ACTIVE CFRP-BASED CONFINEMENT STRATEGIES FOR RC COLUMNS WITH RECTANGULAR CROSS SECTIONS

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Abstract

FRP wrapping is a strengthening technique for RC columns mostly used when a significant confinement increase is required. This technique is extremely effective in the case of circular cross-sections, but of marginally effectiveness for rectangular cross-sections columns. The use of post-tensioned CFRP jackets was an attempt to improve the confinement effectiveness for rectangular RC columns, but the level of success has been quite limited.

This paper analyzes the viability of using an expansive resin to introduce some level of post-tension in CFRP jacket. In a first step, the optimal percentage of water added to trigger the resin expansion was analyzed. Using the obtained optimal value of water, the influence on the level of jacket post-tension of the width of the gap between the concrete surface and the CFRP jacket was investigated, and its time-dependent sensitivity was assessed. Finally, the compression behaviour of specimens confined with this technique was assessed by performing experimental tests. The obtained results revealed that the adopted expansive resin is not an effective technique to assure high levels of post-tension in CFRP jackets for the concrete confinement.

Keywords: Rehabilitation, Strengthening, Confinement, Fibre Reinforced Polymers (FRP).

1. Introduction

Previous experimental research conducted on the use of fibre reinforced polymer (FRP) fabrics for the confinement of reinforced concrete (RC) columns has shown that a significant increase on the load carrying capacity is attained in columns of circular cross section [1,2,3]. These studies also proved that for rectangular cross-section columns, there is a loss of concrete confinement effectiveness that increases with the height/wide ratio of the column's cross section. Even for circular RC columns, it was observed that a significant increase on the load carrying capacity, provided by carbon fibre reinforced polymer (CFRP) confinement arrangements, can only be achieved for column's axial deformation much higher than

The limit value generally accepted as corresponding to unconfined concrete crushing [2]. To overcome these drawbacks, it was decided to study the possibility of applying a certain level of post-tension to the FRP fabrics, in order to obtain an active confinement, aiming to achieve a significant lateral confinement in the column for deformation levels below the strain corresponding to the unconfined concrete compressive strength [4,5]. The resulting increase of axial load carrying capacity of active confined RC columns is directly related to the level of post-tension applied to the FRP material [5]. Moreover, the level of post-tension is limited by several factors, mainly those related to the geometric singularities in rectangular cross sections of columns, which promote the occurrence of stress concentrations that leads to the local failure of the FRP fabrics.

In the experimental work herein described, the effectiveness of the active confinement due to the use of an expansive resin is explored. Research was conducted using cubic specimens confined with distinct FRP post-tensioned solutions. Carrying out compression tests, the effectiveness of this technique was assessed by measuring the increment of the load carrying capacity of tested specimens. The strains in the CFRP fabrics were also measured. The experimental program is described, and the main results are presented and discussed.

2. Experimental Program

2.1 Materials

A concrete with an average uniaxial compressive strength of 42 MPa was used to produce the specimens.

Unidirectional CFRP fabrics were adopted. The material properties, given by the manufacturer, are indicated in Table 1, where f_{tk} is the characteristic value of the tensile strength, E_{tK} is the characteristic value of the elastic modulus, and ε_{tk} is the characteristic value of the ultimate tensile strain.

Table 1: Material Properties of CFRP.

Fibre type	Thickness (mm)	f_{tk} (MPa)	E_{tk} (GPa)	ε_{tk} (mm/m)
300/300	0.172	3860	242	15

The adopted expansive resin is composed by two components: A (base); and B (hardener). This resin presents (Table 2): low viscosity; fast hardening; high stability; foams in contact with water, with a volume increase up to ten-times the original volume.

Table 2: Technical data for Resin.

