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AXIAL COMPRESSIVE BEHAVIOR OF NON-BONDED NATURAL FIBER ROPE-CONFINED CONCRETE: EXPERIMENTAL STUDY

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Abstract- In this research, an experimental investigation was carried out to determine the compressive behavior of normal (20 MPa) and medium (40 MPa) strength plain concrete confined by non-bonded cotton fiber rope reinforced polymer (FRRP). For this purpose, a total of 20 circular concrete cylinders were tested monotonically under axial compression. The study parameters covered the number of FRRP layers, strength of concrete and FRRP spiral spacing. Experimental results showed that the non-bonded manually wrapped cotton FRRP significantly enhanced the axial deformation of both normal (20 MPa) and medium (40 MPa) strength concrete, although less improvement was observed in the ultimate strength. The results also indicated that the effectiveness of cotton FRRP decreases with an increase in strength of concrete, increases with an increase of the FRRP layers and decreases with an increase of spiral spacing. Overall, the use of non-bonded manually wrapped cotton fiber ropes can result in improving the axial load and deformation capacity of concrete specimens.

Keywords- Axial stress-strain behavior, cotton FRRP layers, strength of concrete and cotton FRRP spacing.

1 Introduction

The reinforcement of old concrete buildings is needed by modification in demands regarding its use and loading conditions [1]. To date, numerous approaches have been used in a successful way to reinforce a given structure [2]. In the early stages of retrofitting, steel and concrete jacketing was widely used for the confinement of concrete columns. However, these confining materials have some serious issues including their physical properties such as weight, corrosion problems, enlarging the column sizes and long casting period due to their curing requirements.

In recent decades, synthetic fiber reinforced polymer (FRP) composites have been introduced. Various features and advantages regarding the application of these FRPs on RC columns, beams etc. have been thoroughly investigated, both in analytical and experimental way [3-4]. The benefits of these FRPs are high resilience, high tensile properties, lightness in weight, and straightforward application. Different types of synthetic FRPs such as carbon, aramid etc. have been used systematically for the repairing of structures and strengthening of RC components [5-8]. Typically, these FRPs are applied to the structural members externally by mixing enough resin with it. Rochette and Labossiere [9] studied the strengthening performance of the aramid and carbon FRPs for the enhancement in compressive stress-strain behavior of both rectangular and square concrete columns. A remarkable increase in compressive strength and strain of these FRP-confined square and concrete columns was reported.

The proposal to use natural fiber reinforced polymer (NFRP) to strengthen the concrete structures was given by Triantafillou et al. in 2006 [10]. The axial compressive behavior of concrete confined by NFRP composite [11-12] was recently studied by Pimanmas et al. [11] and Yan [12]. It was concluded that NFRP composites were very successful in altering the confined concrete's behavior. The main advantages of NFRP are that these materials are eco-friendly, sustainable, and cheap, along with reduced respiratory disorder. Despite the fact that these NFRPs have been shown to be effective in enhancing the ultimate stress, strain and ductility of concrete members [13-15], in many countries of the globe the production of these natural fibres particularly in the fabric's form, is still a problem.

In contrast to the above-mentioned studies in which the concrete columns were usually confined by fabric sheets of FRPs, the use of non-bonded vinyl and polypropylene fiber ropes as external confinement was explored by Rousakis [16-17]. The widespread features of rope confinement are readily accessible, easy to use, affordable and friendly in environment. The research findings showed that these non-bonded fiber ropes were very effective in improving the confined concrete's ultimate stress and strain. The use of epoxy bonded natural and synthetic fiber ropes (hemp, cotton, and polyester) as an external confinement was also explored by Hussain et al. [18]. It was observed that these ropes exhibited high efficiency in enhancing the ultimate compressive stress, strain and ductility of the confined concrete.

