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## RESEARCH ARTICLE

# EXPERIMENTAL STUDY ON HIGH STRENGTH CONCRETE COLUMNS WITH GFRP WRAPS UNDER COMPRESSION

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## ABSTRACT

This paper presents the results of an experimental study on high strength concrete columns with externally confined using GFRP wraps. A total of seven specimens of 150 mm diameter and 900 mm height were cast and tested. One specimen was used as reference and the remaining six specimens were wrapped with three GFRP materials having different thickness. The columns were tested under uni-axial compression up to failure. Necessary measurements were taken for each load increment. The HSC columns with GFRP wrapping exhibited improved performance in terms of strength, deformation ductility and energy absorption.

**Key words:** Ductility, Energy absorption, GFRP, High strength concrete.

## INTRODUCTION

Existing reinforced concrete columns may be structurally deficient for several reasons: substandard seismic design details, improper transverse reinforcement, flaws in structural design, and insufficient load carrying capacity. Over the last few years, there has been a worldwide increase in the use of composite materials for the rehabilitation of deficient reinforced concrete structures. One important application of this composite retrofitting technology is the use of fiber reinforced polymer (FRP) jackets or sheets to provide external confinement to reinforced concrete columns when the existing internal transverse reinforcement is inadequate. Reinforced concrete columns need to be laterally confined in order to ensure large deformation under load before failure and to provide an adequate load resistance capacity.

In the case of a seismic event, energy dissipation allowed by a well-confined concrete core can often save lives. On the contrary, a poorly confined concrete column behaves in a brittle manner, leading to sudden and catastrophic failures. With the development of technology, the use of high-strength concrete members has proved most popular in terms of economy, superior strength, stiffness, and durability. With the increase of concrete strength, the ultimate strength of the columns increases, but a relatively more brittle failure occurs. The lack of ductility of high-strength concrete results in sudden failure without warning, which is a serious drawback.

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Several research scholars have shown that addition of compressive reinforcement and confinement will increase the ductility as well as the strength of materials effectively. Concrete, confined by transverse ties, develops higher strength and to a lesser degree ductility [1]. In recent years, the application of FRP in the construction industry can eliminate some unwanted properties of high-strength concrete, such as its brittle behavior. FRP is particularly useful for strengthening columns and other unusual shapes [3]. Focusing attention on the behavior of compression members, the main parameters investigated in literature [2–5] 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.

### Experimental Investigation

An Experimental investigation was conducted on seven column specimens having 900mm height and 150mm diameter. Six bars of 8mm diameter for longitudinal reinforcement and 6mm diameter mild steel ties spaced at 115mm for lateral ties for all columns 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 and thickness. The details of specimens and their details are presented in Table 1.

## Material Properties

M60 concrete was used for casting the specimens. The mix ratio adopted was 1:1.73:2.51:0.34:0.8 % (cement: fine aggregate: Coarse aggregate: Water: Hyperplastizicer). The characteristic compressive strength achieved was 63.64 MPa. The concrete composition is presented in Table 2. The steel used for longitudinal reinforcement was ribbed steel with yield strength of 450 MPa and that for lateral ties was mild steel with yield strength of 300 MPa.

**Table1: Specimen Details**

| Detail of specimens | Diameter (mm) | Type of GFRP (mm) | Thickness of GFRP (mm) |
|---|---|---|---|
| S24R | 150 | - | 0 |
| S24CSM3 | 150 | CSM | 3 |
| S24CSM5 | 150 | CSM | 5 |
| S24WR3 | 150 | WR | 3 |
| S24WR5 | 150 | WR | 5 |
| S24UDC3 | 150 | UDC | 3 |
| S24UDC5 | 150 | UDC | 5 |

## Preparation and Casting 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 pipes were covered with polymer sheets position to avoid any leakage. Cover blocks were placed at appropriate location to ensure adequate cover to the reinforcement. The interior of the pipes were 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 concrete mix was filled into the moulds in layers. Adequate compaction was carried out using needle vibrator to avoid honey combing. The specimens were removed from the moulds without any damage and cured in a standard manner for a period of 28 days

**Table 2: Concrete Composition**

| 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 | 680 |
| | 10mm | 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 |

## 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 facilitate proper adhesion of FRP wrapping. The wrapped surfaces were gently pressed with a rubber roller to ensure proper adhesion between the layers and proper distribution of resin. Fig.1 - 3 show the application of FRP wrap on the surface of the column specimen.

## EXPERIMENTAL SETUP

Testing of specimens was carried out in a loading frame of 2000 KN 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 dialation was measured using the lateral extensometer. Fig 4,5 and 6 shows the loading setup and failure status of GFRP.

