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EXPERIMENTAL STUDY ON COMPRESSIVE STRENGTH AND FAILURE MODE OF GFRP WRAPPED CONCRETE CYLINDER

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ABSTRACT

Fiber-reinforced polymer (FRP) wrap has been established as an effective method of strengthening of concrete structures. GFRP (Glass Fiber Reinforced Polymer) is one type of FRP that is made of glass fibers in a polymeric matrix. In case of unsupported long column, buckling effect makes the column more vulnerable under compressive loading. To minimize this problem, wrapping of concrete column with GFRP composite jacketing could be a solution. There were three series of sample and each series consists of 4 cylindrical specimen having concrete mixing ratio 1:2:4, water-cement ratio was 0.5, curing period was 28 days where two specimens were unwrapped and rest two were wrapped with single layer GFRP jacketing with varying heights of 12 inches, 16 inches, 20 inches and diameter 4 inches for each series. The average compressive strength of unwrapped cylindrical specimens of series I, series II and series III were 9.923 MPa, 6.854 MPa, and 3.771 MPa respectively whereas for wrapped cylindrical that were 50.369 MPa, 45.635 MPa, and 27.783 MPa respectively. The increase in strength of wrapped specimens is 5 times for series I 7 times for series II and 7.5 timed for series III. Numerical average of strain of unwrapped and wrapped specimens of series I, II, III are 0.01225, 0.01255, 0.007 and 0.05255, 0.03185, 0.0339 respectively which shows due to lateral confinement variation of strain among unwrapped and wrapped specimens are too high. Failure of unwrapped specimens mostly happened due to shear fracture and compression failure, in contrast, wrapped specimen fails due to the rupture of GFRP jacketing. So, using glass fiber wrap is an effective way to minimize buckling, without increasing the self-weight of cylindrical specimens significantly

Keywords: *GFRPC jacketing, Wrapped and Unwrapped specimen, Failure pattern, Compressive (axial) loading, Retrofitting*

1. INTRODUCTION

A large number of old buildings in our country are considered as structurally unsafe and at risk of failure as they were constructed long ago using older design codes [BNBC 93] that does not meet the demand of new building design codes. Replacement of such deficient elements of those structures is a huge challenge and demands a substantial amount of time and resources. So external strengthening has now become a suitable alternative for these structures. The process of strengthening of older structures without destroying the existing structure is called retrofitting. Retrofitting is the maintenance, rehabilitation, and upgrading of existing structural members is one of the most suitable processes of the solution in case of structural problems. Wrapping of columns with fibers, especially with glass fiber is being done nowadays all over the world. Its major benefit is its high longitudinal tensile strength in the direction of the fibers. Other advantages include its non-corrosive behavior and thus is beneficial in coastal environments (Balendran, Rana, Maqsood, & Tang, 2002). Retrofitting with FRP materials is a technically sound and cost-effective repair technology and is now extensively being used in Bangladesh.

FRP composites have been used for decades since the early 1940s in the defense industry, in particular, the aeronautical and naval industries, as well as military applications (Bonacci & Maalej, 2001). During this time, it was recognized as having a high strength to weight ratio, non-corrosive, thus resistant to weather conditions and the corrosive effects of the sea and salt air (Masoud & Soudki, 2006). A composite material called Fiber-reinforced plastic (FRP) is made of polymer matrix reinforced with fibers. The fibers are usually glass (in fiberglass), carbon (in the carbon-fiber-reinforced polymer), aramid, or basalt (Hadi, 2007). Fibers are used in polymeric composite materials because of their high strength, high stiffness, and lightweight (Ameli, Ronagh, & Dux, 2007). The polymer matrix is usually a polyester, epoxy or vinyl ester resin, with its primary role to embed and bond the continuous fibers. It also provides a protective barrier to the fibers, preventing any surface damage during service life. The strength and ductility of the circular column increase significantly due to FRP wrapping. The FRP wrap did not increase the strength of square columns because of sharp corners. However, the square column with rounded corners exhibited higher strength and ductility compared with sharp corners. There are various types of FRP are currently being used all over the world, they are: Glass Fiber Reinforced Polymer (GFRP), Basalt Fiber Reinforced Polymer (BFRP), Aramid Fiber Reinforced Polymer (AFRP), Carbon Fiber Reinforced Polymer (CFRP) etc.

