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Experimental Axial Compressive Behavior of Partially Confined Concrete Columns with Combined External and Internal FRP Strips

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Abstract: Current researches have demonstrated that the partial confining design by discrete strips is a promising and economic alternative to the full strengthening technique. In this connection, this study consists to evolve a new sustainable technique for confining concrete columns under axial compression. The proposed design technique consists to embed discontinuously hexagonal fibers reinforced polymer (FRP) strips and wrapped the outer concrete partially using external circular FRP strips. A detailed experimental program was realized on standard dimension composite-encased concrete cylinders under compressive loading until failure to evaluate the axial compressive strength and the corresponding failure mode of the reinforced concrete. In addition, mechanical characterization tests were performed to provide the behavior laws of used raw materials. The emphasized experimental results namely: stress versus hoop and axial strain curves and the rupture patterns of all tested samples indicate clearly an improvement on the stiffness, axial stress and strain of the reinforced concrete columns compared to conventional unconfined ones.

Keywords: Axial behavior; Experimental; Hexagonal FRP strips; Partially confined-concrete.

Introduction

Over the last years, a considerable number of research have been conducted on the use of composite materials in concrete structures, and have shown a significant improvement in the axial compressive resistance and ductility of concrete columns due to the lateral confinement of FRP (Hadi et al., 2015; Liang et al., 2019; Wu et al., 2006). In the first experimental studies based on retrofitting columns with composite FRP, the columns were generally fully enveloped ensuring continuous confinement along their longitudinal axes. The previous investigations have revealed that fully FRP confinement can materials increased the strength and ductility of concrete columns compared to unreinforced control specimens (Guo et al., 2016; Hadi et al., 2013; Rahman et al., 2018).

Furthermore, many experimental approaches have been carried out on the behavior of partially confined specimens with different types of FRP composites (Campione et al., 2015; Totonchi et al., 2019; Zeng et al., 2020, Zeng et al 2021). Partially FRP-wrapped columns were also demonstrated to exhibit improvement in resistance and ductility, confronted with unreinforced control columns. (Djenad el al., 2022) have introduced a new confined concrete columns design with encased-FRP/Grid components with partial hexagonal FRP and steel wire grid discontinuously embedded as strips in the concrete matrix. In addition, (Ali Ahmed et al., 2022) have investigated the experimental behavior and the reliability of concrete columns repaired by externally bonded double- FRP spiral strips under axial compression loading.

In this respect, the new technique considered in this experimental program consist on the embedded of hexagonal FRP strips inside the columns to provide high mechanical proprieties of reinforced concrete by partial-embedding of FRP composite. The design of FRP strips shaped to be hexagonal is motivated by their lightness, high rigidity and form-stability combined to high compression resistance compared to conventional circular shape. This article intended to examined the behavior in axial compression of partially confined columns with a GFRP strips. A total of 12 columns were cast and tested in this article. The different results of the tests in terms of failure mechanism, stress-strain behavior, ultimate axial stress-axial strain response have been presented in detail.

Experimental Investigation

The new confinement technique suggested in the present article consists of partially confining cylinders with hexagonal and circulars FRP strips. A total of 12 concrete cylinders with dimensions Ø160 mm x 320 mm was cast and tested under axial compression. Three cylinders, considered a reference named "P", were tested to failure to measure the characteristic compressive strength of concrete at 28 days. The other cylinders were confined by partial integration of hexagonal FRP strips "FC-1", other wrapped with circular FRP strips "FC-2", and else double confined concrete with an inner and outer confinement with GFRP strips "FCC". The main objective of this work is to introduced the different results of this experimental program, understand the real observed and overall mechanical behavior to obtain preliminary conclusions about the importance of the proposed technique in terms of resistance and deformation enhancement.