**Fig.1. Cleaning under progress**

**Fig. 2. GFRP Wrapping under Progress**

**Fig. 3. GFRP Wrapped Specimen**

**Fig. 4. Loading setup**

**Fig 5. Failure status of CSM**

**Fig. 6. Failure status of UDC**

**Ultimate Strength:** The thickness of GFRP wrap and types of wrapping material are the most influential parameters. The increase in ultimate strength was found to be a 5.00% for specimen with 3mm thick CSM wrapping and 17.5% for specimen with 5mm thick CSM wrapping when compared to the reference column. The increase in ultimate strength was found to be 27.5% for specimen with 3mm thick WR wrapping and 33.00% for specimen with 5mm thick WR wrapping when compared to the reference column. The increase in ultimate strength was found to be 12.00% for specimen with 3mm thick UDC wrapping and 18.50% for specimen with 5mm thick UDC wrapping when compared to the reference column. Fig.8 shows the increase in ultimate stress when compared to the reference columns.

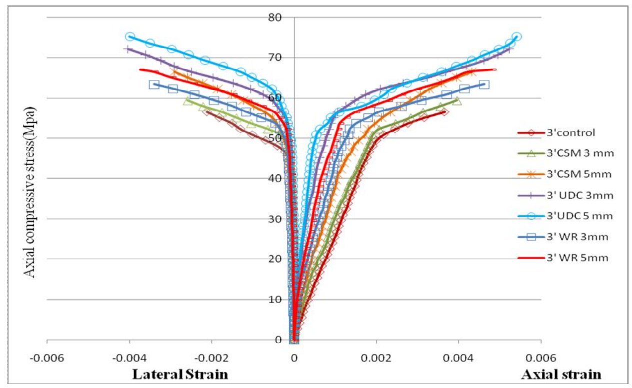


**Fig.7. Stress-Strain curve of GFRP**

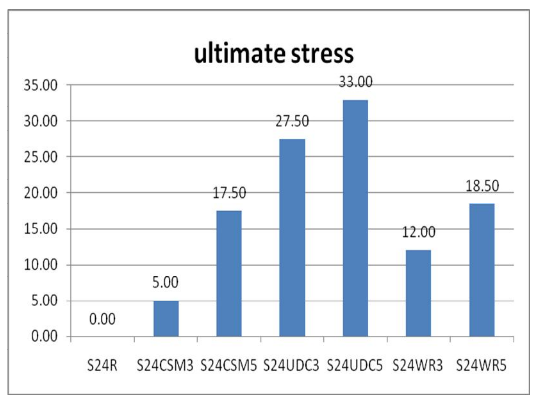


**Fig.8. Increases in Ultimate Stress for the wrapped Specimens.**

**Table 3: Test Results at ultimate load level**

| Specimen designation | Ultimate Load (kN) | Ultimate Axial Deflection (Mpa) | Ultimate Axial Stress (Mpa) | Ultimate Micro-Strain | Deflection Ductility | Energy Ductility | Energy Absorption per unit volume |
|---|---|---|---|---|---|---|---|
| S24R | 1000.00 | 3.29 | 56.59 | 3655.56 | 2.01 | 3.23 | 2245.88 |
| S24CSM3 | 1050.00 | 3.56 | 59.42 | 3955.44 | 2.43 | 3.84 | 3313.75 |
| S24CSM5 | 1175.00 | 3.89 | 66.49 | 4322.22 | 2.76 | 4.48 | 3361.63 |
| S24UDC3 | 1275.00 | 4.90 | 72.15 | 5444.44 | 4.95 | 7.96 | 5148.00 |
| S24UDC5 | 1330.00 | 5.04 | 75.26 | 5600.00 | 6.72 | 11.04 | 5414.68 |
| S24WR3 | 1120.00 | 4.17 | 63.38 | 4633.33 | 3.50 | 5.75 | 3745.05 |
| S24WR5 | 1185.00 | 4.33 | 67.06 | 4811.11 | 4.33 | 7.25 | 4215.40 |

## RESULTS AND DISCUSSION

The principal test results are presented in Table 3 and Fig.7 show the stress – strain curve of GFRP.

### Axial strain

The increase in axial strain was found to be a 8.21% for specimen with 3mm thick CSM wrapping and 18.23% for specimen with 5mm thick CSM wrapping when compared to the reference column. The increase in axial strain was found to be 26.74% for specimen with 3mm thick WR wrapping and 31.61% for specimen with 5mm thick WR wrapping when compared to the reference column. The increase in axial strain was found to be a 48.93% for specimen with 3mm thick UDC wrapping and 53.17% for specimen with 5mm thick UDC wrapping when compared to the reference column. Fig9 shows the increase in ultimate axial micro - strain when compared to the reference columns.

