ACTIVE REINFORCEMENT OF CYLINDRICAL RC COLUMNS WITH A FRP SHEET AND EXPANSIVE MICRO-CONCRETE

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Keywords: Self-compacting concrete, Expansive, Confinement, FRP jacket

Abstract

The aim of this work is to obtain an active reinforcement made of composites that works for the whole range of loads the structure supports. For its implementation, it is used a CFRP outer jacket and an expansive micro-concrete filling, which is placed between the column and the carbon fiber jacket, whose diameter is greater than the column's. To design the expansive self-compacting concrete, specific tests were first performed. From these tests it is considered that the optimum additive dose is 15%.

After strengthening the columns with the CFRP outer jackets the deformations produced on the sheets due to the expansion of the concrete filler were measured. When the expansion stabilized, compressive strength tests were performed. The results obtained in these tests showed that the technique is suitable to improve the compressive strength and the ductility of the elements, as the pressure of the containment can ensure the capacity of columns badly damaged.

In addition, a FEM model was developed to obtain the stress states of the column and the outer jacket after the expansion and during the test. The numerical model was able to predict the failure load and the area where the failure took place.

1 Introduction

Reinforcing columns using confinement techniques is a well-known methodology of which exist different variations. With the development of synthetic long fibers of high elastic modulus (aramid, carbon fibers…) two different reinforcement alternatives have been further developed: direct confinement methods (wrapping), in which the column is wrapped with the fiber and then a covering is applied, and indirect confinement methods, in which a formwork that contains the fiber is built and it is filled with a cement mortar of enough strength. The main inconvenient of the wrapping method is that the reinforcement does not work for the loads acting when the reinforcement is applied. It will only work when an overload is applied, what will make the column strain and the reinforcement will become in tension. On the other hand, the main inconvenient of the indirect confinement method consists on the fact that the filling of the space between the column and the reinforcement is a difficult task, and it cannot be assured that the filling is complete. An alternative to improve these situations is to design a self-compacting and expansive micro-concrete to be used as the filling of the formwork (ACI 223-98 2001, Hammer et al. 2001). The self-compacting characteristic of the mortar will assure the right filling of the space between the column and the formwork of carbon fiber while the expansive characteristic of the mortar will optimize the structural function of the system. The importance of this methodology consists on improving the execution of the solution, as the use of a self-compacting micro-concrete ensures that the filling is continuous, so it can transmit from the first moment stresses between the column and the formwork, while the expansive characteristic of the mortar transforms this system in an active confinement reinforcement.

2. Procedure to evaluate the degree of restriction on columns

The aim of designing expansive concretes is to fix the dose of expansive additive needed to reach an expansion equal or greater than the shrinkage of the concrete. ACI Code 223 defines a relation between the expansion of the concrete member, the expansion of normalized concrete prisms and the reinforcement of the element when the concretes have the same composition and are cured at identical conditions. The test that measures the expansion on concrete prisms is described in the standard ASTM C878. The effect described in these two standards is similar to the system proposed in this paper, as the reinforcement sheet restricts the expansion of the micro-concrete placed between the column and the CFRP sheet.
To reproduce these situations experimentally, the concrete cylindrical column is substituted by a rigid steel ring, which is wrapped by a reinforcement sheet. When the right setting of both the ring and the reinforcement sheet is ensured, the gap between them is filled with the expansive concrete. With the same concrete, several prismatic specimens are made as indicated in ASTM C878, so that we can obtain comparable data. The real expansion of the expansive micro-concrete is measured with strain gauges placed in the sheet. In addition, other strain gauges are placed in the interior of the ring to make sure that it works as a rigid solid, as indicated in figure 1.

