



# STUDY ON THE COMPRESSIVE PERFORMANCE OF PLAIN-WOVEN FABRIC CONFINED CONCRETE COLUMNS

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## ABSTRACT

*FRP wrapping is a popular method for reinforcing concrete columns using fully and partially wrapping strengthening techniques. However, compared to the fully wrapped confinement mechanism, partially wrapped FRP columns in confined concrete are not well understood. This paper presents an experimental study on the axial compressive behavior of circular concrete columns partially wrapped with plain FRP fabric, with the aim of enhancing our understanding and optimization of FRP strengthening techniques. This study investigates the effects of four types of fiber-reinforced polymer (FRP) wraps and one concrete mix design on the axial behavior of FRP-confined concrete. The results indicated that the plain-woven fabric effectively improved the compressive stress and axial strain of the concrete columns. PWF-C displayed an increase of 70.96 % and 255.5%, compressive stress and axial strain compared to control specimen. PWF-G showed enhancements of 54.35% and 263.33% compared to the control specimen. The maximum improvement in compressive stress was observed for the hybrid plain-woven fabric (PWF-G-H), which was 84.72 % higher than that of the control specimen. Similarly, the maximum strain was observed for PWF-G, which was 263 % higher than that of the control specimen. The samples exhibited gradual cracking during loading, and the failure damage was mostly inclined along the warp direction of the fabric.*

**Keywords:** Plain Woven Fabric; Carbon Fiber, Glass Fiber, Concrete Compression;  
Confined Concrete, Stress–Strain Curves

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## 1. INTRODUCTION

The construction industry relies heavily on concrete as a primary building material, particularly in reinforced concrete (RC) structures designed to endure loads over their lifespans. However, the load-bearing capacity of RC structures diminishes over time because of factors such as concrete carbonation and steel reinforcement corrosion[1]. Consequently, many RC structures have required repair and strengthening over the past two decades, leading to the exploration of various innovative materials and cost-effective techniques[2].

The choice of materials and techniques for repairing and strengthening deteriorated RC structures depends on factors, such as material availability and financial constraints[3]. Ongoing research aims to discover affordable, robust, and long-lasting materials, along with innovative techniques that can restore the structural strength without significantly increasing the self-weight[4]. Historically, deteriorated RC elements were often reinforced by overlaying Ordinary Portland Cement (OPC) concrete, but this method increased structural dead load without commensurate strength gains [5]

Strengthening deteriorated columns via RC jacketing can substantially enhance the load-bearing capacity; however, it also increases the cross-sectional area and self-weight, requires skilled labor, and incurs high costs [6]. Steel jacketing offers higher concrete strength but suffers from cost concerns and material compatibility issues, such as differing Poisson's ratios, leading to reduced effectiveness and constant confinement pressure upon reaching the yield stress[7].

Over the past 30 years, fiber-reinforced polymer (FRP) composites have emerged as a lightweight, corrosion-resistant alternative for strengthening RC beams and columns with minimal self-weight increase. FRP significantly boosts the strength and ductility of concrete elements, with FRP tubes increasingly replacing RC in new construction owing to their multifunctionality[8].

FRP's superiority of FRP lies in its higher tensile strength, lower weight, and superior corrosion resistance compared with steel. FRP wraps are popular for reinforcing existing RC structures, whereas FRP tubes are preferred for new construction owing to their convenience and performance. Moreover, FRP's lower life-cycle cost of FRPs, considering steel reinforcement corrosion, makes them economically viable[9].

Research has shown that complete FRP confinement can significantly improve the compressive strength and deformation capacity of circular concrete columns. An alternative approach is to surround the concrete column with FRP strips or rings that are arranged longitudinally, which is known as an FRP partially wrapped concrete column. This method involves wrapping the column with discrete (i.e., spaced) FRP elements. Strengthening columns with discrete FRP strips is intended to prevent buckling failure caused by FRP, which is prone to occur in concrete-filled FRP tubes due to the significant axial stiffness of the FRP tube. In addition, fewer materials made from fiber-reinforced polymer (FRP) are needed for FRP partial wrapping of concrete columns. As a result, it is easier and quicker to apply FRP partial wrapping strengthening compared to FRP full wrapping strengthening.[10].