Glass fiber reinforced polymer (GFRP) is one kind of FRPs which is using glass fibers are the predominant reinforcing fiber in all forms. E-glass is the most commonly used fiber. It has high electrical insulating properties, good heat resistance, and has the lowest cost (Barghi, Azadbakht, & Hadad, 2012). S-glass fibers have higher heat resistance and about one-third higher tensile strength than e-glass. The specialty of glass fibers are resistant to the alkaline environment found in concrete but have a much higher cost. There are some advantages of GFRP which are: High Strength: GFRP has a very high strength to weight ratio and within a range between 10 to 30 GPa (Sugarman, 1967). Lightweight: of GFRP increase workability in case of maintenance, rehabilitation and upgrading of structural members, Resistance: GFRP resist outer surface of structure from acid rain, salts, and chemicals, Able to Mold Complex Shapes: GFRP can be molded in any shape or format because of this property. In this research, glass fiber was used as the main materials and other materials were used for preparing concrete. In this research, Nitowrap EP (GF) is used as GFRP for strengthening specimens to improve compressive strength and deformation characteristics. Cylindrical specimens were wrapped by Nitowrap GF conjunction with epoxy sealer cum primer, Nitowrap 30, and a high build epoxy saturant Nitowrap 410. Nitowrap (GF) type 1 was used and its major properties are: Weight of fiber - 920 g/m^2, Fiber orientation - Unidirectional, Tensile strength - 3400 N/mm^2.

2. METHODOLOGY

An experimental program was conducted to investigate the behavior and static response of cylindrical specimens (wrapped & unwrapped) by glass fiber under static loading. The specimen was categorized into three series: Series I, Series II and Series III with varying heights of 12 inches, 16 inches, 20 inches and diameter 4 inches for each series. Every Series consists of 4 cylindrical specimens of which 2 specimens were unwrapped and 2 specimens were wrapped by single-layer glass fiber. Tinius Olsen universal testing machine was used during this experiment. This machine consists of a output device which shows the value of static loading and strain amount for corresponding loading.

2.1 Specimens Preparation

Concrete was prepared by using coarse aggregate (brick chips), fine aggregate (sand), binding materials (Portland cement) and water. The ratio of cement, sand and brick chips was maintained at 1:2:4, the water-cement ratio was 1:2 and curing period was 28 days. Concrete was prepared for making 12 cylindrical specimens. The same mixing ratio of concrete were maintained for all three series. The most widely used construction cement is Portland cement and in this research Crown Cement was used, silica sand was used as fine aggregates and uniformly graded brick chips were used as coarse aggregates.

2.1.1 Wrapping of Cylindrical Specimens

Cylindrical specimens of different Series I, II, III were wrapped by epoxy adhesive. Epoxy was prepared by mixing of nitowrap 410 hardener and nitowrap 410 base in a ratio of 1:2.

Figure 1: Wrapping of specimens

2.2 Experimental Setup

Wrapped and Unwrapped specimens of different series were tested using the Tinius Olsen universal testing machine shown in Figure 2. Specimens were positioned into the crosshead of Tinius Olsen universal testing machine. Data were collected up to the total failure of specimens. The strain data and static loading data from the universal testing machines were recorded using the data acquisition system and imported into an excel spreadsheet for critical analysis

Figure 2: Wrapped and Unwrapped specimens under static loading

3. RESULTS AND DISCUSSION

3.1 Figures and Graphs

From figure 3, Combined stress vs. strain graph of series I depicts that, unwrapped specimens strength capacity was 11.971 MPa (specimen I) and 7.875 MPa (specimen II) at the time of failure, whereas wrapped specimens strength capacity was 50.367 MPa (specimen I) and 50.372 MPa (specimen II) at the time of failure.