Materials Preparations

The concrete used in the experimental tests for the preparation of the different cylinders is an ordinary concrete with Portland cement. The concrete mix proportion is determined from the Dreux-Gorisse method founded on the particle size analysis of different solid components. Table 1 summaries the mix proportion of the ordinary concrete defined for this experimental protocol. The cylinders were prepared according to Eurocode 2, using a conventional rotary drum concrete mix, followed by a slump test, as indicted the Figure.1 (a). The concrete was casted in standardized molds, as presented in Figure.1 (b), then demouled after 24 hours, the specimens were kept humid at a moderate and constant temperature for 28 days according to NF EN 12390-2 standard. After 28 days the specimens were dried on the surface and to avoid the eccentricity of the axial compressive force during the tests, specimens must undergo surfacing. The compressive strength of the used concrete at 28-day which was obtained to be 27.3 MPa.

Table 1. Mix proportions of used concrete

Component	Amount
Cement CPJ 42.5 (kg/ m^3)	370
Sand (kg/ m^3)	635,98
Fine aggregate (kg/ m^3)	201,5
Coarse aggregate (kg/ m^3)	424,94
Water (ml/ m^3)	200
Super plasticizer (l/m^3)	5 L
Slump test	8 cm

Figure 1. (a) Concrete preparation; (b) Concrete casting

For the composite strips embedded in the concrete, the used fabric is bidirectional fiberglass mat (GFRP) formed from a set of surface filaments of warps and wefts, as represented in the Figure 2 (a). The thickness of GFRP fabric is 0.35 mm. For partially concrete encased FRP strips columns, hexagonal GFRP strips of 30 mm width and 140 mm diameter have been used as inner concrete confinement. Table 2 recapitulate the different characteristics of used fabric, which have been determined by (Si Salem et al, 2015; Si Salem et al, 2020; Ait Taleb et al, 2016, Djenad et al, 2022b, Ait Taleb el al, 2020) on GFRP coupons according to ASTM D3039 standard tensile test. The specimen confinement with GFRP is ensuring by welded mesh bars of 3mm diameter, with 2 hexagonal straps of 140 mm overall diameter, as exposed in Figure.2 (b). 24 FRP strips of 45 cm length and 30 mm width were measured and catted, 4 strips then were placed around the bars using the epoxy resin STR, with net spacing of 30 mm.

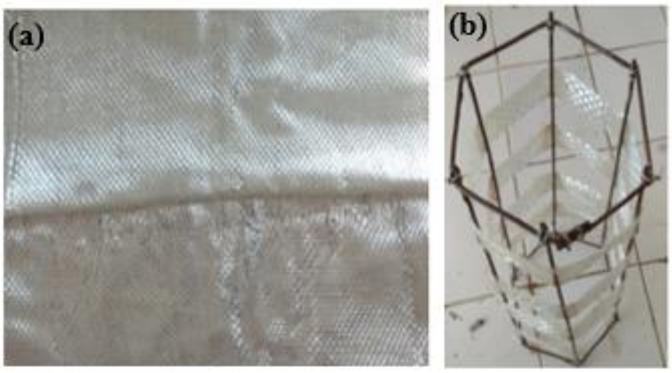


Figure 2. (a) Fiber glass fabric; Conception with GFRP strips

Table 2. Average properties of used FRP and grid

Used materials	Thickness (mm)	Young modulus (Gpa)	Tensile stress (Mpa)	Ultimate tensile strain (‰)
GFRP fabric	0.35	82	1400	5.61

A total of 12 FRP strips of 55 cm length and 6 cm width was measured using the same GFRP fabric and placed partially around the specimens to reinforced the outer concrete, figure .3 (a). After cutting, the GFRP strips were placed around the hardened specimen using an adhesive resin, as indicated in Figure.3 (b). The used epoxy resin STR was mixed with a hardener during five minutes to avoid the inclusion of air bubbles, as presented in Figure.3 (c). Finally, specimens were left to dry at room temperature during 7 days.