Characteristic	Unit	Value	Standard	Comments
Density	g/cm³	1.13	DIN 53 479	at 20 ºC and 50 % relative humidity
Viscosity	MPa	Approx. 200 ± 50	DIN 53 018	at 20 ºC and 50 % relative humidity
Mixing ratio	p.b.v.	1:1	–	component A : component B
Pot life	Seconds	30	–	at 20 ºC and 50 % relative humidity
Lowest application temperature	ºC	+6	–	Temperature of structural part
Compressive strength	N/mm²	Approx. 40	DIN EN 196 T 1	at 20 ºC and 50 % relative humidity
Slant Shear Strength	N/mm²	Approx. 13.3	BS 6319, part 4	–
Flexural tensile strength	N/mm²	Approx. 3.5	DIN EN 196 T 1	–
Volume expansion in contact with water	–	1 – 10 times	–	Depending on counter-pressure

2.2 Tests Specimens

In the experimental program 11 different possible solutions to introduce some level of post-tension in the CFRP jackets were explored, see Table 3. The unreinforced concrete specimens (cubes of 150 mm edge) were strengthened according to the solutions presented in Figure 1. Due to the exploratory character of this experimental program, concrete specimens of relative reduced dimensions were adopted. The main objective of these tests was to measure the strain variation in the fibres direction of the CFRP jacket, caused by the expansion of the resin

The code adopted to identify the specimens has the following meaning: UR represents the reference unconfined specimen; BW is the specimen confined with inactive CFRP; PW indicates that the specimen is post-tensioned; The following two numbers indicate the water percentage adopted for the resin, while the last two numbers specifies the gap between the CFRP wrapping fabrics and the concrete specimens, in mm.

Table 3: Specimen details

Specimen identification code	Resin water %	Gap with (mm)	Connection type
UR	-	-	none
BW	-	-	bonded
PW04.05	4	5	pos-tensioned
PW04.06	4	6	pos-tensioned
PW04.07	4	7	pos-tensioned
PW05.05	5	5	pos-tensioned
PW05.06	5	6	pos-tensioned
PW05.07	5	7	pos-tensioned
PW07.05	7	5	pos-tensioned
PW07.06	7	6	pos-tensioned
PW07.07	7	7	pos-tensioned

The vertical corners of the concrete cubes were rounded with 20 mm radius to prevent damage at the CFRP fabrics, see Figure 1. To confine as much as possible the concrete cross-sectional area effectively confined Thériault and Neale [6] recommended for the minimum radius the value of b/6, where b is the edge of the square cross-section. However, Rochette and Labossière [7] reported that significant strength increase is achieved for wrapped prisms with corner radius of 25 mm. Masia *et al.* state that the strength and ductility of concrete columns strengthened by CFRP wrapping increase with the increase of the corner radius [8].

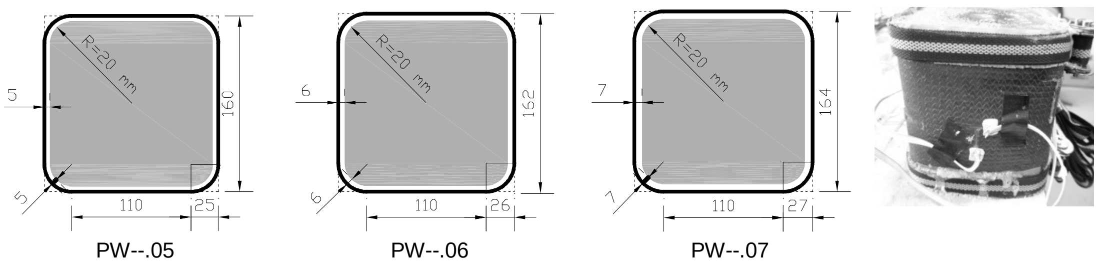

Figure 1: Wrapping dimensions (mm) for specimens with post-tensioned CFRP fabrics.

To prefabricate the CFRP jacket, a single CFRP layer, with the fibres in the horizontal direction, was first wrapped around a formwork. The latter presents the geometry of the concrete column plus the width of the gap needed to introduce the expansive resin. In order to provide a sufficient anchorage and prevent slip between layers, an overlap length of 100 mm was applied, proved to be sufficient for this purpose [7].