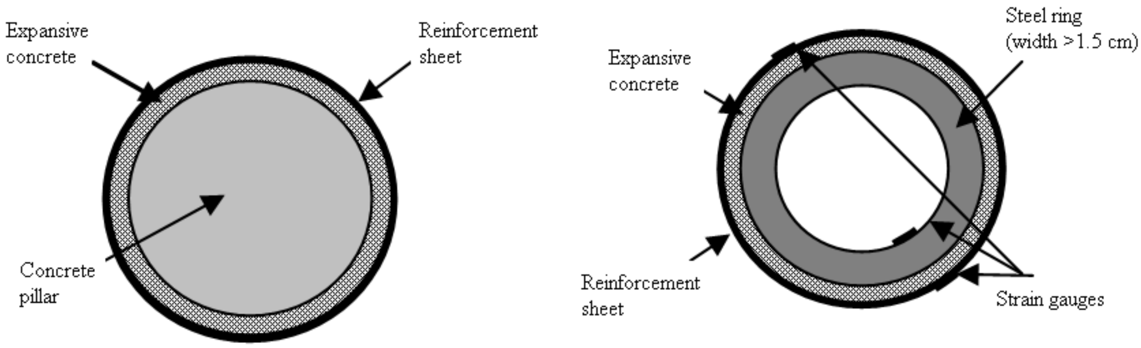

Figure 1. Cylindrical reinforced column and scheme of the apparatus designed to evaluate the restriction to the expansion made by the reinforcement

According to ACI 223, there is a linear relationship between the expansion measured in the prismatic specimens made according to standard ASTM C878 and the effective expansion of the concrete member. When represented, these lines always go through the coordinate origin. This is why only one test is necessary to identify the line that represents the effective restrain in the reinforcement system.

3. Test methods to evaluate self-compacting and expansive characteristics

There are several tests used to evaluate the self-compacting characteristics. The most used tests are: L-box test, V-funnel test and Slump-flow test.

3.1 Self-compacting micro-concrete

It has been used a self-compacting pre-dosed micro-concrete served by a commercial company, whose characteristics can be seen in table n.1.

Characteristic	Standard	Parameter	Value
Density	UNE EN 12350-6	D (kg/m^3)	2.290
Air Content	UNE EN 12350-7	%	2
Slump - flow test	UNE EN 12350-8	d_f (mm) T_{50} (s)	725 2
V funnel	UNE EN 12350-9	T_v (s)	3
L box	UNE EN 12350-10	C_{bl}	0.98

Table 1. Characterization of the self-compacting micro-concrete in fresh

This micro-concrete have all the characteristics needed to be considered self-compacting. Several mechanical properties of this micro-concrete were measured at the age of 28 days, after been cured at normalized standard conditions (20^{o}C, RM>95%). The results of these tests are summarized in table n. 2.

Characteristic	Standard	Parameter	Value
Compressive Strength	UNE EN 12390-3	f_c (MPa)	25.8
Flexure strength	UNE EN 12390-5	f_{cf} (MPa)	4.1
Elastic Modulus	UNE 83361	E (GPa)	23.5

Table 2. Mechanical parameters of the self-compacting micro-concrete in hardened state

3.2 Expansive micro-concrete

Once the self-compacting characteristic was evaluated, the expansion was measured over prismatic specimens with the aim of evaluating the dose of expansive additive that was needed to balance the shrinkage of the concrete. Several prismatic specimens were made according to standard ASTM C878. Three doses of expansive additive were tested (10%, 15% and 50% respect to the amount of cement). For each dose of additive, enough specimens were made to evaluate the expansive characteristic for two different curing regimes: 1. Seven days in a wet chamber (20±2 ^{o}C, RM>95%) and later in a dry chamber (20±2 ^{o}C, RM>50±5%); 2. The specimens were wrapped with an insulator plastic and kept in a wet chamber (20±2 ^{o}C, RM>95%) the first seven days and in a dry chamber later on (20±2 ^{o}C, RM>50±5%). As the excessive expansion of the specimens with the higher dose of expansive additive (50%) broke them, and the dose of 10% of the expansive additive was not enough to counter the shrinkage of the concrete, both dosages were discarded of the investigation. In figure n. 2 can be seen the expansion of the concrete members with a dose of 15% of the expansive additive.