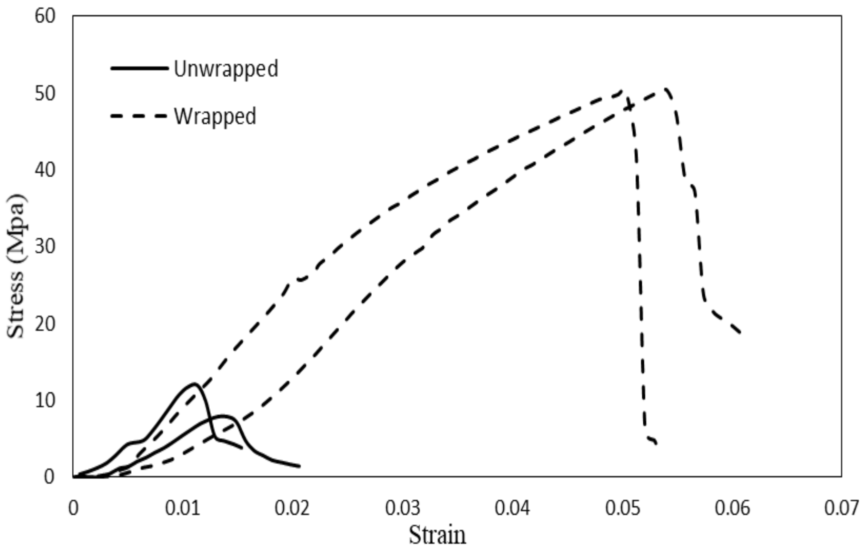

Figure 3: Combined stress vs. strain graph of (Series I) specimen

From figure 4, Combined stress vs. strain graph of series II depicts that, unwrapped specimens strength capacity was 7.227 MPa (specimen I) and 5.941 MPa (specimen II) at the time of failure, whereas wrapped specimens strength capacity was 47.797 MPa (specimen I) and 43.474 MPa (specimen II) at the time of failure.

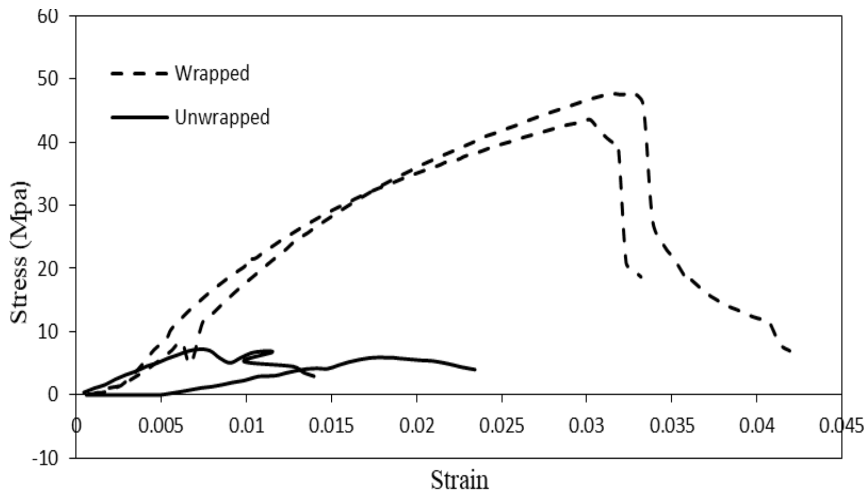

Figure 4: Combined stress vs. strain graph of (Series II) specimen

Figure 5 indicates, Combined stress vs. strain graph of series III depicts that, unwrapped specimens strength capacity was 4.298 MPa (specimen I) and 3.244 MPa (specimen II) at the time of failure, whereas wrapped specimens strength capacity was 25.259 MPa (specimen I) and 30.31 MPa (specimen II) at the time of failure.