Afterwards the expansive resin was cast in the gap between the concrete specimen and the CFRP jacket. To minimize expansion in the vertical direction the following system is adopted: at each end of the specimen, a cork ring is placed to fully fill the space between the prefabricate jacket and the concrete specimen. The bottom ring is fixed, and the top ring could be removed to facilitate the resin introduction. Cork was chosen to allow some deformation to occur with the purpose of preventing cracking of the CFRP jacket during the application of the expansible resin. Immediately, before placing the prefabricate shells, a 0.1 mm thickness neoprene sheet is applied to prevent the resin from leaking during expansion. With a nylon strip and using a post-tension system, the bottom end of the CFRP jacket is pressed against the cork ring. After filling the space between the concrete specimens and the prefabricate jackets with the resin, the superior extremity is blocked using the mobile cork ring and the nylon strip. The expansion of the resin after adding water only leaves few minutes to carry out this procedure. Therefore, the speed of execution is very important for the success of the strengthening operation. Figure 2 illustrates the main phases of this CFRP post-tensioned method.

CFRP prefabricated post-tensioned jackets were used to strengthen the concrete specimens. Unstrengthened and strengthened with bonded CFRP were also considered situations to serve as reference.

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

Figure 2: Construction of the specimens with post-tensioned CFRP jackets: (a) the cork ring; (b) neoprene sheet; (c) Prefabricated precured CFRP jacket; (d) cork ring; (e) block of the bottom and top ends using a nylon strip with post tensioning system.

2.3 Loading and data acquisition

The specimens were subjected to monotonic uniaxial loading with displacement control considering a constant displacement rate of 15 µm/s up to failure. The specimens had an age of about 40 days when tested.

Strain gages bonded to the CFRP jacket, in the fibers direction, were used to measure the strains in the center of two opposite faces and at two opposite corners of the specimen, at middle height.

3. Results

The experimental program was developed in three different phases. In the first phase the optimal dosage of water was determined to expand the resin. In the second phase the post-tensioning of the CFRP jacket was measured, and in the last phase the specimen load carrying capacity was determined.

3.1 Control of the expansive resin

In contact with water, the resin volume increases up to 10 times. Several tests were conducted for different percentages of added water (in percentage of resin volume): 0%, 1.25%, 2%, 3%, 4%, 5% and 7%.

As Figures 3 and 4 show, the resin without any addition of water did not suffer expansion. With the increase of the percentage of added water, the resin´s volume also increased until an addition of 3% of water. For percentages higher than this limit, the resin´s increase of volume starts decreasing. It was also observed that with the increase of the water percentage, the exothermic reaction becomes faster and the size of the air bubbles formed inside the resin gets smaller. Associated to the highest volumetric expansion of the resin, corresponding to 2 to 4% of water addition, low volumetric stability was also registered.

0.00% 1.25% 2.00% 3.00% 4.00% 5.00% 7.00%

Figure 3: Resin expansion for several water percentages.

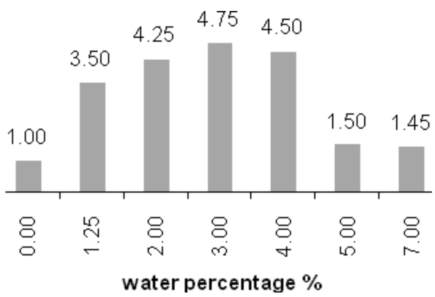

Figure 4: Resin volumetric expansion ratio versus added water percentage into the resin.

It was concluded that the mixture with 5% of water seems to have more volumetric stability, allowing a volume increase of approximately 50%. Therefore, 4%, 5% and 7% of added water into the resin were selected for the experimental program

3.2 Measurement of the fibre post-tension

The expansive resin was placed in the gap between the concrete specimen and the prefabricated CFRP jacket, in order to post-tension the jacket. The deformation of the CFRP jacket stabilized 1 hour after having been introduced the resin.

