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STRENGTH AND DUCTILITY OF HIGH STRENGTH CONCRETE COLUMNS WITH GLASS FIBRE REINFORCED POLYMER WRAPS

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ABSTRACT

The paper deals with the analysis of experimental results in terms of load-carrying capacity and strains, obtained from tests on circular concrete column, strengthened with external glass fibre composite. A total of seven specimens of 150mm diameter and having a height of 600 mm were cast and tested. One specimen was used as reference and remaining six specimens were wrapped with three GFRP materials having different thickness. The columns were tested under uni-axial compression up to failure. Necessary measurement was taken for each load increment. The HSC columns with GFRP wrapping exhibited better performance in terms of strength, deformation and ductility capacity.

Keywords: Confinement; ductility; glass fibre reinforced polymer (GFRP); strength

1. INTRODUCTION

Concrete with strength higher than 40 MPa is generally referred to as high strength concrete. Some basic concepts relating to strength and ductility have been introduced in ACI code with respect to the compression member [1]. With developments in technology, the use of high strength concrete members has proved to be most promising in terms strength, stiffness, durability and economy [2]. As the strength of concrete increases, it becomes more brittle. The lack of ductility of high strength concrete columns can result in sudden failure. Several research works have proved that the strength and ductility can be improved by the use of spiral confinement, rectangular and circular lateral ties [3,4].

The strengthening and seismic retrofit of existing reinforced concrete (RC) columns using fibre reinforced polymer (FRP) composite jackets is based on a well-established fact, that lateral confinement of concrete can substantially enhance its compressive strength and ultimate axial strain. In a circular column, subject to axial compression, the concrete is uniformly confined by the FRP jacket.

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In recent years, external wrapping has been identified as an effective method of confining concrete. Among the various materials available for the purpose, FRP has proved to be more beneficial. The application of FRP in the construction industry can eliminate some unwanted properties of high strength concrete, such as the brittle behavior of high strength concrete. FRP is particularly useful for strengthening columns and other unusual shapes. Several research studies have been reported an improving the strength and ductility of normal strength columns. Only limited literature is available on enhancing the ductility of high strength concrete column members. Hence an attempt has been made to investigate the strength and ductility performance of high strength concrete columns with external GFRP wrapping [4,5,6]. Focusing attention on the behavior of compression members, the main parameters investigated in literature are the type of FRP material (carbon, glass, aramid, *etc*.) and its manufacture (unidirectional or bi-directional wraps), the shape of the transverse cross-section of the members, the dimensions and the shape of specimens, the strength of concrete, and the types and percentages of steel reinforcements.

The present paper deals with the analysis of experimental results, in terms of load carrying capacity and strains, obtained from tests on circular concrete columns, reinforced with external E-glass fiber composite. The study parameters included the material and stiffness of FRP confinement wraps.

2. EXPERIMENTAL INVESTIGATION

An Experimental investigation were conducted on 7 column specimens having 150 mm diameter and a height of 600 mm. six bars of 8 mm diameter for longitudinal reinforcement and 6mm diameter mild steel ties spaced at 115 mm for internal lateral confinement were used for all columns. Out of the seven columns, one reference column was tested without any wrapping and the remaining six columns were wrapped with GFRP of varying configuration with different thickness. The designation of specimens and their details are presented in Table 1.

Table 1: Specimen details

Sl No.	Designation of specimen	Diameter (mm)	Type of GFRP (mm)	Thickness of GFRP (mm)
	R0	150	-	0
	CSM3	150	CSM	3
	CSM5	150	CSM	5
	WR3	150	WR	3
	WR5	150	WR	5
	UDC3	150	UDC	3
	UDC5	150	UDC	5

2.1 Material properties

The concrete used for casting the specimens was designed for a compressive strength 60MPa. The characteristic compressive strength achieved was 63.64 MPa. The material properties of concrete mixtures are shown in Table 2. The steel used for longitudinal reinforcement was ribbed steel with yield strength of 450 MPa and for lateral ties was mild steel with an yield strength of 300 MPa was used for lateral ties. The properties of the GFRP wraps used for the present investigation are presented in Table 3.

