detailed reinforced concrete columns. New Zealand Society of Earthquake Engineering (NZSEE) Conference, Wairakei, New Zealand.

Chai, Y. H., Priestley, M. J. N., and Seible, F. 1991. Seismic retrofit of circular bridge columns for enhanced flexural performance. ACI Struct. Journal, 88(5): 572–584.

Chun, S. S., and Park, H. C. 2002. Load carrying capacity and ductility of RC columns confined by carbon fiber reinforced polymer. In Proc. 3rd int. conference on composites in infrastructure, University of Arizona, San Fanscisco, USA, in CD-ROM format.

Elsanadedy, H. M., and Haroun, M. 2005. Seismic design criteria for circular lap-spliced reinforced concrete bridge columns retrofitted with fiber-reinforced polymer jackets. ACI Struct. Journal, 102(3): 354–362.

Fam, A. Z., and Rizkalla, S. H. 2001. Confinement model for axially loaded concrete confined by circular fiber-reinforced polymer tubes. ACI Struct. Journal, 98(4): 451–461.

Gallardo-Zafra, R., and Kawashima, K. 2009. Analysis of carbon fiber sheet retrofitted RC bridge piers under lateral cyclic loading. Journal of Earthquake Engineering, 13: 129–154.

Marques, S. P. C., Marques, D. C. dos S. C., Silva, J. L. da, and Cavalcante, M. A. A. 2004. Model for analysis of short columns of concrete confined by fiber-reinforced polymer. Journal of Composite for Construction, ASCE, 8(4): 332–340.

Norris, T., Saadatmanesh, H., and Ehsani, M. R. 1997. Shear and flexural strengthening of R/C beams with carbon fiber sheets. Journal of Structural Engineering, ASCE, 123(7): 903–911.

Priestley, M. J. N., and Seible, F. 1995. Design of seismic retrofit measures for concrete and masonry structures. Construction and Building Materials, 9(6): 365–377.

Spoelstra, M. R., and Monti, G. 1999. FRP-confined concrete model. Journal of Composite for Construction, ASCE, 3(3): 143–150.

Teng, J. G., Huang, Y. L., Lam, L., and Ye, L. P. 2007. Theoretical Model for Fiber-Reinforced Polymer-Confined Concrete. Journal of Composite Construciton, ASCE, 11(2): 201–210.

Youssef, M. N., Feng, M. Q., and Mosallam, A. S. 2007. Stress–strain model for concrete confined by FRP composites. Composite Part B: Eng, 38(5-6): 614–628.