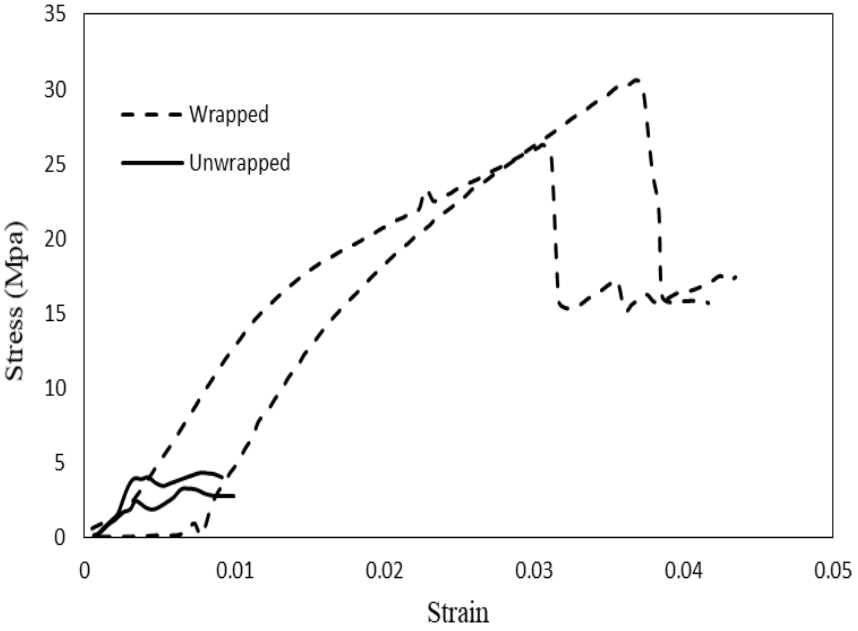

Figure 5: Combined stress vs. strain graph of (Series III) specimen

So, from all of these, it can clearly specify from the comparison of strength capacity of specimens that all of the wrapped specimens of Series I, II, III had more strength than all of the unwrapped specimens because of single layer wrapping of GFRP jacketing provide more strength to the wrapped specimens with negligible amount of increasing self-weight.

From the "stress vs. strain" curve (figure 6), it was observed that unwrapped specimen showed a

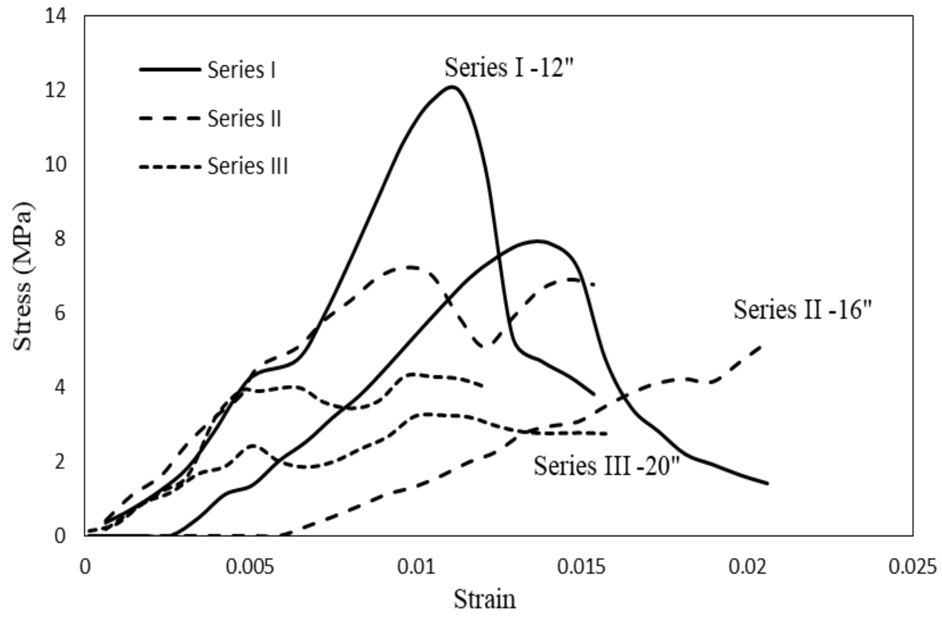

Figure 6: Combined stress vs. strain graph of unwrapped specimen

different curve pattern that doesn't match with the standard stress-strain curve. There are many reasons that were responsible for it and this was the casting of the specimen was from different batches, some specimen's end surface was not properly horizontal.

From Figure 7, wrapped specimen showed consistency and maintaining a slop of increasing strength with deflection due to confined with glass fiber. One or two sudden breakpoints were being noticed where load increases with no deflection and then sudden deflection occurred. It was because of failure in one or two string, or the bonding got lose in between the fiber and concrete surface.