Kumar V used stainless steel wire mesh (SSWM) to reinforce the concrete column and carried out a compression test. The results indicate that SSWM 40×32 can be used for the structural reinforcement of circular concrete columns, which can withstand 86% higher axial loads than the original[11]. Li G compared the effects of different fibre orientations on composite-constrained concrete. The study found that axial fibers resisted axial forces. The effect of directional stress is the best, and the failure modes corresponding to different fiber orientations are different [12].

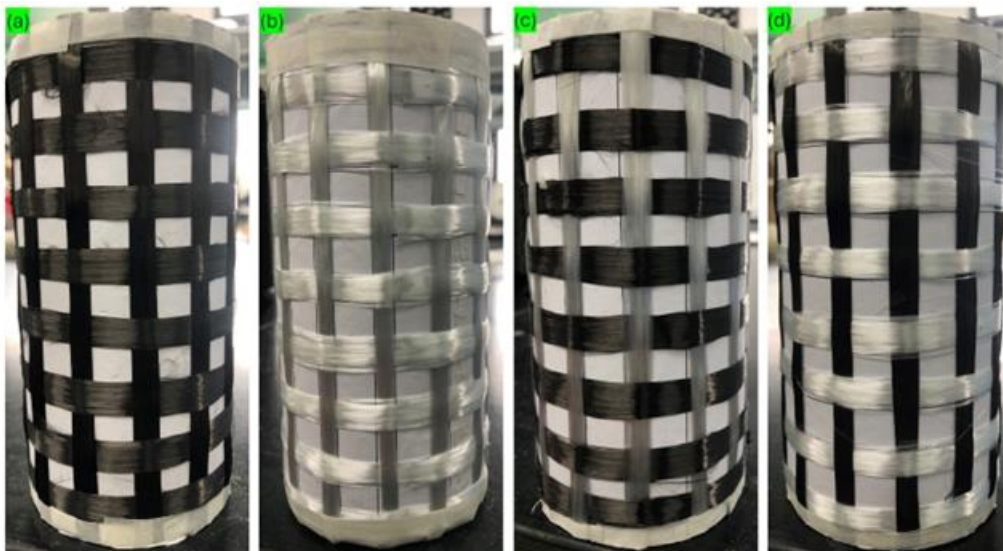
In order to achieve this objective, an experimental program was implemented to investigate the axial compressive behavior of circular columns that were wrapped with plain woven fabrics made from two distinct fiber materials (carbon and glass) as well as their hybrids. Fifteen specimens were created and subjected to testing. The outcomes of the tests, concerning how various FRP materials impact the axial compressive performance of FRP partially wrapped concrete, are detailed and analyzed.

## 2. EXPERIMENTAL PROGRAMS

### 2.1 Materials

The experimental plain-woven fabric was composed of T300-12K carbon fiber and 1200 tex alkali-free glass fiber. The epoxy glue was produced using resin obtained from Yuezi Industrial Co. Ltd. (Shanghai, China). The warp and weft densities of the fabric are 10 ends per 20 cm, and fabric porosity is 34%, respectively. The thicknesses of the carbon and glass fabrics were respectively 0.5 millimeters and 0.7 millimeters.

### 2.2. Sample preparation



**Figure 1** Plain woven fabric confined concrete columns (a) PWF-C, (b) PWF-G, (c) PWF-C-H, (d) PWF-G-H

The concrete column samples were cast simultaneously with commercial concrete. The grade of the concrete was C20. These ratios are listed in Table 1. After allowing the concrete to cure for 28 days, the compressive strength of the tested sample was measured to be 21.8 MPa. The concrete columns were all topped with high-strength epoxy resin to ensure that they were evenly stressed, avoiding off-axis compression. This was done to guarantee that the concrete columns were level. All of the concrete columns were thoroughly cleaned and sanded before being wrapped with the woven fabric. The concrete columns were measured for their perimeter and height to determine the dimensions for cutting the woven fabric.