The aim of present study is to extend the study of concrete confinement in which non-bonded natural fiber (cotton) ropes are used as a confining material. In this regard, the effect of concrete strength, number of FRRP layers and spiral spacing on the stress-strain response is observed in detail. The research findings can be helpful in developing retrofitting schemes in which locally manufactured low-cost cotton fiber ropes can be satisfactorily used instead of imported and costly synthetic FRPs which also require high skilled labor.

2. Experimental Program

In this study, a total of 20 concrete cylindrical specimens were prepared out of which 12 specimens were confined with cotton FRRPs and remaining were the control specimens. The parameters used in this study were the compressive strength of concrete, the number of FRRP layers and the pitch distance in case of spiral wrapping. Table 1 gives the details of research specimens. The diameter and height of the specimens was 150 and 300 mm, respectively, as shown in Figure 1. All the specimens were prepared in 4 batches. The concrete specimens that were prepared in first 2 batches had compressive strengths of (20 MPa) and the specimens of remaining 2 batches had compressive strength of (40MPa). After fulfilling the curing requirements at 28 days, the top and bottom sides of the cylinders were made smooth and flat with the help of concrete cutting machine. The labeling of specimens is done as XNYM in which X represents the type of rope used as FRRP (C for cotton); N indicates concrete's compressive strength (20 for 20 MPa and 40 for 40 MPa); Y represents the type of wrapping (F for Full and S for spiral); and the last alphabet M indicates the number of rope layers. For example, C40F2 designates that this specimen has compressive strength of 40 MPa and is fully wrapped with two layers of cotton rope. The controlled specimens are simply labeled as XN, in which X represents control and N represents the compressive strength of the concrete.

Table 1-Details of experimental test matrix

Sr. no.	Designation	Identical specimens	Confining material	Wrapping type	No. of layers	Pitch distance (cm)
1	X20	4	-	-	-	-
2	X40	4	-	-	-	-
3	C20F1	2	Cotton	Full	1	0
4	C20F2	2	Cotton	Full	2	0
5	C20S1	2	Cotton	Spiral	1	1
6	C40F1	2	Cotton	Full	1	0
7	C40F2	2	Cotton	Full	2	0
8	C40S1	2	Cotton	Spiral	1	1

2.1 Concrete

The details of the concrete mix proportions are given in Table 2 and Table 3. Concrete cylinders of two different strengths were prepared in the laboratory. The ingredients of concrete were mixed by using mechanical mixer. Due the limited mixing capacity of the mixer, concrete cylinders were prepared in four different batches. In the first two batches, ten concrete specimens of strength 20 MPa were cast and in the last two batches, remaining concrete specimens of strength 40 MPa were cast. For each batch, two similar control specimens were also prepared and tested along with their confined parts to find their unconfined compressive strength f_{co}.

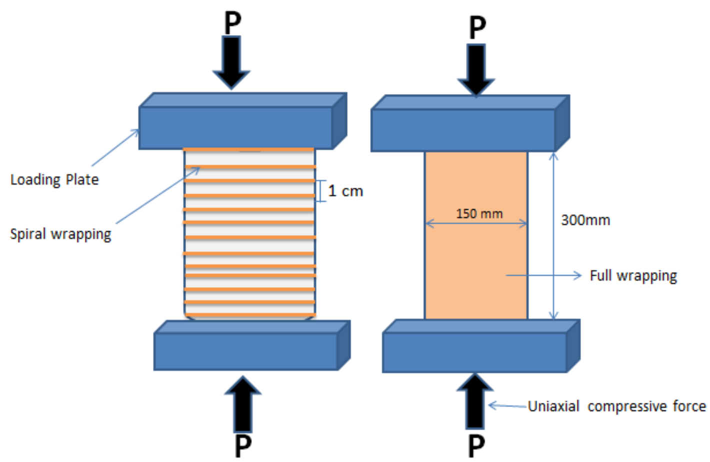


Figure 1: Schematic diagram of concrete specimens showing spiral and full FRRP wrapping

2.2 Cotton FRRP wrapping

After having prepared the concrete cylinders, the specimens were confined with cotton ropes. The diameter of the cotton rope, used as an external confinement, was 3 mm. The specimens were wrapped fully and spirally, as shown in Figure 2a. A pitch distance of 1 cm was used in case of spiral wrapping. To avoid premature failure of the confined specimens during the test, the top and bottom ends of the cylinders were additionally wrapped by providing 25 mm strip of the cotton rope bonded with high strength epoxy resin.

