Confinement of Concrete by Fiber Reinforced Polymer Tube: A Review

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Abstract: Researchers studied a lot of strengthening techniques of concrete, one of which is the technology of concrete confinement. This technique is common to utilize fiber fabric impregnated with epoxy resin adhesive. Relevant applications mainly include strengthening the existing structure and new structural construction. This paper presents a review of previous studies on the confinement of concrete using fiber-reinforced polymer (FRP) tubes. Four main parameters were investigated in this study: the number of layers of FRP tubes, cross-sectional shape and slenderness ratio, material types of FRP tubes, and concrete types. The results of the investigation showed that increasing the number of FRP tubes resulting in a significant improvement in the behavior of confined specimens, circular cross-section specimens exhibited better behavior than square. Also, the behavior of confined square specimens improvement with increasing the angular radius. A carbon fiber reinforced polymer tube is better than (aramid, glass, and basalt) fibers. Finally, the concrete confining technique significantly improved the behavior of specimens regardless of the type of concrete confined, and the effect of confining decreases with the increase of compressive strength of the concrete confined.

Keywords: Confinement of concrete, fiber-reinforced polymer, slenderness ratio, and angular radius.

1. Introduction

The external strengthening of the structures is one of the important challenges in civil engineering. The need to strengthening structures goes back to different causes such as increased serving loads, errors in design or during implementation, codes updating, the service period may need to extend, and exposure to different environmental conditions. Sudden failure of structures may be happened because of these factors; so researchers in civil engineering found many techniques of external strengthening [1,2]. One of the strengthening techniques is concrete confinement by fiber-reinforced polymer (FRP) tube. The concrete confinement technique is one of the external strengthening techniques for structural sections, which is considered one of the promising techniques in the field of structural engineering. There are four methods of confinement within this technique, include, concrete-filled steel tubes, double skin steel tubes, concrete filled fiber tubes and fiber-reinforced polymer-concrete-steel-double skin tubular members [3,4]. Concrete confinement by fiber tube is achieved by wrapping/jacketing the fiber fabric in a suitable method around the concrete section, which is based on epoxy resin as an adhesive. It is called concrete confined with FRP tube. This technique is used either to strengthen or repair old and damaged construction sections...
or to construct new buildings. Therefore, this technique is implemented by two methods: the first is to wrap/jacket the fiber fabric impregnated with epoxy adhesive around the structural part to be repaired or strengthened, and the second is to wrap the fiber fabric impregnated with epoxy adhesive around a plastic mold to manufacture tubes, which it is used directly in the process of casting concrete, this method is used in the construction of new buildings [5,6]. There are several studies in the past touched on the confinement of concrete technology using FRP tubes, it was addressed to study the effect of several factors, so this paper provides a review of a study on the use of this type of confinement (FRP-tube) were studied to investigate the following parameters: number of fibers tube layers, cross-sectional shape and slenderness ratio, material types of FRP tube, and concrete types.

2. Effect of number of fibers tube layers

In (2007) Ozbakkaloglu, et al, [7] studied the effect of the number of layers of carbon fiber reinforced polymer (CFRP) on the behavior of the confined concrete under the axial compressive load. Where the number of carbon fiber tube layers studied was 3 and 5 layers. The results indicated that the increase in the number of layers led to significant improvement in the carrying capacity of the axial stress, as shown in Figure 1.

![Figure 1: The effect of CFRP tube layers [7]](image1.jpg)

In (2014) Vincent and Ozbakkaloglu [8] examined the influence of the number of layers on the behavior of confined concrete under axial compression used aramid fiber-reinforced polymer (AFRP) tubes. The variables consist of 4 - layers of AFRP. The results indicated that the increase of the number of layers AFRP tube was led to an enhancement of the behavior of confined specimens in terms of axial stress, as shown in Figure 2.