The glue was then mixed in equal parts with the main agent and curing agent according to a 3:1 ratio. This mixture was then applied evenly to the woven fabric before being used to impregnate the surface of the concrete.

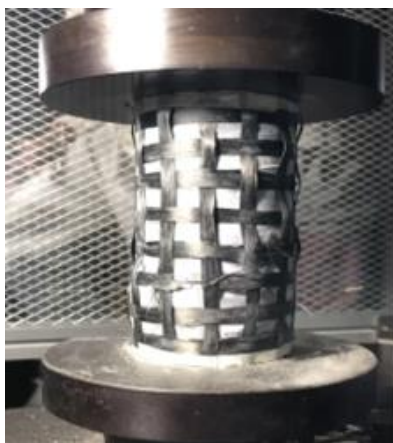
**Table 1.** Mixed ratio of concrete

Cement	Sand	Coarse aggregate	Water
1	2.37	3.77	0.6

In this study, 15 circular cross-section concrete columns with a diameter of 70 millimeters and a height of 140 millimeters were prepared. Five groups of specimens were formed, with one group serving as a control (PC) for comparative analysis without any reinforcement. The four remaining groups were classified into three categories: carbon fiber (PWF-C), glass fiber (PWF-G), and carbon-glass hybrid (PWF-C-H and TWF-G-H) based on the direction of the yarns used in the plain-woven fabric. In the category of carbon-glass hybrid composites, samples that have glass fiber warp yarns and carbon fiber weft yarns are labeled as TWF-C-H, while those with carbon fiber warp yarns and glass fiber weft yarns are denoted as TWF-G-H, as illustrated in Figure 1.

### 3. EXPERIMENTAL EQUIPMENT AND INSTRUMENTS

The compression test was carried out using a Lanbo Sansi LD26 electro-hydraulic servo universal testing machine, as illustrated in Figure 2. The control displacement technique was utilized, and the loading rate was 2 mm/min. The experiment was terminated once the stress attenuation reached 40%.

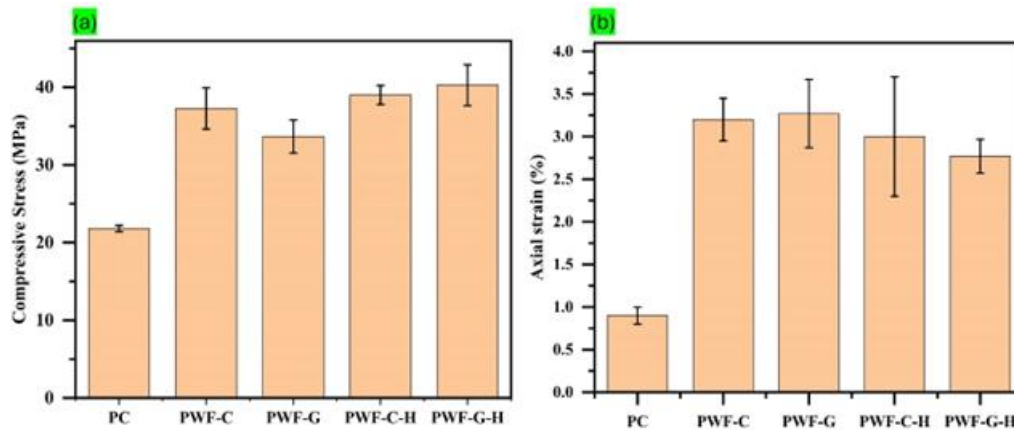


**Figure 2** Compression test.

## 4. EXPERIMENTAL RESULTS

### 4.1. Compressive performance

The experimental results of the compressive stress and axial strain, along with the standard deviation, are shown in Figure 3. The average axial compressive strength ( $f_{co}$ ) of the pure concrete column (PC) is 21.8 MPa, and the average axial strain ( $\epsilon_{co}$ ) was 0.9 %. Graph 3 indicates that the plain-woven fabric PWF-G-H exhibited the most effective confinement, surpassing the control specimen in both strength and axial strain by 84.72% and 233.33%, respectively. When comparing the confined samples with PWF-C-H to the unconfined ones, the confined samples demonstrated a substantial increase in compressive strength and axial strain, amounting to approximately 78.8% and 207.7%, respectively. In addition, the PWF-C sample exhibited a significant improvement in compressive strength and axial strain, increasing by 70.96% and 255.5%, respectively, compared to the control specimen.