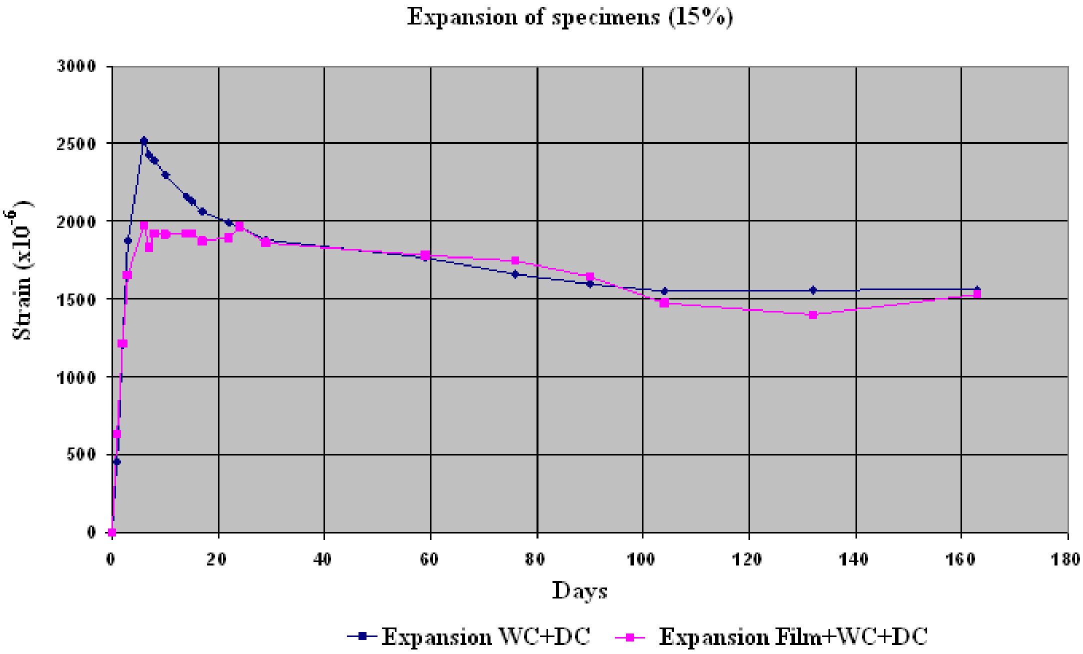

Figure 2. Expansion of the specimens with a dose of 15% of expansive additive

The maximum expansion reached with a dose of 15% of expansive additive is five times greater than the ones reached with the dose of 10% and were in an appropriate range. As to the drying regimes, its speed is independent of the dose of additive.
Several rings were cast to evaluate the degree of restriction imposed by them, with two different types of reinforcement, a carbon sheet. Three curing regimes were evaluated. One ring was kept in a wet chamber, another one was wrapped with an insulator plastic and kept in a dry chamber and the last ring was kept in a dry chamber without any protection. In the following figure the expansions in the carbon sheet reinforcement are shown. Figure n. 3 shows the average strains of three gauges set in a circumference at 120°.