![Figure 2: The effect of AFRP tube layers [8]](image2.jpg)
In (2014) Yu, et al, [9] studied the effect of the number of fiber tube layers on the behavior of the confined self-compact concrete (FRP-confined SCC), tested under axial compression. The specimens were prepared with a circular cross-section that was confined with carbon and glass fiber fabric. The number of fiber tube layers studied included that (1, 2, 3, and 6) layers of Carbon FRP and (1, 3, 6, and 9) layers of Glass FRP. The results showed that the behavior of FRP-confined SCC is based on the stiffness of FRP-jacket. So, when the FRP-confined, the stiffness of the specimen was larger, the lateral expansion became smaller. Therefore, the specimens exhibited increasing in ultimate axial stress and deformation capacity with an increase in the number of FRP layers.

In (2016) Xie and Ozbakkalogu, [10] studied the effect of the number of FRP tube layers on the behavior of specimens confinement with a circular cross-section, under axial compression load was studied. The number of FRP tube layers studied was (3 or 5) layers of basalt FRP, (3 or 6) layers of Carbon FRP. The results indicated that increasing the number of layers leads to improvement in the compressive strength and ultimate strain of the specimens.

In (2016) Ozbakkaloglu and Xie, [11] studied the effect of FRP tube layers on performed of confined specimens under axial compression load. So, was examined the number of layers (1 or 2) layers of Carbon, Basalt, and S-glass FRP. The results were shown that an increasing number of layers caused increasing in compressive strength and developed hoop rupture strain of confined concrete.

In (2019) Alzeebaree, et al, [12] studied the effect of the number of FRP tube layers on the resistance of sulfuric attack in terms of compressive strength of specimens confined with fiber-reinforced polymer at static and cyclic load. That used Carbon FRP and Basalt FRP. So, investigated the number of fiber tube layers (i.e. 1 or 3-layers). The results were shown that the confinement of specimens with 3-layers gave more strength and durability than the confinement with 1-layer, as shown in Figure 3.

In (2019) Chan, et al. [13] examined the effect of the number of layers of glass fiber reinforced polymer GFRP tube, (2, 4, and 6-layers) was studied on the behavior of the rubber concrete under the axial compressive load. Where, 14 specimens were poured with different replacement rates of aggregates with rubber crumb ranging from 0% to 75%. After fourteen days of curing, the specimens were wrapped with GFRP tubes. The results illustrated that the axial stress and the deformation capacity were significantly increased with the number of GFRP layers, as shown in Figure 4.

![Figure 3: The effect of CFRP and BFRP tube layers [12].](image)
In (2020) Usman, et al. [20] studied the axial compression behavior of confined specimens of concrete reinforced with steel fibers. The main variables studied included, the number of layers of CFRP tube (i.e. 1 and 3-layers). The specimens were completely prepared and cast with dimensions 300 mm high × 150 mm diameter. After 28 days of curing, the specimens were wrapped with CFRP and then examined under axial compression load. The results indicated that the confinement with 3-layers of carbon fibers gave better compression strength than a 1-layer. The compressive strength of 3-layers specimens is estimated to increase about (70-80%) of unconfined specimens' strength, as shown in Figure 5.

In (2020) Faleschini, et al. [15] presented an experimental study on the behavior of reinforced concrete columns, confined by textile carbon fiber reinforced with cementitious material (FRCM) under axial compression load. The most important variables included the number of carbon fiber layers (1 and 2) layers. The results showed that the technique of confinement by (FRCM) gave a noteworthy improvement in the behavior of the columns. So, increasing the number of layers from (1 to 2) layers, it gave an improvement rate between (20-23%).

3. Effect of cross-sectional shape and slenderness ratio
In (2007) Ozbakkaloglu, et al, [7] present a study about the effect of the angular radius of the specimens having a square section with dimensions (200 × 200) mm and a length of 600 mm on the behavior of the confined specimens under axial compression load. Where, the angular radius was (10, 20, or 40) mm. The results showed that as the angular radius increased, the specimens’ behavior improved, and the stress-carrying capacity was increased, as shown in Figure 6.
Figure 6: The effect of the angular radius [7].