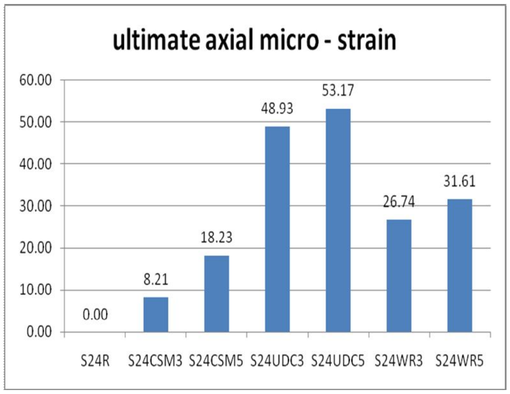


**Fig. 9. Increases in Ultimate axial micro- strain for the wrapped Specimens**

### Deflection ductility

Deflection ductility was found to be a 20.87% for specimen with 3mm thick CSM wrapping and 37.31% for specimen with 5mm thick CSM wrapping when compared to the reference column. Deflection ductility was found to be a 74.13% for specimen with 3mm thick WR wrapping and 115.42% for specimen with 5mm thick WR wrapping when compared to the reference column. Deflection ductility was found to be a 146.26% for specimen with 3mm thick UDC wrapping and 234.32 % for specimen with 5mm thick UDC wrapping when compared to the reference column. Fig10 shows the increase in ultimate deflection ductility when compared to the reference columns.

### Energy ductility

Energy ductility was found to be a 18.88% for specimen with 3mm thick CSM wrapping and 38.68% for specimen with 5mm thick CSM wrapping when compared to the reference column. Energy ductility was found to be a 78.02% for specimen with 3mm thick WR wrapping and 124.45% for specimen with 5mm thick WR wrapping when compared to the reference column. Energy ductility was found to be a 146.43% for specimen with 3mm thick UDC wrapping and 241.79% for specimen with 5mm thick UDC wrapping when compared to the reference column. Fig11 shows the increase energy ductility when compared to the reference columns.

### Energy Absorption

Energy absorption was found to be a 47.54% for specimen with 3mm thick CSM wrapping and 49.67% for specimen with 5mm thick CSM wrapping when compared to the reference column. Energy absorption y was found to be a 66.75% for specimen with 3mm thick WR wrapping and 87.67% for specimen with 5mm thick WR wrapping when compared to the reference column. Energy Absorption was found to be a 129.22% for specimen with 3mm thick UDC wrapping 141.09% for specimen with 5mm thick UDC wrapping when compared to the reference column. Fig12 shows the increase energy absorption when compared to the reference columns.

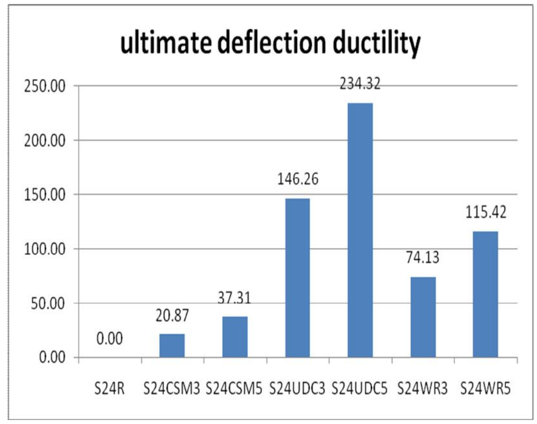


**Fig.10.Increases in deflection ductility for the wrapped specimen**

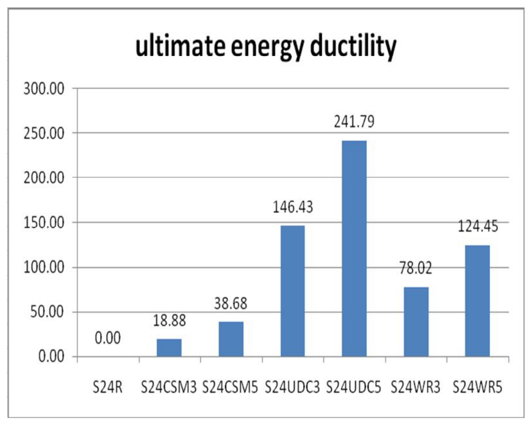


**Fig. 11.Increases energy ductility for the wrapped Specimens**

## 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 33.00% for 5mm thick UDC wrapping when compared to reference column.
- The maximum ultimate axial strain was increased by 53.17% for 5mm thick UDC wrapping when compared to reference column.
- The maximum deflection ductility was increased by 234.32% for 5mm thick UDC wrapping when compared to reference column.
- The maximum energy ductility was increased by 241.79% for 5mm thick UDC wrapping when compared to reference column.

- The maximum energy absorption was increased by 141.09% for 5mm thick UDC wrapping when compared to reference column.

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