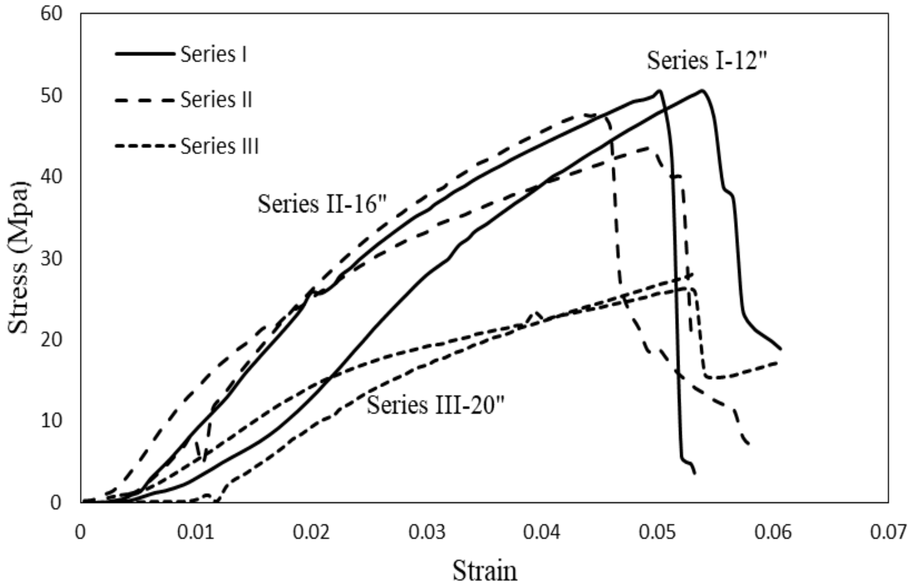

Figure 7: Combined stress vs. strain graph of wrapped specimen

3.2 Mode of Failure

Figure 8: Failure pattern of unwrapped cylindrical specimens.

Figure 9: Failure pattern of wrapped cylindrical specimens.

Figure 8 indicates, failure pattern of unwrapped specimens that failure was happened due to shear crack and compression failure. In some cases, it happened due to failure of weak concrete at top of the specimen. Whereas in figure 9, wrapped specimens failed due to failure of glass fiber confinement and all of these were compression failure. Specially, for Series III (height 20 inches) both wrapped and unwrapped specimens' failure also occurred due to buckling effect.

3.3 Tables

Table 1: Result of Unwrapped specimen

Type of Specimen	L/r ratio	Specimen Weight (Kg)	Load Max. (N)	Displacement (mm)	Strength (N/mm^2)	Average Strength (N/mm^2)	Strain
Unwrapped	12	4.99	97058	3.449	11.971	9.923	0.0113
		4.89	63852	4.035	7.875		0.0132
	16	6.49	58591	2.931	7.227	6.584	0.0072
		6.45	48168	7.259	5.941		0.0179
	20	8.31	26520	3.893	4.298	3.771	0.0076
		8.20	35108	3.535	3.244		0.0064

Table 2: Result of Wrapped specimen

Type of Specimen	L/r ratio	Specimen Weight (Kg)	Load Max. (N)	Displacement (mm)	Strength (N/mm^2)	Average Strength (N/mm^2)	Strain
Wrapped	12	5.22	408342	16.487	50.367	50.3695	0.0541
		5.21	408380	15.315	50.372		0.051
	16	6.54	387510	13.282	47.797	45.6355	0.0327
		7.02	352960	15.361	43.474		0.031
	20	8.35	212890	15.546	25.259	27.7837	0.0306
		8.59	249555	18.912	30.3084		0.0372

4. CONCLUSIONS

Lateral confinement of concrete with GFRP can significantly increase concrete strength and ductility. Because of lateral confinement, wrapped specimens have higher strength as specimens will fail when concrete and FRP both will be failed whereas unwrapped specimens will fail when concrete will fail. And, in case of ductility, FRP string will be strained when specimens are loaded but when load are releasing from specimens string will be back in their original position just like ductile materials. As a result, significant change in lateral strain as well as axial strain was observed in wrapped specimens than unwrapped specimens. In this experimental study, the uniaxial compressive strength capacity of cylindrical specimens for both unwrapped and wrapped by glass fiber are observed. From the test results and calculated strength values for Series I, II and III. it is clearly noticeable that after using glass fiber wrap self-weight of the specimen increased by 5% whereas strength capacity increased by 407%, 594% and 636% respectively. And, amount of strain increases for unwrapped column, because GFRP confinement helps concrete to carry more compressive load with being strained highly.Average value of strain of both unwrapped and wrapped specimens of series I,II,III are 0.01225, 0.01255, 0.007 and 0.05255, 0.03185, 0.0339 respectively. So, Considering slenderness ratio which is not vary with wrapped and unwrapped condition but vary with height of cylindrical specimens that increase with strength capacity decreases. This happens due to buckling effect of cylindrical specimens. This studies shows that buckling of cylindrical specimens can be minimized largely by using glass fiber wrap at the same time without increasing self-weight of cylindrical specimens significantly.

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