2.3 Test setup

In this experimental study, all the concrete specimens were tested under monotonic axial compression with the help of universal testing machine (UTM) having a capacity of 2000 kN, as shown in Figure 2b. Due to limited instrumentation available, axial deformation was noted with the help of two dial gauge meters. Load was applied axially at the rate of 2.5 kN/sec and the deformation was recorded after every 10 sec.

Figure 2: Specimens wrapping and instrumentation details, a. cotton FRRP wrapped specimens, and b. instrumentation and loading setup

Table 2-Concrete mix proportion for 20MPa

Item	Value
Cement (kg/m^3)	301.47
Sand (kg/m^3)	772.194
Coarse aggregates (kg/m^3)	1020
Water (kg/m^3)	195.95
Water/cement ratio (kg/m^3)	0.65
Maximum aggregate size (mm)	20

Table 3- Concrete mix proportion for 40MPa

Item	Value
Cement (kg/m^3)	500
Sand (kg/m^3)	609.654
Coarse aggregates (kg/m^3)	1020
Water (kg/m^3)	250
Water/cement ratio (kg/m^3)	0.5
Maximum aggregate size (mm)	20

3. Research Methodology

The casting and preparation of concrete specimens was done in the initial stage of the research. These specimens were then wrapped manually with the cotton FRRPs without using any epoxy coating for its binding with concrete surface. To avoid stress concentration, 25 mm cotton strip along with high strength epoxy was provided on top and bottom ends of the cylinders. After preparation, testing of all cylinders was done by applying pure compressive load with the help of UTM. Experimental results of the confined specimens including stress-strain curves were obtained. At the last, analysis and comparative study of the stress-strain curves obtained by testing these specimens was done using various research parameters.

4. Test Results

4.1 Stress-strain response

Initially, for both the normal strength (20 MPa) and medium strength (40 MPa) concrete, the stress- strain curve followed an ascending branch reaching up to the unconfined concrete strength, f_{co}. After reaching f_{co}, a sudden significant drop in axial strength was observed because of growth of concrete cracks and inadequate confinement of cotton FRRPs at this moment. After reaching the maximum drop when concrete core dilated enough to engage the FRRP confining pressure, the curve of normal strength concrete ascended almost linearly depending on the number of FRRP layers, while curve of medium strength concrete followed an almost a uniform straight plateau. In case of spiral wrapping, the curve for both normal and medium strength concrete descended gradually after the maximum stress drop point. In general, the overall response of non-bonded cotton FRRP confined concrete can be classified as trilinear.

4.2 Effects of FRRP layers

The stress-strain response of both normal and medium strength FRRP confined concrete cylinders are shown in Figure 3. For both types of concrete strength, it was observed that the last part of the curve greatly enhanced with an increase in FRRP layers. In the normal concrete strength specimens confined by one or two FRRP layers, a similar drop in strength after the unconfined peak strength was observed which shows that the external confinement of non-bonded ropes is not sufficiently activated yet. After the maximum drop, curves of both specimens ascended again indicating that the ropes are strained enough to provide enough confining pressure until their failure. For double layer of FRRP, the ultimate stress was about 18 MPa compared to the 12 MPa of single FRRP. Similarly, in case of specimens confined with single layer of FRRP the ultimate strain was 10%, whereas in specimens with two layers of FRRPs the ultimate strain was observed to be 18% (Figure 3a). In case of medium strength concrete specimens, the external confinement of single FRRP layer was not enough to maintain the load after the sudden drop. In these specimens, the strength was observed to be continuously decreased at a slow rate with an increase in axial deformation until their failure. In specimens confined by two FRRPs layers, a long approximately horizontal plateau is observed indicating that the strength is efficiently sustained even at high axial deformation of about 24% (Figure 3b). In contrast, Hussain et al. observed relatively less strength softening in epoxy bonded cotton rope confined circular specimens [18]. A significant drop in strength after the peak load was also observed by Rousakis for specimens confined by three full layers of non-bonded polypropylene fiber ropes [17]. In case of spiral confinement, the strength could not be sustained after the maximum drop; however, the specimens failed at high axial deformation compared to the control specimens. Effect of FRRP layers on ultimate axial stress and strain is shown in Figures 4 and 5, respectively.