**Figure 3** Compressive behavior of groups (a) Compressive stress, (b) Axial strain.

On the other hand, the samples reinforced with PWF-G demonstrated a significant improvement in compressive strength, showing a 54.35% increase compared to the control specimen. Additionally, they exhibited a remarkable 263.33% increase in axial strain, surpassing the control sample. It can be observed that the hybrid fabric-confined concrete performed better than the pure fabric of carbon and glass fabric-confined concrete columns, which was significant given the cost reserves of the materials applied. The decrease in compressive stress was observed when the glass fiber was oriented in the warp direction compared to when it was oriented in the weft direction. Similarly, the decrease in axial strain was observed when the carbon fiber was oriented in the weft direction as opposed to when it was oriented in the warp direction. The ineffectiveness of the laterally applied fiber strength in preventing the lateral expansion of concrete can be attributed to the loss of strength caused by this application.

#### 4.2. Axial Stress versus Strain Curves of FRP Confined Concrete

Figure 4 depicts the axial stress-displacement curves for various plain-woven fabric-confined concrete specimens. The illustration provides a visual representation of the stress-displacement relationship for different specimens. At the outset, the graph lines for the confined concrete samples mirrored those of conventional unconfined concrete, suggesting a lack of confinement effectiveness at low stress levels. The upward sloping second branches observed in all the FRP-confined concrete specimens indicated the initiation of FRP confinement, effectively restraining the expanded concrete. The behavior of PWF-G revealed a bilinear trend with a less steep slope in the second branch. On the other hand, PWF-C, PWF-C-H, and PWF-G-H all demonstrated initial behavior in the confinement of concrete specimens that was similar to unconfined concrete. After conducting initial observations, it was discovered that the concrete samples exhibited an increase in confinement pressure when subjected to the pressure-applying wet-laying procedure. The formation of steeply ascending second branches revealed that PWF-C, PWF-C-H, and PWF-G-H were applying a greater degree of confinement pressure on the dilating concrete. The higher pressure can be attributed to the significantly higher modulus of elasticity and ultimate tensile strength of the wraps, which leads to a greater increase in the confined concrete strengths. This cost-effective alternative is demonstrated in Figure 5, which shows the stress-displacement behavior of the specimens. Using fewer strands of carbon fiber, this hybrid material outperforms PWF-C confined concrete, as demonstrated in Figure 4.