Table 2: Properties of control mix concrete

Sl. No	Materials	Quantity
1.	53 Grade cement (kg /m^3)	450
2.	Fine aggregate(kg /m^3)	780
3.	Coarse aggregate(kg /m^3) 20mm 10mm	 680 450
4.	Water(kg /m^3)	160
5.	Silica fume(kg /m^3)	25
6.	Hyper plasticizer (Glunium B223)	0.8 % by weight of binder

Table 3: Properties of GFRP

Sl.No	Type of fibre in GFRP	Thickness (mm)	Tensile strength (MPa)	Ultimate elongation (%)	Elasticity modulus (MPa)
1.	Chopped Strand Mat	3	126.20	1.60	7467.46
2.	Chopped Strand Mat	5	156.00	1.37	11386.86
3.	Uni-Directional Cloth	3	446.90	3.02	13965.63
4.	Uni-Directional Cloth	5	451.50	2.60	17365.38
5.	Woven Rovings	3	147.40	2.15	6855.81
6.	Woven Rovings	5	178.09	1.98	8994.44

2.2 Preparation and casing of specimens

The specimens were prepared by casting them in asbestos cement pipe moulds. After sizing, the pipes were placed firmly in position using a lean mix mortar at the base. The bottom faces of the pipes were covered with polymer sheets to avoid any leaks. Cover blocks were placed at appropriate places to ensure adequate cover to the reinforcement. The interior of the pipes was applied a liberal coat of lubricating oil to prevent concrete from adhering to the asbestos cement pipe. Steel reinforcement cage was prepared for each specimen according to the requirements. The reinforcement cages were placed into the asbestos cement pipe formwork and positioned in such a way that pre determined cover was available on all sides. The designed concrete mix was filled into the moulds in layers. Adequate compaction was carried out using needle vibrator to avoid honey combing. Figures 1 to 3 shows the preparation and casting of specimens. The specimens were removed from moulds without any damage and cured in a standard manner for a period of 28 days.

Figure 1. Asbestos cement pipe moulds

Figure 2. Reinforcement cage with cover block

Figure 3. Casting under progress

2.3 Wrapping with FRP

The cured specimens were prepared for wrapping with FRP. The surfaces of the specimens were ground with a high grade grinding wheel to remove loose and deleterious material from the surface. A jet of compressed air was applied on the surface to blow off any dust and dirt. Then, all surface cavities were filled up with mortar putty to ensure a uniform surface and to ensure proper adhesion of FRP to concrete surface. The wrapped surfaces were gently pressed with a rubber roller to ensure proper adhesion between the layers and proper distribution of resin. Figure 4 and Figure 5 show the application of FRP wrap on the surface of the column specimen.

Figure 4. Wrapping under progress

Figure 5. Wrapped specimen

3. EXPERIMENTAL SET-UP

Testing of specimens was carried out in a loading frame of 2000kN capacity. The instruments used for testing included deflectometers having a least count of 0.01mm and a lateral extensometer. The specimen was placed with capping at both ends. The load was applied using a hydraulic jack in uniform increments of 25 kN. Axial compression was measured using two dial gauges placed at top and bottom of the specimen. The dilution was measured using the lateral extensometer.

4. TEST RESULTS AND DISCUSSION

The results relating to the ultimate load, ultimate stress, and ultimate axial deflection of the specimens are presented in Table 4. The stress–strain curves are shown in Figure 6.