4.3 Effect of concrete strength

It can be observed from Figure 6 that the effectiveness of FRRP confinement is less for medium strength concrete specimens compared to the normal strength concrete specimens. This observation agrees with the previous findings of Ozbakkaloglu and Vincent (2014) for carbon FRP confined concrete [19] and Wahab et al. (2019) for their specimens confined by jute and polyester hybrid confinement [20]. In general, a higher drop after the peak strength is observed for specimens with medium concrete strength. In specimens confined by single layer of FRRP, the curve after the maximum drop slightly ascended again in normal strength concrete, whereas in specimen with medium strength concrete the curve descended gradually until the FRRP failure (Figure 6a). In case of two layered specimens, the curve in normal concrete specimens ascended near to the peak strength, whereas in specimens with medium strength concrete the load was efficiently sustained at high axial deformation (Figure 6b). Interestingly, the specimens with medium concrete strength exhibited higher axial deformation compared to the normal strength concrete specimens. In case of spiral wrapping, a similar response is observed in both concrete specimens except that a higher drop is observed for medium strength concrete specimen, see (Figure 6c). Effects of concrete strength on ultimate axial stress and strain are shown in Figures 7 and 8, respectively.

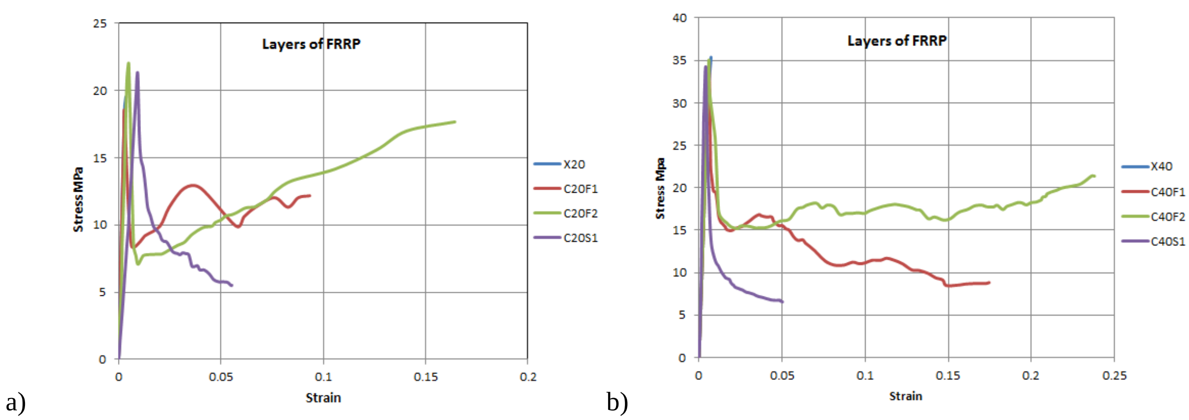
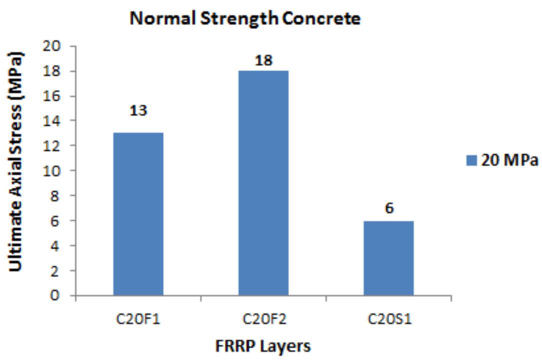