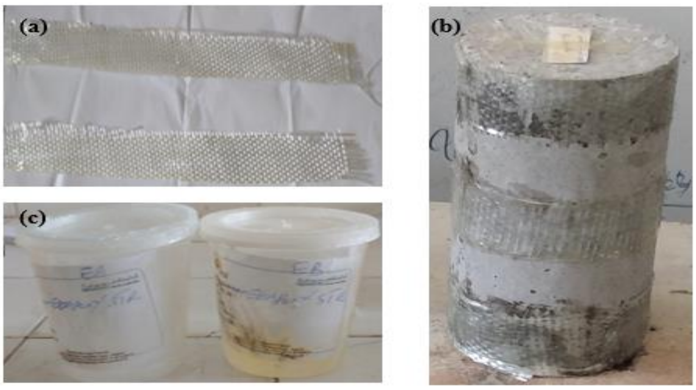


Figure 3. (a) Fiber glass strips; (b)The components of the adhesive; (c) The specimen confined with GFRP strips

Test Setup and Instrumentation

The test machine is a universal ELE (IBERTEST) type of 3000 KN capacity with a loading rate of 0.5 KN/s, equipped with a data acquisition system and a digital software control, is used for testing all the columns. The testing machine indicates the applied load as a function of longitudinal displacement, allowing thus the axial stress- axial strain curves. The loading rate is kept constant during the test procedure and the columns were instrumented to record axial stress-stain measurements, Figure.4. The test allows also to observe the failure mechanisms of the confined concrete columns and to evaluate the contribution of the embedded metallic grid in resistance, ductility and confinement level.

Figure 4. Axial compression loading set-up

Experimental Results and Analyzes

In this session, the confrontation of the overall response of the different reinforced concrete cylinders with the unconfined concrete was performed. The failure mechanisms corresponding to the different specimens regarded in this research are performed and analysed, in order to deduce the parameters influencing the structural ductility, as well as the passage from a brittle failure mode to a ductile failure mechanism.

Stress-Strain Behavior

Figure 5 shows the axial behaviour of unconfined columns “P” and partially confined columns with GFRP strips ("FC-1”, "FC-2" and "FCC"). The test results of the three identical columns were find to be approximatively similar to each other; consequently, the average of the three columns of each confinement configuration was presented. Detailed results of all tested columns are summarized in Table 4. It can be seen from the figure that all the columns showed similar behaviour at the initial stage, a slope which follows that of the unconfined concrete, i.e., the stress increases with increasing strain. After the ultimate resistance achievement, the stress of the unreinforced columns “P” decreased considerably conducting to a total failure. The strength of the confined specimens ("FC-1”, "FC-2" and "FCC"), was significantly increased with a considerable increasing of deformation, this is due to activation of confinement effect provided by the hexagonal FRP strips. Integrating GFRP strips and the wrapped the outer concrete with GFRP strips provides high tensile strength during transversal expansion of the concrete core, which allows to prevent the cracks propagation.

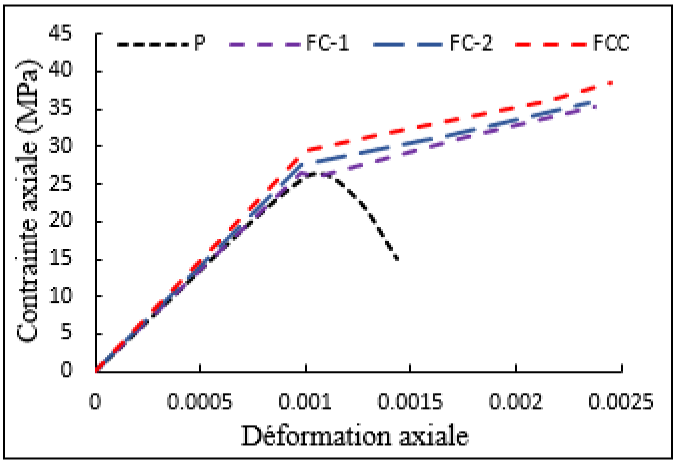
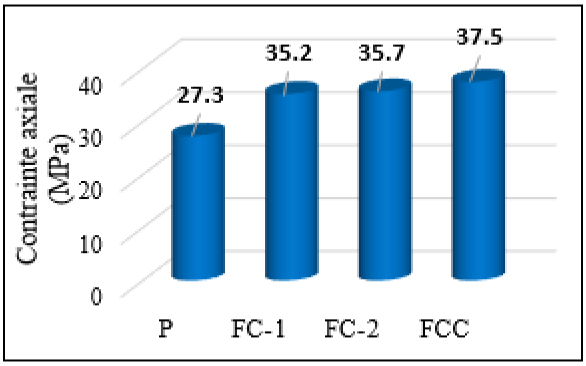