In (2014) Vincent and Ozbakkaloglu, [8] studied the effect of the slenderness ratio on the behavior of specimens confined under an axial compression load, in terms of stress enhancement ratio, deformation capacity, and failure mode. The slenderness ratio (H/D) studied for specimens confinement by aramid fiber-reinforced polymer (AFRP) with circular section were (1, 2, 3, and 5). The results indicated that the influence of the specimen with H/D = 1 exhibits a higher stress enhancement ratio and higher deformation capacity. On the other hand, the specimens with H/D 2 to 5 exhibit a higher stress enhancement ratio but a decrease in deformation capacity. The specimens with H/D (1or 2) failed in rupture AFRP from top to bottom but the specimens with H/D 3or 5 were exhibit localized rupture in AFRP, as shown in Figure 7.

Figure 7: The effect of slenderness ratio [8]
In (2016) Xie and Ozbakkalogu, [10] studies the effect of cross-sectional shape on the behavior of concrete-filled fiber tubes under axial compression. So, they studied the cross-section of the specimen (circular or square). The dimension of circular specimens (152.5mm diameter × 305mm height) and the square cross-section specimens had an angular radius of 30mm. The confined specimens' results exhibited rupture FRP at a mid-high of circular specimens and rupture FRP near one of the corners of the square specimen as a failure mode. Furthermore, the specimens with square cross-section gave lower hoop rupture strain $\varepsilon_{h,up}$ compared with the circular cross-section specimens.

In (2016) Ozbakkaloglu and Xie, [11] studies the effect of cross-section shape on the behavior of confined specimens. Where, they studied the shape of the circular and square cross-section. The specimens with dimensions (152.5 mm diameter× 305 mm height), and rounded corner by radius 30mm for square specimens. Test results indicated that for the concrete with a circular cross-section specimens were fail with rupture FRP at the mid-high region, while the square cross-section specimens exhibit rupture FRP near one of the corners. Also, the square specimens exhibit higher hoop rupture strain at flat sides compared by corners. The specimens with a circular cross-sectional were exhibited higher strength and axial strain than the square specimens.

In (2020) Faleschini, et al. [15] present an experimental study on the behavior of reinforced concrete columns, confined by textile carbon fiber reinforced with cementitious material (FRCM) under axial compression load. The specimens were confined 28 days after casting it, and tested (10 and 14) days after confinement. The most important variables included the cross-sectional shape, square H 1000 mm × b 300 mm, and circular H 1000 mm high × D 300 mm. The results showed that the technique of confinement by (FRCM) gave a noteworthy improvement in behavior for each cross-sectional shape of the columns. So, the behavior of the specimens with a circular section was better than the specimens with a square section, as shown in Figure 8.

![Figure 8: The effect of cross-sectional shape](image)

4. Effect of material types of FRP tube

In (2014) Yu, et al. [9], studied the effect of material type of fiber tube on the behavior of the fiber-reinforced polymer confined self-compact concrete, tested under axial compressive. So, the variables included the type of fiber-reinforced polymer (carbon, and glass). The specimens were prepared with a circular cross-section. The results were shown that all specimens failed with rupture in the hoop direction accompanied by a sudden drop in axial load. The behavior of specimens confined by CFRP exhibited increasing in ultimate axial stress and deformation capacity, than the specimens confined by GFRP.
In (2016) Xie and Ozbakkalogu [10], studied the effect of fiber tube material type on behavior of concrete-filled fiber tube under axial compression. So, they studied, carbon and basalt fiber reinforced polymer (CFRP and BFRP). The results were shown that the specimens confined by CFRP exhibited an increase in compressive strength and decreasing in ultimate axial strain compared with the specimens confined by BFRP.

In (2016) Ozbakkaloglu and Xie [11], presented a study about the effect of type of fiber tube material on compressive behavior of concrete-filled fiber tube. The type of fiber tube studied (carbon CFRP, basalt BFRP, and S-glass GFRP). The results showed that the CFRP exhibit higher strength and axial strain than the other types of fiber tubes but, S-glass fiber gave hoop rupture strain higher than the remaining types of fibers (CFRP or BFRP).