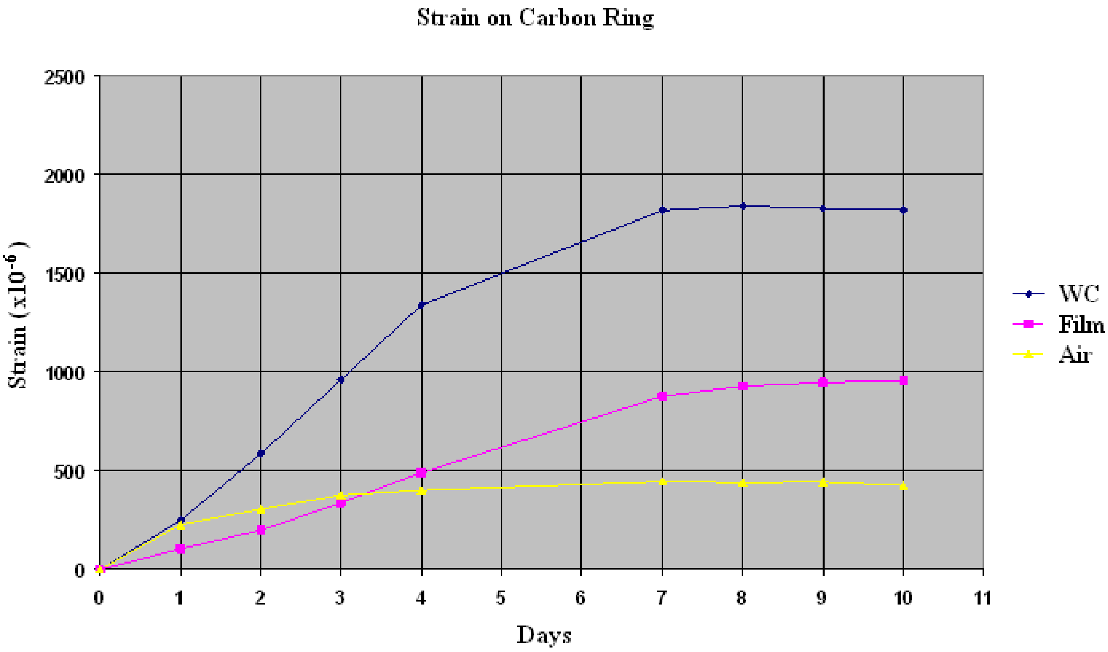

Figure 3. Expansion of a ring reinforced with a carbon fiber sheet

The results show that the outer carbon fiber sheet was stressed independently of the curing regime used due to the action of the expansive concrete that was used to fill the gap between the outer sheet and the steel ring that simulates the concrete column. The strains measured on the inner ring were insignificant, what indicates that the experiment is valid. The results obtained on these tests allow to compare the strain measured on them with the ones obtained in the prismatic specimens. The results show that the relationship between the strain measured on the carbon sheet and the one measured on the prismatic specimens is linear, as the standard ASTM C878 indicated, with a very high degree of correlation. Therefore, the scheme proposed in ACI 223 could be used to predict the expansion of the dispositive described in this work, by updating the design abacus with the results of this investigation.

4. Experimental program

The reinforcement technique proposed in this work was applied to several short columns of circular section to measure its efficiency and validate the confinement method proposed in this work. Ten low strength concrete cylindrical columns, which were 90 cm high and had a diameter of 24 cm were fabricated. The reinforcement consisted on a carbon fiber sheet with 32 cm of diameter and 1.3 mm thick, whose tensile strength was about 508 MPa. Two columns (named PH-1 and PH-2) were tested without any kind of reinforcement, while other two columns were tested with a carbon fiber sheet wrapped around them (named PHR-1 and PHR-2). The last six columns (PHRE-1 to PHRE-6) were tested with carbon fiber sheet with the expansive micro-concrete filling the gap between them, following the technique proposed on this work. The concrete used had a compressive strength of 24 MPa. Table n. 3 shows the compressive strength obtained for each of the columns tested, as well as the average load, average stress and the average transverse and longitudinal strains.