Figure 5. Axial stress-axial strain curve of the different columns

The confrontation of the different stress-strain curves illustrated in figure 6 shows a positive improvement of compressive resistance and ductility. Indeed, the ultimate concrete strengths obtained for "FC-1", "FC-2" and "FCC"), columns are respectively 35.2 MPa, 35.7 MPa and 37.5 MPa, compared to 27.3 MPa for the unreinforced column. the confined columns with encased hexagonal GFRP strip and outer confinement presents a gain in resistance of the order of 37.36 % and a more extensive deformation before rupture therefore a greater ductility effect which represents a significant contribution.



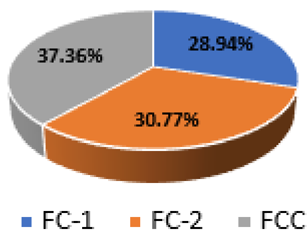


Figure 6. Confrontation of the different stress-strain curves

Failure Modes

The failure mechanisms corresponding to the different specimen subject to a uniaxial compressive load are illustrated in Figure 7. For the specimens reinforced by integrating of GFRP strips, the concrete cover collapsed because no confinement was provided to the outer concrete. For columns wrapped with GFRP strips, the concrete cover cracking is observed when the compressive resistance of the control column was approached, however, the columns still remain with higher deformation after the crushing of the concrete cover. The crushing of the outer concrete was effectively controlled owing to the confinement ensured by the GFRP. Incorporating GFRP strips in concrete induce a high tensile strength during transversal expansion of the concrete core, which helps to prevent the cracks propagation. The external GFRP composite allows the passage from a brittle failure mechanism to a ductile failure mode this ductility contribution confers on the composite column interesting deformation capacity.

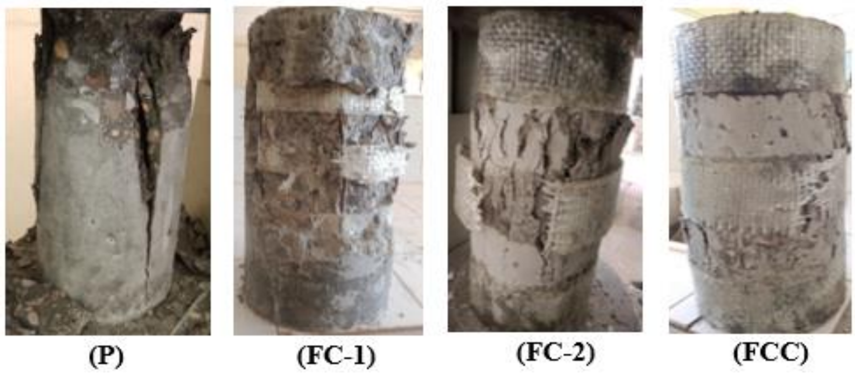


Figure 7. The modes of failure in the concrete column

Conclusion

This work consists in investigating experimentally the behaviour of confined concrete cylinder with GFRP strips. This new technique aims to increase the stiffness and strength of the member, to allow ductile failure and to prevent sudden collapse under axial compression loading. The proposed technique ensures the continuity of the concrete within the structure, avoids the problem of interface failure and facilitates the production process.

All the reinforced concrete columns achieve a considerable improvement in resistance and ductility. The hexagonal GFRP strips ensures the confinement of the inner concrete, while the GFRP jacket provides a complement to the outer concrete but it remains insufficient because of the level of confinement is very low. The ultimate resistance and deformation of the confined columns can be significantly increased by increasing the GFRP fiber amount and decreasing the GFRP strips spacing. This study tells us that with a reasonable confinement level, the average stress of the concrete is improved by nearly 36% for the confined columns with embedded and wrapped GFRP strips.

Recommendations

The framework of this research reveals only a small part of the mechanical aspects of concrete reinforcement by GFRP strips. An important number of experiments and tests are necessary to draw complete conclusions about the interest of this technology.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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