In (2019) Alzeebaree R., et al. [12], studied the effect of the sulfuric attack on compressive strength and durability of specimens confined with fiber-reinforced polymer FRP at static and cyclic load. Standard dimensions of circular specimens were (100mm diameter ×200mm height). Investigated parameter included the type of FRP (i.e. carbon CFRP or basalt BFRP). So, with the melting of epoxy adhesive between the layers of carbon fiber and basalt fiber, the color of the fabrics turned to a grayish-white color, and the basalt fiber was more white than the carbon fiber, this indicates that BFRP was more effected by acid attacks. So, the CFRP exhibited higher resistance for acid than the BFRP.

In (2020) Estevan, et al. [16], studied the behavior of masonry rocks confined under an axial compression load. The total number of specimens is 32, with dimensions 83 mm diameter × 218 mm height, and each specimen consists of three pieces of rocks with dimensions of 83 mm diameter × 70 mm height bonded by two layers of lime mortar with a thickness of 4 mm. The study variables included confinement of masonry rocks with two different types of compounds, including carbon and glass unidirectional fiber, quad axial glass fiber, reinforced with epoxy adhesive matrix (CFRP, GFRP), the basalt and glass fiber mesh reinforced with cementitious materials FRCM, as shown in Figure (9).

![Figure 9: Types of fiber fabric](image)

(a) (b) (c) (d) (e)

The results indicated that the unidirectional CFRP and GFRP gave a significant improvement in axial stress and deformation capacity better than quad axial glass fiber, which was estimated at (2 and 10-times) respectively. On the other hand, the basalt and glass fiber mesh reinforced with cementitious materials FRCM gave limited confinement strength of up to 26% of the unconfined masonry rocks, and the basalt fiber mesh is better than that of glass fiber mesh, as shown in Figure (10).
Figure 10: Effect of the different types of fiber fabric on the behavior of confined masonry stone [16]

5. Effect of types of confined concrete

In (2014) Yu, et al. [9], studied the behavior of the fiber-reinforced polymer confined self-compact concrete (FRP-confined SCC), tested under axial compression. The main variables included the strength of concrete (29.6, 47.0, and 105.0) MPa. Twenty four specimens were prepared with circular cross-section 152.5mm diameter × 305mm height, divided by three series according to the strength of concrete. The results were shown that all confined specimens exhibited increasing in ultimate axial stress and ultimate axial strain with an increase in strength of unconfined concrete specimens. Therefore, the specimens that (105 MPa) compressive strength provided higher axial stress and axial strain than the specimens that 30 MPa compressive strength.

In (2015) Xie and Ozbakkalogu [17], studied the influence of high strength concrete reinforced by steel fiber, including two types of concrete was studied the firstly high strength concrete reinforced with steel fiber (SFRHSCFFT). The second was slurry infiltrated fiber concrete with steel fiber (SIFCONFFT), on compression behavior. That prepared with circular cross-section confinement via 4-layers of aramid fiber tube AFRP. So, studied the effect of different forms of steel fiber, included hooked-end, or crimped), also studied the effect of length/diameter ratio of steel fiber (aspect ratio, As=Lf/Df) included (37, 44 and 67), volume fraction included (0%, 1.5%, and 2.5% for HSCFFT, and 0% or 5% for SIFCONFFT) of steel fiber were examined. The test results were proved that the presence of steel fiber in concrete gave rising of strength, ultimate strain, and hoop rupture of confined specimens. So, the specimens exhibited higher compressive strength and ultimate strain with the raise volume fraction of steel fiber and decreasing with increasing the aspect ratio. Hence, the SIFCONFFT specimens with volume fraction 5%, the SFRHSCFFT specimens with volume fraction and aspect ratio of (2.5% and 37) respectively, gave a higher strength and ultimate strain compared with other specimens. Also, the hooked-end steel fiber was obtaining a higher ultimate condition than the crimped steel fiber. Also, exhibit higher hoop strain rupture compared with the crimped steel fiber specimens.
In (2016) Xie and Ozbakkalogu [10], studied the behavior of recycled aggregate concrete (RAC) filled fiber tube under axial compression. The main parameters included in this study were replacement proportions of RCA% of (0%, 50%, and 100%), and compressive strength of unconfined specimens, i.e. normal and high strength concrete (NSC and HSC), about (40 and 70) MPa at age 28 days respectively. The results of unconfined specimens indicated that increasing the replacement ratios of RAC caused decreasing in strength and increasing in ultimate axial strain. While, the confined specimens' results exhibited increasing content of RAC% in concrete led to decrease in axial strength enhancement ratio, and axial deformation capacity. Also, was caused an increase in ultimate strain. Finally, at any limited amount of confinement, the axial stress enhancement ratio, axial strain enhancement ratio, and hoop rupture strain decreased with increased compressive strength of unconfined concrete.