The expansion of CFRP jacket was measured in the centre of two opposites faces (Figure 5), in the horizontal and vertical direction, i.e., in the alignment and transverse direction of the fibres. In the corner of two opposite edges of the specimen, the horizontal strains were also recorded, Figure 6. The strain variation recorded by these strain gauges shows that 4% of water added to the resin assured more homogeneous strain field, regardless the width of the gap between the CFRP jacket and the concrete specimen. As it can be observed in the Figures 5 and 6, a gap of 7 mm with provided the highest transversal expansion.

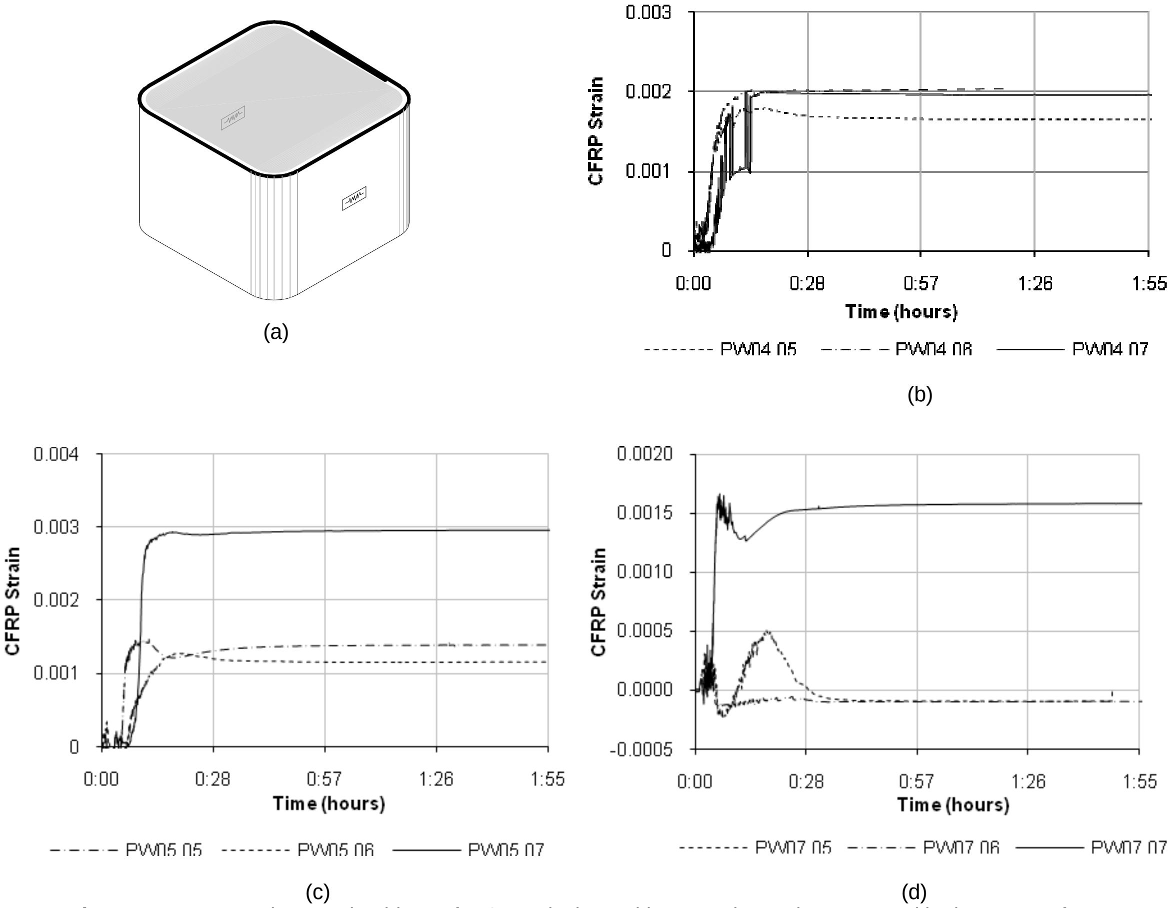

Figure 5: Transversal expansion history for CFRP jackets with expansive resin, measured in the centre of two opposite faces: (a) position of the horizontal strain gages; (b) PW04; (c) PW05; (d) PW07.