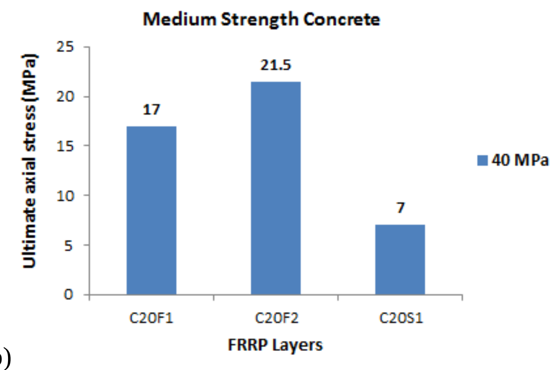
Figure 3: Effect of FRRP layers on stress-strain response, a. normal strength concrete, 20MPa, and b. medium strength concrete, 40MPa

4.4 Effect of FRRP spacing

Figures 9a and b represent the effect of FRRP spacing on the stress-strain response of normal and medium strength concrete. For 20 MPa concrete, the reduced effective confinement of spiral FRRP could not sustained the load after drop in peak strength and exhibited a descending branch until failure at about 5%, whereas in specimens with full FRRP wrapping the confining pressure was enough to sustain the load even at higher axial deformation of about 9% (Figure 9a). On the other hand, for 40 MPa concrete, although full wrapping of FRRP could not sustained the load after the sudden drop, however, it exhibited a gradual strength softening and failed at high axial strain of 17% compared to the 5% failure strain of spirally confined concrete (Figure 9b). Effect of FRRP spacing on ultimate axial stress and strain is shown in Figures 10 and 11, respectively.

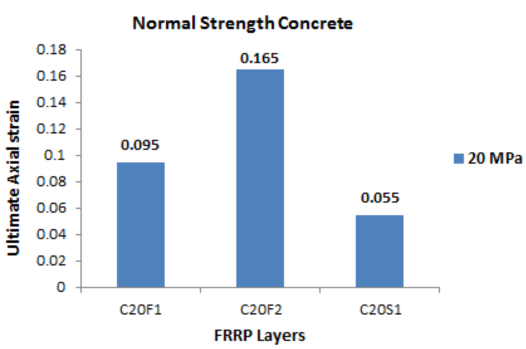


a)

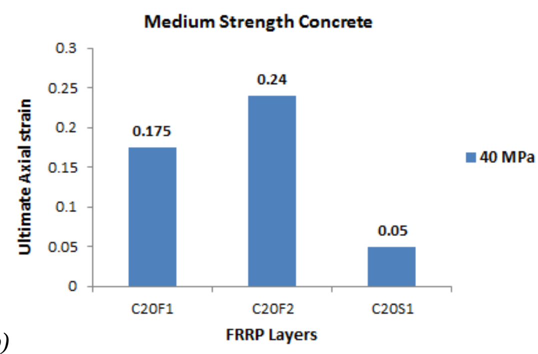


b)

Figure 4: Effect of FRRP layers on ultimate axial stress, a. normal strength concrete, and b. medium strength concrete



a)



b)

Figure 5: Effect of FRRP layers on ultimate axial strain, a. normal strength concrete, and b. medium strength concrete

4.5 Ultimate failure modes

The ultimate failure modes of the unconfined and FRRP confined concrete specimens are shown in Figures 12 and 13. The un-strengthened specimens failed in a conventional way by concrete crushing at peak compressive stress. Whereas the cotton FRRP strengthened specimens were failed by the tensile rupture of cotton FRRPs. The tensile rupture of the cotton FRRPs started in the periphery of epoxy bonded cotton strips provided at the top and the bottom, and then the splitting of FRRPs was very gradual during the ultimate failure. The failure was very quiet even in case of double FRRP layers for both normal and medium strength concrete.