In (2016) Ozbakkaloglu and Xie [11], presented a study about the compressive behavior of geopolymer filled fiber tube. The variables included the type of concrete, ordinary Portland concrete, and geopolymer concrete (OPC and GPC). Compressive strength for each type of concrete (OPC or GPC) was constant at about 25 MPa at 28 days. Test results indicated that each type of concrete (OPC or GPC) was developed the same hoop rupture strain. It is worth noting that types of concrete utilized in this study (OPC or GPC) did not affect overall compressive strength, which exhibited comparable strength enhancement ratio for both types of concrete at the same amount of confinement.

In (2019) Alzeebaree R. et al. [12], studied the effect of a sulfuric attack on compressive strength and durability of geopolymer concrete and ordinary Portland concrete (GPC and OPC) specimens confined/unconfined with fiber-reinforced polymer tube at static and cyclic load. Standard dimensions of specimens were (100mm diameter ×200mm height). Geopolymer concrete GPC cured at heat temperature (70°C for 48h), then demolded and remains at room temperature until the testing day. The results illustrated that the confined/unconfined-GPC specimens exhibited higher resistance of sulfuric attack than the OPC specimens. After exposure to sulfuric attack for 90 days, the OPC/GPC-confined specimens showed decreasing in compression strength compared with unexposed and confined specimens. Thus, GPC specimens are more strong and durable than OPC specimens, as shown in Figure 11.

![Figure 11: Compressive strength of GPC and OPC specimens [12]](image)

In (2019) Chan, et al. [13] studied the behavior of rubber concrete confined by glass fiber reinforced polymer tube under axial compressive load. Fourteen specimens were prepared and cast. The most important parameter that was studied is the percentage of replacing aggregate with rubber crumb (0%, 12.5%, 25%, 50%, and 75%) by volume. The results indicated that confining the rubber concrete by the glass fiber tube led to a significant improvement in its behavior, also increased in axial stress enhancement ratio and axial deformation capacity, as shown in Figure 12.
In (2020) Usman, et al. [14] presented an experimental study on the axial compression behavior of confined specimens of high-strength concrete reinforced with steel fibers. The main variables studied were the volume fraction of added hooked-end steel fibers (0.5%, 1.5%, and 2.5%). The specimens were casting with dimension 300 mm high × 150 mm diameter. After 28 days of curing, the specimens were wrapped with carbon fiber fabric and then examined under axial compression load. The results indicated that the best volume fraction addition of steel fibers 2.5%, which gave the best improvement in compressive strength and post-peak behavior of the specimens, as caused an increase in ultimate strain, that shown in Figure 13.

6. Conclusion
From the previous brief review of some research, which covered the four main axes, included that the effects of the number of layers of the fiber tube, the cross-sectional shape and slenderness ratio, material types of the fiber tube, and the types of confined concrete, we can conclude with the following observations:

1. For any material type of fiber-reinforced polymer tube, the axial stress and deformation capacity of confined specimens increases with the increase in the number of fiber tube layers, resulting in a significant improvement in the behavior of confined specimens.
2. Confined circular cross-section specimens exhibited better behavior than square cross-section specimens. Also, the behavior of confined square specimen improvement with increasing the angular radius.

3. Fiber-reinforced polymer (FRP) tubes or mesh fiber reinforced by cementitious material (FRCM) gave a significant improvement in confined specimen behavior. So, FRP showed improvement in specimens' behavior higher than FRCM. Moreover, the carbon fiber fabric tube is better than other types (i.e. aramid, glass, and basalt).

4. The concrete confining technique significantly improved the behavior of specimens regardless of the type of concrete confined. It is worth noting that the effect of confining decreases with the increase in compressive strength of the concrete confined.

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