The highest strain values in the CFRP jacket provided by the adopted expansion resin systems were 0.003 and 0.0025 at the middle and at the corners of the specimen, respectively, and occurred at PW05.07 specimen, using the expansive resin with 5% of water in a gap of 7mm between the CFRP jacket and the concrete specimen, Figure 5 c) and Figure 6 c). This maximum strain level corresponds to 20% of the ultimate tensile strain of the adopted sheet of carbon fibres. The minimum strain level introduced in the CFRP jacket was recorded in the specimens with 7% of water added to the resin.

Negative strain values were measured for the transversal strains at the corners of the specimen, Figure 6. The higher volumetric expansion of the resin observed at the middle of each face of the CFRP jacket causes compression at the corners, Figure 7.

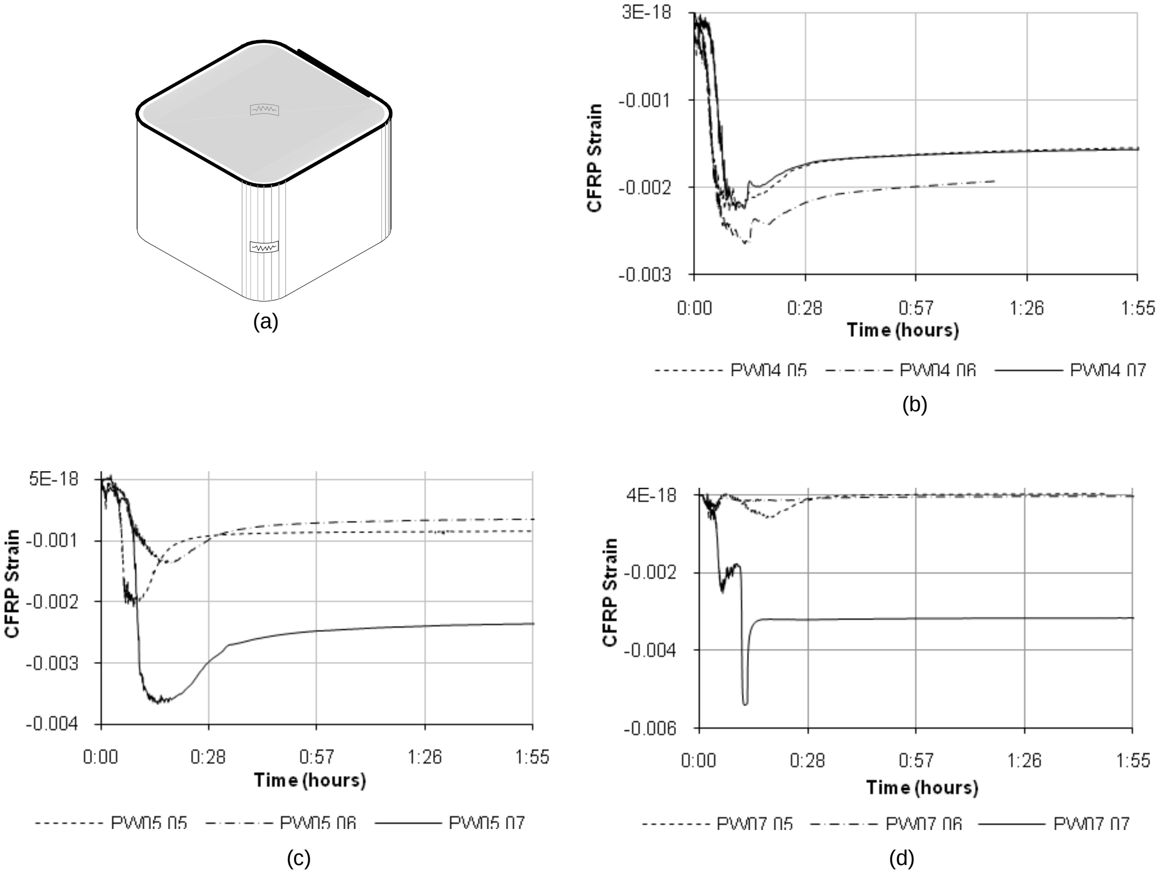

Figure 6: Evolution of transversal expansion with time for CFRP jackets with expansive resin, measured at the corner of two opposite edges: (a) position of the horizontal strain gages; (a) PW04; (b) PW05; (c) PW07.

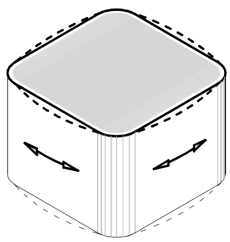

Figure 7: Deformation of the CFRP jacket with the expansion of the resin.

As expected, almost null values of vertical strains were measured at middle height of two opposite faces of the CFRP jacket. This was due to the reduced specimen´s height, 150 mm, and due to the fact that the fibres are placed horizontally, Figure 2.e).

3.3 Response of strengthened specimens to axial loading

Figure 8 shows the axial compressive strength registered in all tested specimens, after 14 days of having applied the post-tension system in the strengthened specimens. The stress-strain diagrams obtained in these tests are shown in Figure 9.