Column	Ultimate Load (kN)	Average Load (kN)	Average Stress (MPa)	Strain ($\times10^{-6}$)	Transverse Strain ($\times10^{-6}$)
PH-1	1032	1043	23.06	2011	435
PH-2	1054				
PHR-1	1673	1621	35.83	5791	3083
PHR-2	1569				
PHRE-1	2682	2780	61.45	2855	2427
PHRE-2	2830				
PHRE-3	2653				
PHRE-4	2957				
PHRE-5	2708				
PHRE-6	2851				

Table 3. Results of the column tests

In the specimens jacketed with expansive filling, the average initial deformation of the jacket before the test due to expansion of the filling micro-concrete was 0.685 ‰. The initial confinement of the carbon sheet due to the expansive effect represents 22% of the tensile strength of the sheet. From these values an approximate formula has been proposed to quantify the combined effect of confinement of the sheet and the expansive filling. The equivalent ultimate stress of the concrete (f_{cc}), calculated from the initial section of the column, can be estimated using the following formula:

$$f_{cc}= f_{co} \cdot [1 + 3.7 \cdot (f_{pc}/f_{co})^{1/2}] \quad (1)$$

$$f_{pc} = 2 \cdot t_c \cdot f_{rc} / d_c \quad (2)$$

where f_{pc} is the confinement pressure over the concrete that is produced by the reinforcement carbon fiber jacket, t_c is the thickness of the sheet, d_c is the diameter of the reinforcement, f_{rc} is the ultimate stress of the reinforcement and f_{co} is the ultimate stress of the concrete unconfined.

5. Finite Element Method modelization

Several FEM models have been developed to determine the stress state of the columns after the expansion and during the compression test (until the breakage of the reinforcement sheet).
Each material was modeled on its own (original concrete of the column, expansive micro-concrete and the CFRP sheet), including the plasticization effects of the concrete and the union between the expansive micro-concrete and the CFRP. The elements used were solid type of eight nodes for the concrete and shell element of four nodes for the reinforcement.
The FEM shows that when it is introduced the expansive concrete in the gap between the original column and the sheet, the strains measured in the ring dispositive are obtained, so the sheet has a tension stress.
The results obtained after the expansion of the concrete can be seen in figures n. 3 and n.4.

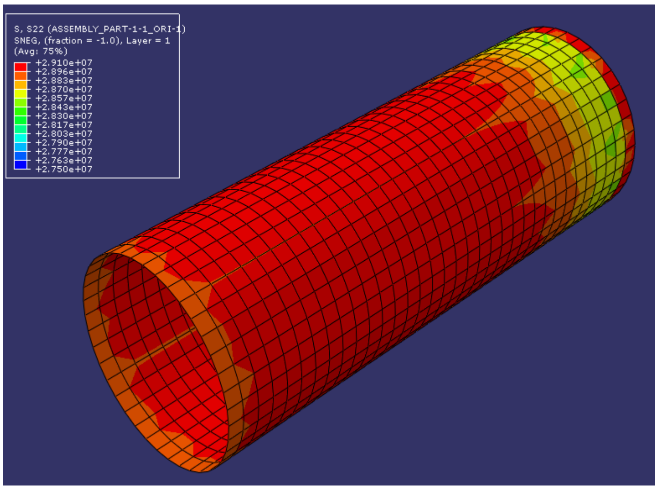

Figure 4. Stress in the jacket after the expansion

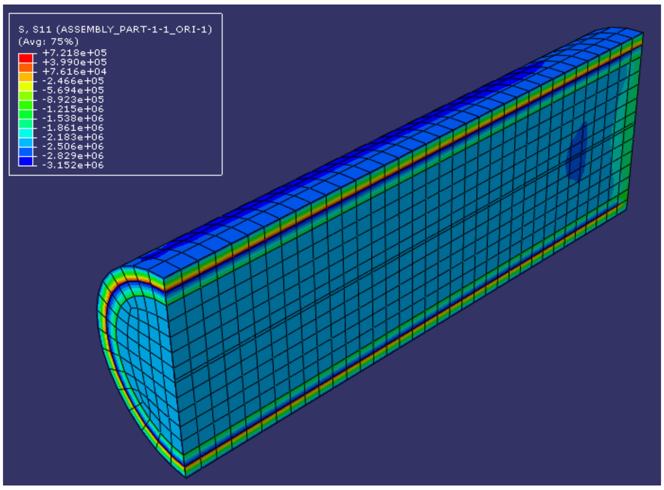

Figure 5. Stress in the concrete after the expansion

The results obtained in the columns after the vertical load has been applied are shown in figures n.5 and n.6.