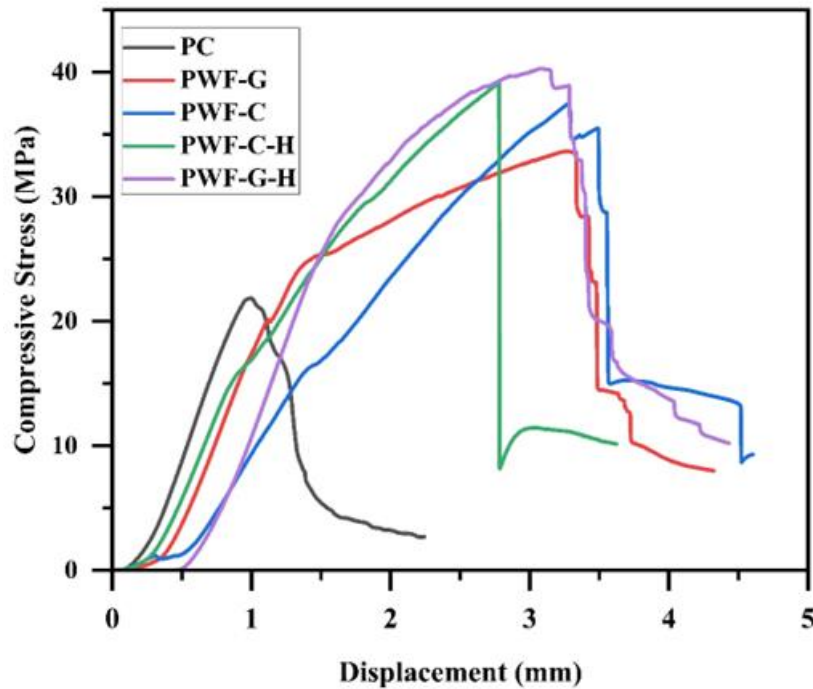


Figure 4 Stress -displacement behavior of specimens.

### 4.3. Failure Mode

Figure 5 depicts the failure modes of the specimens. The control specimen exhibited a failure characterized by numerous vertical cracks, resulting in the spalling of surface concrete layers. As the highest level of demand was reached, there was a sudden decline in demand, which pointed to a brittle type of failure. All of the confined specimens were failed due to inclined cracks that were caused by the hoop tensile stress on the strengthening layer. The specimen PWF-C was damaged due to a localized inclined crack caused by non-uniform hoop strains. A few noticeable vertical cracks were observed on the PWF-G-confined specimens, one of which eventually led to the specimen's final failure. In specimens confined with PWF-G-H, when cracks occurred, the individual yarns deformed within the matrix, resulting in a more noticeable strain-softening stage. The failure originated from a few fibers and expanded to neighboring bundles, resulting in a delay before sudden failure. No telescopic pull-out mechanism was observed for PWF-C-H. The failure was identified by an inclined crack, and the crack widening was relatively smaller than that observed in the case of PWF-C-H. The excellent tensile strength of carbon textiles allowed the specimens to withstand greater axial compressive forces.



Figure 5 Failure morphology. (a)PC, (b) PWF-C, (c) PWF-G, (d) PWF-C-H, (e) PWF-G-H

#### 4. CONCLUSION

In this study, carbon fiber, glass fiber, and their hybrid plain woven fabric were used to partially reinforce concrete columns, and plain-woven fabric-confined concrete was subjected to axial compression tests. Studies on the axial compression performance of the specimens were conducted, and the following conclusions were obtained:

- (1) The manner in which PWF-confined materials exhibit stress-strain curves, as well as their compressive stress and strain behavior, is influenced by the fibers utilized in both the warp and weft directions of the PWF. The selection of fibers in these orientations has an impact on the confinement mechanism and the overall performance of the material when subjected to compressive loads.
- (2) Fibers aligned in the weft direction play a crucial role in enhancing the material's resistance to lateral expansion, which in turn affects compressive stress. In contrast, fibers oriented in the warp direction contribute to enhancing the material's resistance to axial deformation, thereby influencing the compressive strain.
- (3) The use of plain-woven fabric confined concrete columns can effectively improve the load-bearing capacity, and ductility of concrete. The compressive stress and strain of the plain-woven fabric PWF-G-H were 84.72% and 233.3% higher than those of the control specimen, respectively, outperforming the pure PWF-C-confined concrete. This proves that an advantageous composite effect can be obtained with partial FRP wrapping. This shows the potential of the hybrid fabric for the cost control of materials.
- (4) The destruction of the PWF-confined concrete samples was progressive, and the single weft yarn gradually broke, which eventually led to the tearing and destruction of the entire plain woven fabric composite material.
- (5) This study emphasizes the importance of fiber orientation for concrete confinement in terms of how FRP-specific arrangements influence the effectiveness of confinement.
- (6) PWF-G-H demonstrates extendable pull-out-induced deferred failure, indicating improved strain-softening. In contrast, PWF-C-H failed with more axial load resistance and less crack broadening because of the strength of the carbon textile.
- (7) These results suggest that using plain-woven fabric, particularly in hybrid configurations, is an efficient and cost-effective way to improve the performance of concrete columns under axial compression.

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