Table 4: Test results

Designation	Ultimate load (kN)	Ultimate deflection (mm)	Ultimate stress	Ultimate micro-strain	Deflection ductility	Energy ductility	Energy absorption per unit volume
S16R	1080.00	3.01	61.12	5016.67	1.43	1.66	2327.60
S16CSM3	1140.00	3.16	64.51	5266.67	1.90	2.43	2558.35
S16CSM5	1200.00	3.46	67.91	5766.67	2.12	3.05	2895.75
S16UDC3	1300.00	4.82	73.56	8033.33	2.32	3.19	4813.50
S16UDC5	1375.00	4.94	77.81	8233.33	3.86	5.22	5565.75
S16WR3	1170.00	4.23	66.21	7050.00	2.21	2.84	3874.78
S16WR5	1225.00	4.33	69.32	7216.67	3.23	4.62	4226.63

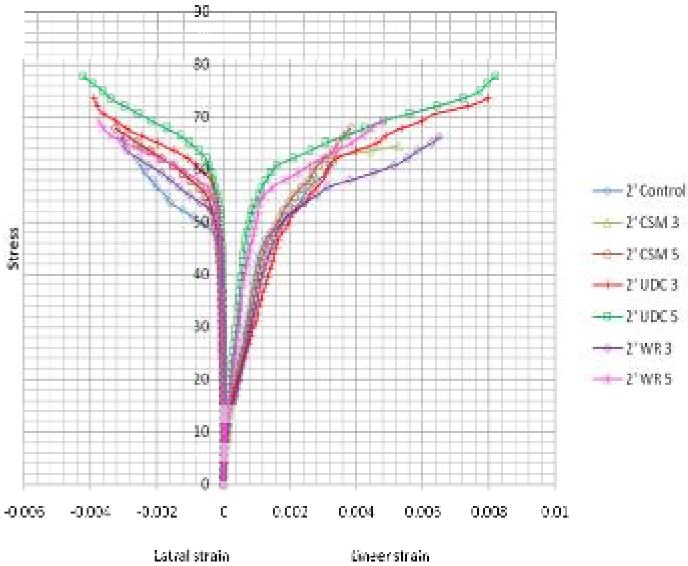

Figure 6. The stress-strain curves for all specimens

4.1 Effect on ultimate stress

The increase in ultimate strength was found to be 5.56% for specimen with 3mm thick CSM wrapping and 11.11% for specimen with 5mm thick CSM wrapping when compared to the reference column. The increase in ultimate strength was found to be 8.33% for specimen with 3mm thick WR wrapping and 13.43% for specimen with 5mm thick WR wrapping when compared to the reference column. The increase in ultimate strength was found to be 20.37% for specimen with 3mm thick UDC wrapping and 27.38% for specimen with 5mm thick UDC wrapping when compared to the reference column. The increase in ultimate stress is shown in Figure 7.