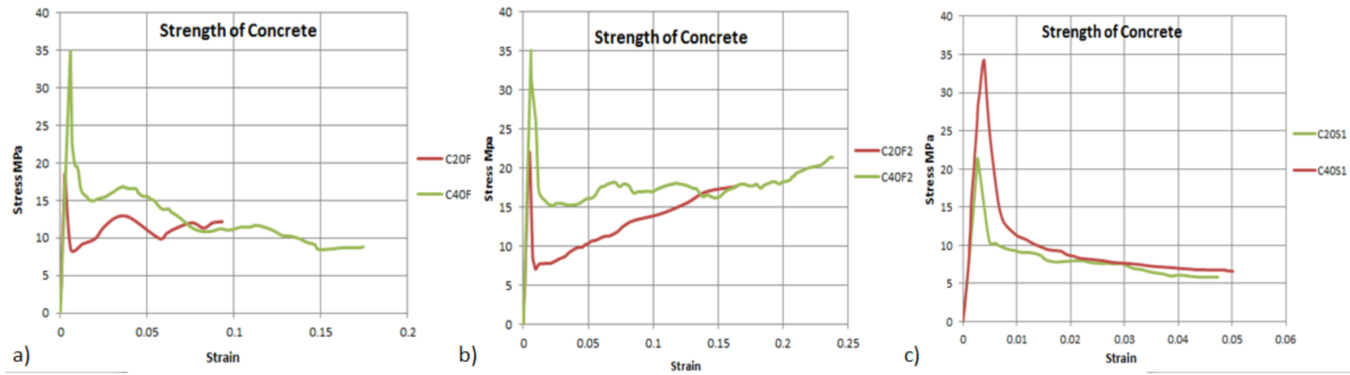


Figure 6: Effect of concrete strength on stress-strain response, a. single layer of FRRP, b. double layer of FRRP, and c. spiral layer

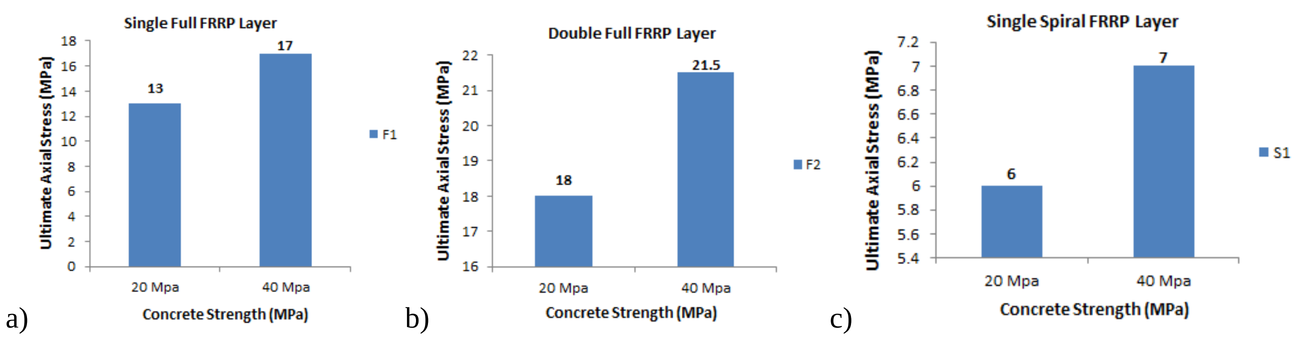


Figure 7: Effect of concrete strength on ultimate axial stress, a. single layer of FRRP, b. double layer of FRRP, and c. spiral layer