The analysis of the results presented in Figures 8 and 9 should consider the dimensions of the tested specimens. The observed strength and ductility for small-scale specimens should not be directly extrapolated to full size columns [8]. Since the steel plates of the universal testing machine used also confine the specimens, the axial strength of the tested cubes is expected to be higher than the corresponding value of full size columns.

All specimens strengthened with a CFRP jacket present an axial strength higher than the original concrete specimen. The best result was obtained for the bonded CFRP jacket with a 26.8% increase. For the specimens strengthened with post-tension, PW05.05 exhibited an increase of 24.6%.

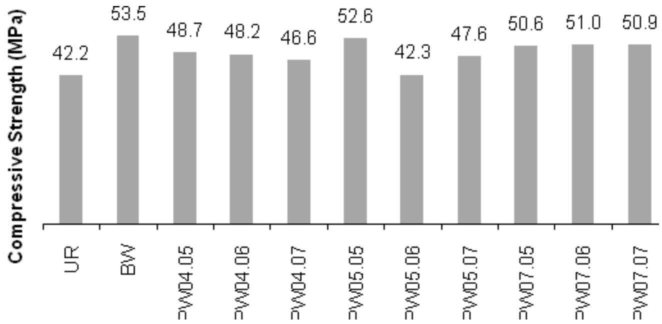

Figure 8: Axial compressive strength for all specimens (MPa).

The confinement of the specimen with bonded CFRP jacket is more effective than the confinement post-tensioned with expansive resin. When specimens are compressed the resin stiffness is insufficient to avoid its squashing. It was observed that the cross section of the original specimen increased and the already cured resin was squashed against the CFRP jacket.

For the PW07 series of specimens, strengthened with a CFRP jacket post-tensioned with expansive resin with 7 % of water, the behaviour under compression was more homogeneous. This was caused by the enhanced consistency of the expanded resin; being the expansion only 25% of its original volume**.** The air bubbles formed inside the expanded resin were smaller, when compared to the size of the air bubbles formed in the expansive resins with other values of water addition (with 4% and 5%).