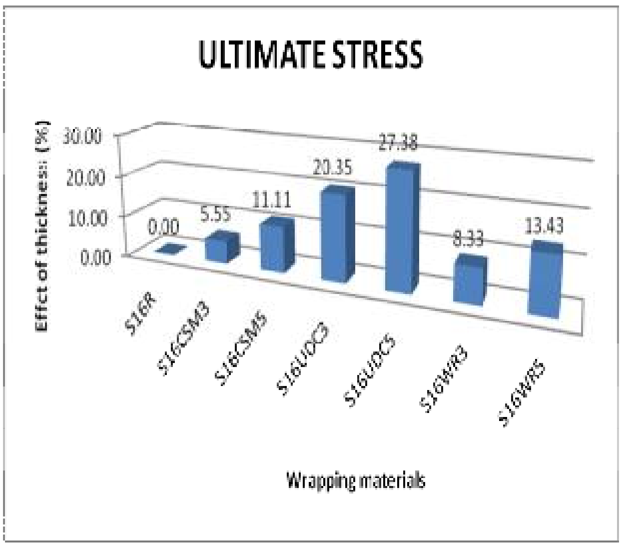

Figure 7. Ultimate stress for all specimens

The increase in ultimate strength was found to be 2.62% for specimen with 3mm thick WR wrapping when compared to the specimen with CSM wrapping of same thickness. The increase in ultimate strength was found to be 2.23% for specimen with 5mm thick WR wrapping when compared to the specimen with CSM wrapping of same thickness. The increase in ultimate strength was found to be 14.03% for specimen with 3mm thick UDC wrapping when compared to the specimen with CSM wrapping of same thickness. The increase in ultimate strength was found to be 14.58% for specimen with 5mm thick UDC wrapping when compared to the specimen with CSM wrapping of same thickness. The increase in ultimate strength was found to be 11.12% for specimen with 3mm thick UDC wrapping when compared to the specimen with WR wrapping of same thickness. The increase in ultimate strength was found to be 12.23% for specimen with 5mm thick UDC wrapping when compared to the specimen with WR wrapping of same thickness.

4.2 Effect on deformation

The increase in axial strain was found to be 4.16 % for specimen with 3mm thick CSM wrapping and 14.95% for specimen with 5mm thick CSM wrapping when compared to the reference column. The increase in axial strain was found to be a 40.53% for specimen with 3mm thick WR wrapping and 43.85% for specimen with 5mm thick WR wrapping when compared to the reference column. The increase in axial strain was found to be 60.13% for specimen with 3mm thick UDC wrapping and 64.19% for specimen with 5mm thick UDC wrapping when compared to the reference column. The increase in ultimate axial strain is shown in Figure 8.

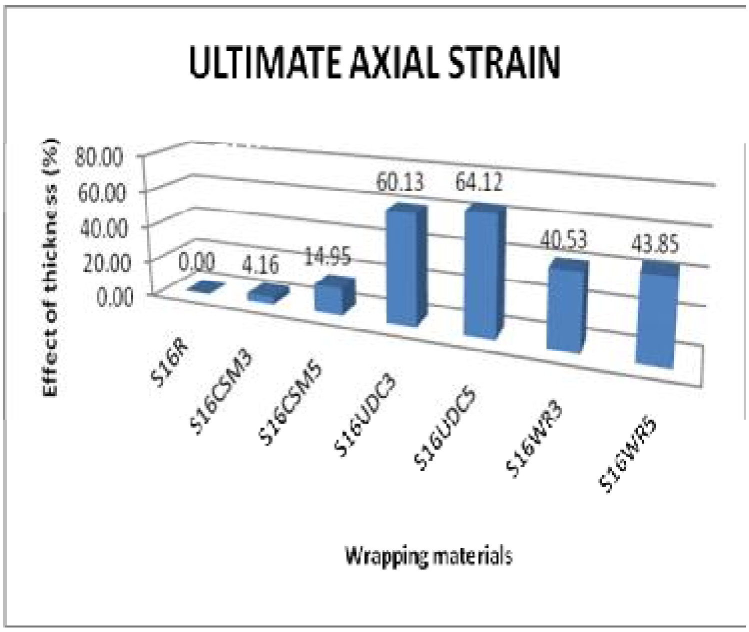

Figure 8. Ultimate micro strains for all specimens

The increase in ultimate axial deformation was found to be 34.88% for specimen with 3 mm thick WR wrapping when compared to the specimen with CSM wrapping of same thickness. The increase in ultimate axial deformation was found to be 25.14% for specimen with 5 mm thick WR wrapping when compared to the specimen with CSM wrapping of same thickness. The increase in ultimate axial deformation was found to be 53.70% for specimen with 3 mm thick UDC wrapping when compared to the specimen with CSM wrapping of same thickness. The increase in ultimate axial deformation was found to be 42.77% for specimen with 5mm thick UDC wrapping when compared to the specimen with CSM wrapping of same thickness.

4.3 Effect on deflection ductility

Deflection ductility was found to be 32.86% for specimen with 3mm thick CSM wrapping and 48.25% for specimen with 5mm thick CSM wrapping when compared to the reference column. Deflection ductility was found to be 54.54% for specimen with 3mm thick WR wrapping and 125.87% for specimen with 5mm thick WR wrapping when compared to the reference column. Deflection ductility was found to be 62.23 % for specimen with 3mm thick UDC wrapping and 169.93% for specimen with 5mm thick UDC wrapping when compared to the reference column. Figure 9 shows the increase in ultimate deflection ductility when compared to the reference column.