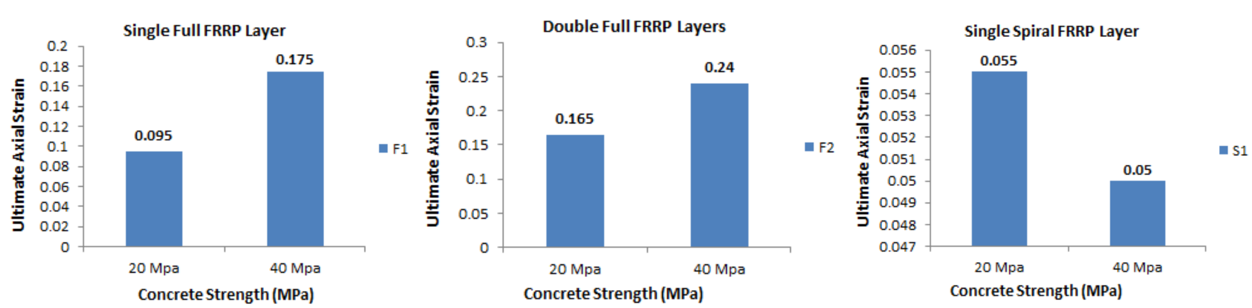


Figure 8: Effect of concrete strength on ultimate axial strain, a. single layer of FRRP, b. double layer of FRRP, and c. spiral layer

Conclusions

This research study includes an experimental work to comprehend the compressive behavior of both normal and medium strength concrete confined with non-bonded cotton FRRP in circular columns. For this purpose, a total of 20 specimens were tested under monotonic axial compressive. The parameters used were number of FRRP layers, concrete strength and FRRP spiral spacing. The conclusions are being summarized as follows:

- Axial stress-strain behavior of non-bonded FRRP confined concrete is trilinear in which the post-peak response was improved with an increase in the FRRP layers.

- For medium strength concrete, the FRRP confinement is less effective compared to normal strength concrete. For a particular number of FRRP layers, higher strength softening was observed in medium strength concrete specimens compared to the normal strength concrete.
- FRRP spiral wrapping technique is found not effective in enhancing the post peak behavior for both normal and medium strength concrete, however, it prevented the brittle collapse of concrete up to high axial deformation

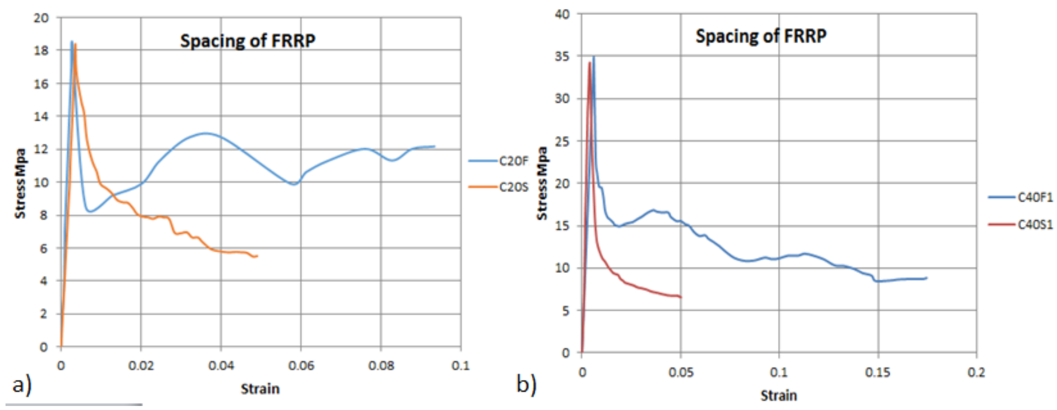


Figure 9: Effect of FRRP Spacing on stress-strain response, a. normal strength concrete, and b. medium strength concrete