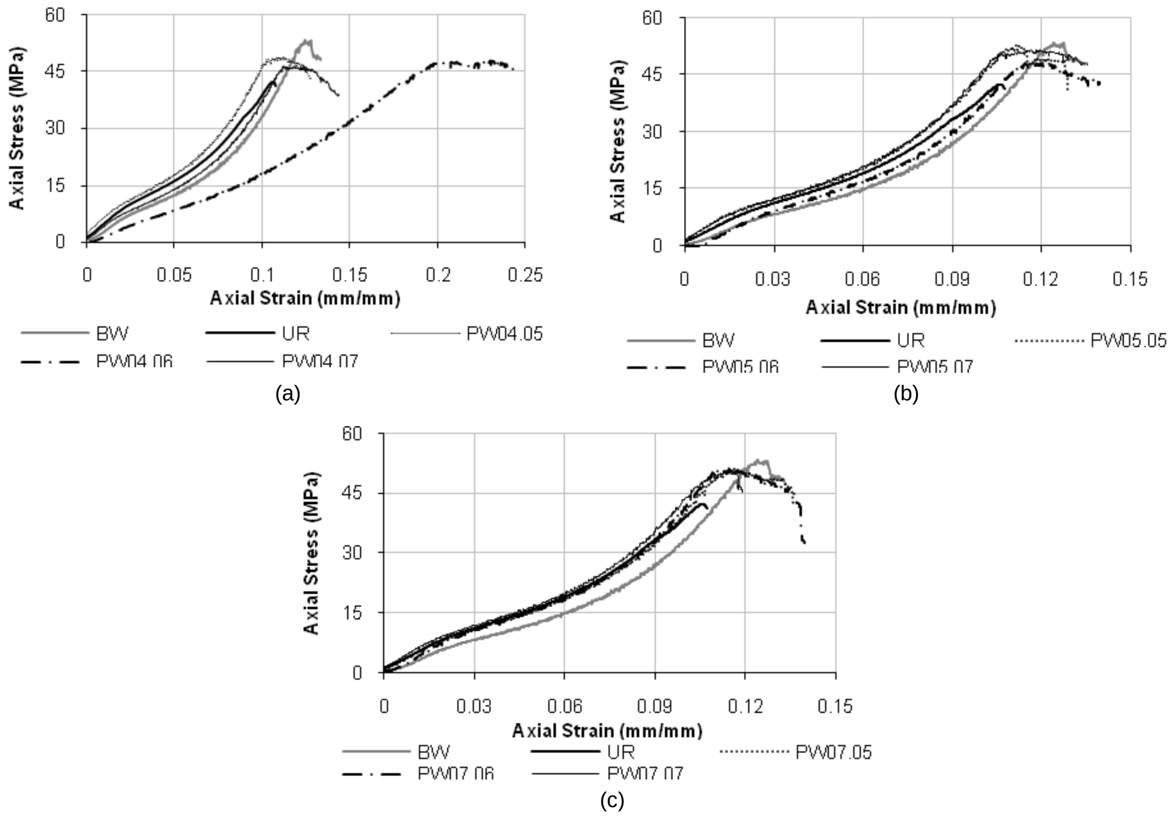

Figure 9: Stress-strain curves for specimens strengthened with bonded CFRP jacket, unstrengthened specimens, and specimens strengthened with post-tensioned CFRP jacket: (a) 4 % of water - PW04;
(b) 5 % of water - PW05;(c) 7 % of water PW07
(Note: the axial strain values can be overestimated since the upper plate of the testing machine was not perfectly unmovable)

4. Conclusions

An experimental investigation was conducted to study the viability of using an expansive resin to post-tension CFRP- based confinement systems for RC columns with rectangular cross-section. Different percentages of water addition to the expansive resin and different values for the gap between the CFRP jackets and the concrete specimen's were considered. The behaviour of the specimens under compression was registered until failure.

It was concluded that by post-tensioning the CFRP jacket with an expansive resin an increase in strength is obtained, but the magnitude of this increase was smaller than the one obtained with the traditional CFRP bonded solution. Therefore, it can be stated that the adopted expansive resin is not an adequate active CFRP-based confinement strategy for RC columns with rectangular cross sections.

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