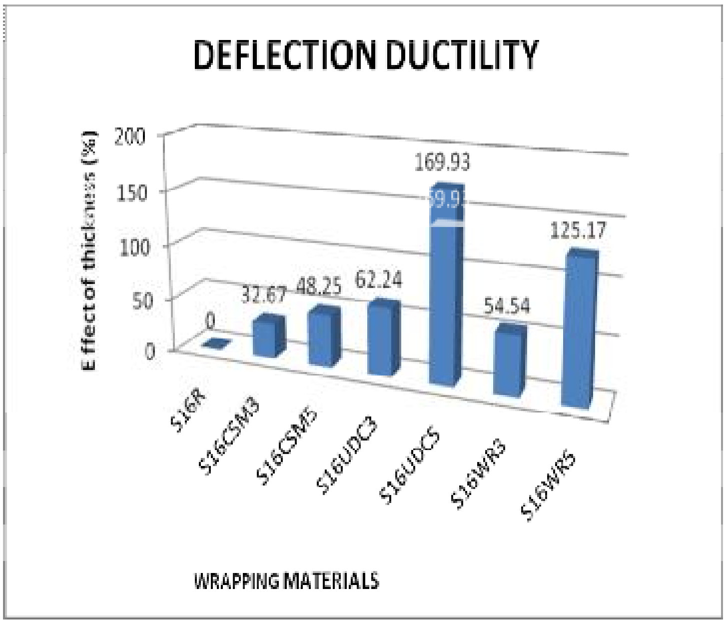

Figure 9. Deflection ductility for the specimens

The increase in deflection ductility was found to be 16.32% for specimen with 3 mm thick WR wrapping when compared to the specimen with CSM wrapping of same thickness. The increase in deflection ductility was found to be 52.36% for specimen with 5 mm thick WR wrapping when compared to the specimen with CSM wrapping of same thickness. The increase in deflection ductility was found to be 22.11% for specimen with 3 mm thick UDC wrapping when compared to the specimen with CSM wrapping of same thickness. The increase in deflection ductility was found to be 82.08% for specimen with 5mm thick UDC wrapping when compared to the specimen with CSM wrapping of same thickness.

4.4 Effect on energy ductility

Energy ductility was found to be 46.39% for specimen with 3mm thick CSM wrapping and 83.73% for specimen with 5mm thick CSM wrapping when compared to the reference column. Energy ductility was found to be 71.08% for specimen with 3mm thick WR wrapping and 178.31% for specimen with 5mm thick WR wrapping when compared to the reference column. Energy ductility was found to be 92.17% for specimen with 3mm thick UDC wrapping and 214.46% for specimen with 5mm thick UDC wrapping when compared to the reference column. Figure 10 shows the increase energy ductility when compared to the reference column.