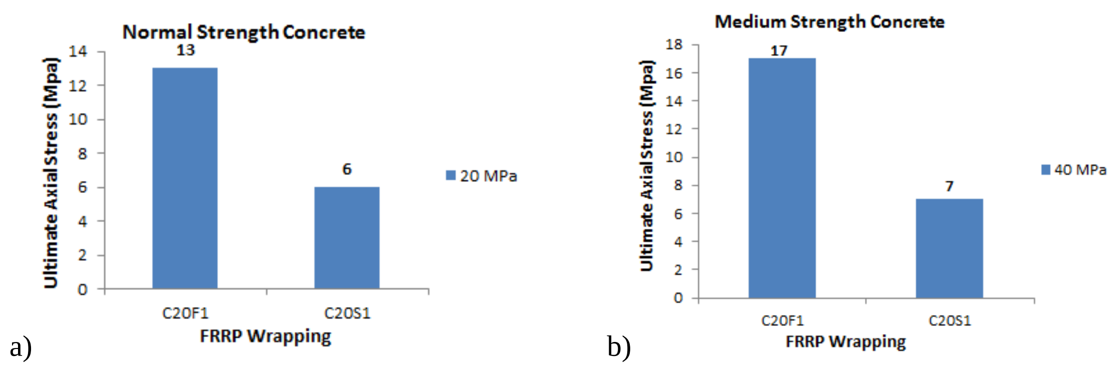


Figure 10: Effect of FRRP Spacing on ultimate axial stress, a. normal strength concrete, and b. medium strength concrete

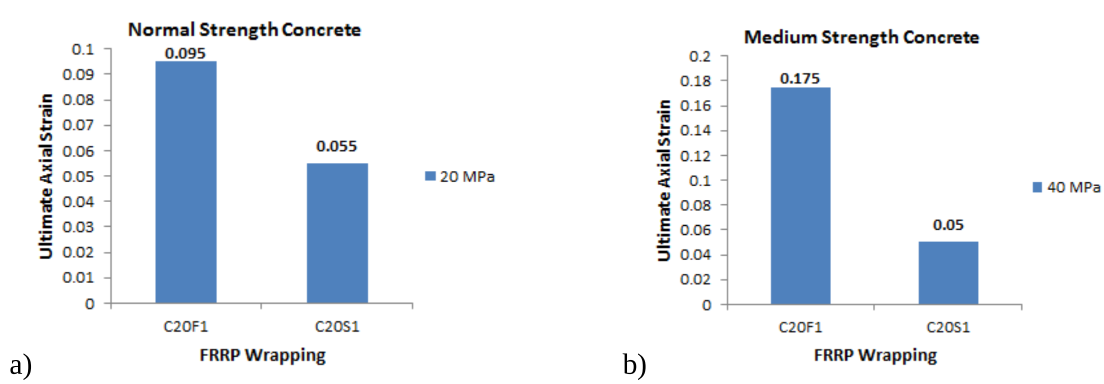


Figure 11: Effect of FRRP Spacing on ultimate axial strain, a. normal strength concrete, and b. medium strength concrete

Figure 12: Typical failure modes of 20 MPa FRRP specimens, a. control specimen, b. full single layer, and c. full double layers and d) spiral layer.

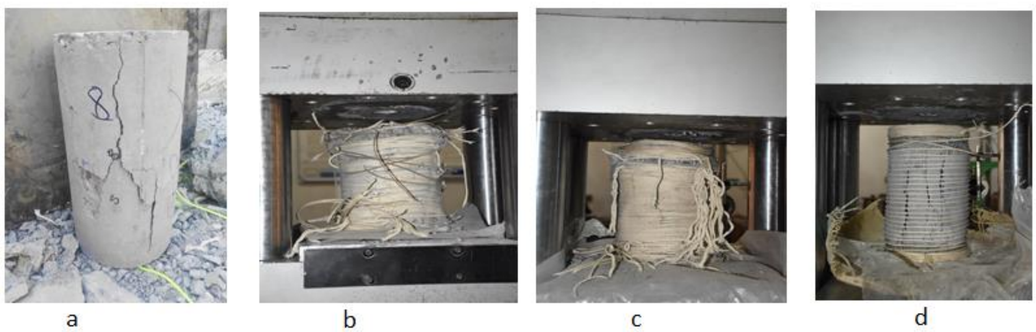


Figure 13: Typical failure modes of 40 MPa FRRP specimens, a. control, b. full single layer, c. full double layers, and d. spiral layer.

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