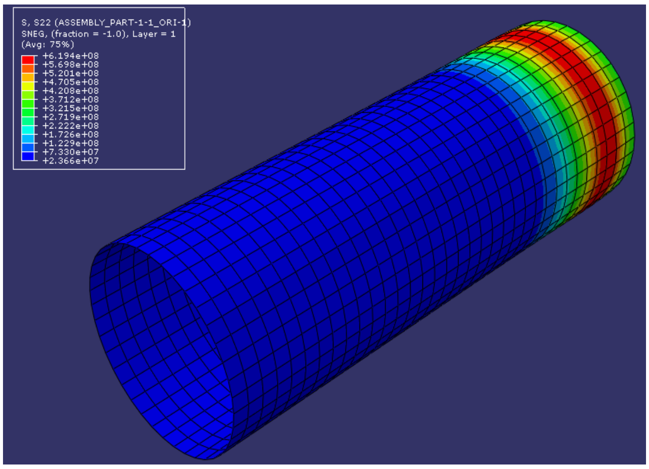

Figure 6. Stress in the sheet at ultimate load

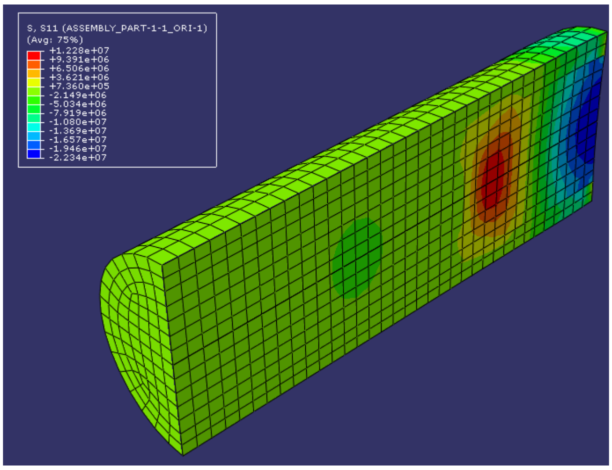

Figure 7. Stress in the concrete at ultimate load

As it is shown in the previous figures, the FEM predicts that the upper area of the columns is the most stressed one and, therefore, is where the breakage of the jacket happens, as the strain in that area is ten times greater than the strain in the center of the column, where the gauges that measure the transverse strain are set.

6. Conclusions

From the results it can be concluded that it is possible to use a self-compacting micro-concrete to fill the gap between circular columns and the reinforcement. The expansive reactions that happen in the concrete stresses the reinforcement sheet, ensuring that the reinforcement starts acting on the very same moment it is placed, not needing an overload to act over the repaired column.

The self-compacting characteristics of the filling micro-concrete have to be previously checked using the specific tests designed to measure the behavior of the concrete in fresh. The expansion will depend on the dose of the additive added to concrete, so it has to be designed previously to the mixture of the concrete. To do so, the linear relationship between the expansion measured in a ring dispositive described in this paper and the expansion of prismatic specimens made according to standard ASTM C878 can be used.

The FEM is a powerful tool that is able to predict the stress state of the sheet and the original column and accurately predicted the way the columns would break, as it showed that the transverse strain in the upper area of the columns was ten times bigger than the transverse strain in the central area, where the strain gauges were set.

Acknowledgements

This work was developed thanks to funding from the Ministry of Education and Science of Spain, to develop the project reference BIA2007-62464, through the convocation of Support for R & D Projects 2007 and the intramural project 201060E118 “Investigation of special advanced concretes to structural applications in engineering and architecture” financed by the CSIC. The authors of the paper also acknowledge the assistance of the companies SIKA, SAU and DENKA SEIKEN Co. Ltd.

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