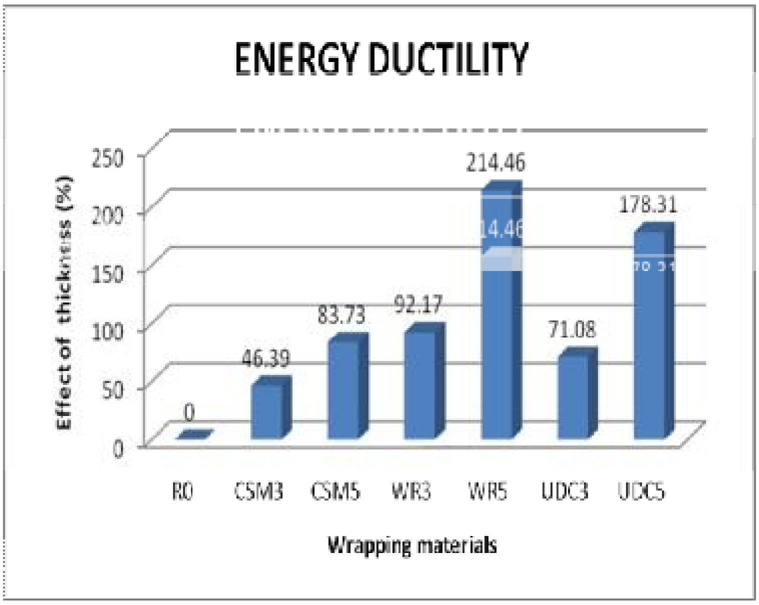

Figure 10. Energy ductility for the specimens

The increase in energy ductility was found to be 16.87% for specimen with 3 mm thick WR wrapping when compared to the specimen with CSM wrapping of same thickness. The increase in energy ductility was found to be 51.48% for specimen with 5 mm thick WR wrapping when compared to the specimen with CSM wrapping of same thickness. The increase in energy ductility was found to be 31.28% for specimen with 3 mm thick UDC wrapping when compared to the specimen with CSM wrapping of same thickness. The increase in energy ductility was found to be 71.15% for specimen with 5mm thick UDC wrapping when compared to the specimen with CSM wrapping of same thickness.

4.5 Effect on energy absorption

Energy absorption was found to be 9.91% for specimen with 3mm thick CSM wrapping and 15.81% for specimen with 5mm thick CSM wrapping when compared to the reference column. Energy absorption y was found to be 66.47% for specimen with 3mm thick WR wrapping and 81.36 % for specimen with 5mm thick WR wrapping when compared to the reference column. Energy Absorption was found to be a 106.36 % for specimen with 3mm thick UDC wrapping 138.64% for specimen with 5mm thick UDC wrapping when compared to the reference column. Figure 11 shows the increase energy absorption when compared to the reference column.

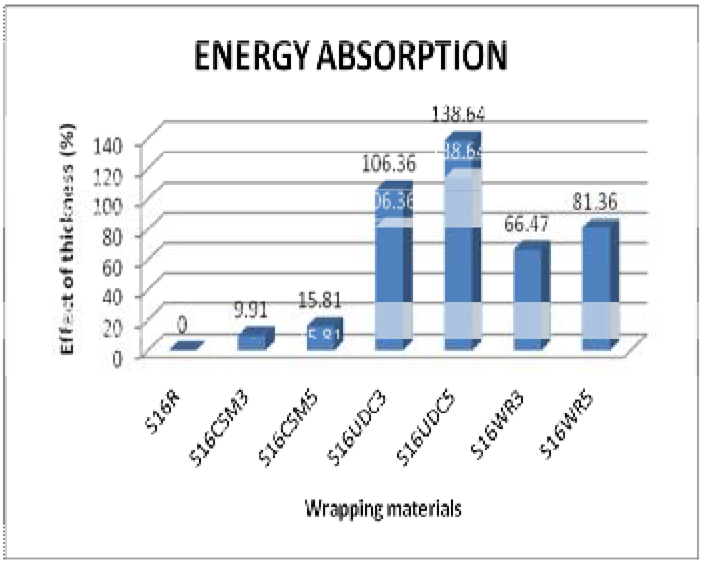

Figure 11. Energy absorption for the specimens

5. CONCLUSIONS

Based on the results presented, the following conclusions are drawn:

- The GFRP significantly improved the ultimate stress, ultimate axial strain, deflection ductility, energy ductility and energy absorption..
- The maximum ultimate stress was increased by 27.38% for 5mm thick UDC wrapping when compared to reference column.
- The maximum ultimate axial strain was increased by 64.12% for 5mm thick UDC wrapping when compared to reference column.
- The maximum deflection ductility was increased by 169.93% for 5mm thick UDC wrapping when compared to reference column.
- The maximum energy ductility was increased by 214.46% for 5mm thick UDC wrapping when compared to reference column.
- The maximum energy absorption was increased by 138.64 % for 5mm thick UDC wrapping when compared to reference column.

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