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EXPERIMENTAL STUDY OF ULTRA-HIGH PERFORMANCE FIBER REINFORCED CONCRETE DOSAGES WITH ULTRA FAST SETTING TIME

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The overall objective of the work is the development of ultra high performance fiber reinforced concrete (UHPFRC) dosages that can be used for shotcrete. In this study, a number of UHPFRC mixtures with different amount of admixtures (plasticizers and accelerating) and different mixing time were tested, to increase either the rate of stiffening or setting of the concrete or the rate of hardening and early-strength development. Workability, consistency and mechanical properties of UHPFRC including compressive and flexural strengths at different ages were assessed. Results showed mixtures than begin their first setting in less than 1 minute, with very good mechanical properties in 24 hours, and without reducing the compressive strength at 28 days. From the results obtained, various uses of these mixtures are proposed taking into account, the new context of the Construction field, with the appearance of new placing concrete techniques.

Keywords: UHPFRC, Shotcrete, Admixtures, Rate of hardening, Workability.

1 INTRODUCTION

During the last century and especially during the last decades, the traditional view of the concrete has changed, due to the development of new techniques and different technologies.

Shotcrete represents a great advance in the concrete works (Yoggi 2002), and also the union of different technologies in the concrete mix design and the incorporation of other components like additives, fibers etc. causes that concrete increases and improves certain properties. Thus have been created Ultra High Performance Fiber Reinforced Concrete (UHPFRC), which began to be developed in France in the 1990s (Ahlborn and Steinberg 2012). It is a cementitious matrix material that has a characteristic compressive strength at 28 days of more than 150 MPa, with high flexural strength, high durability, ductility and good workability (Serna Ros *et al.* 2012) and (Camacho Torregrosa 2013).

These concretes are manufactured with high amounts of super plasticizing additive, whose action increases setting times. However, in order to be sprayed, it is necessary to reduce these times, and therefore, introduce setting accelerator additive. But its action can reduce the final mechanical strength (Galobardes Reyes 2013).

In this research, different mixtures of concrete with ultra high strength adapted to shotcrete techniques are developed. The influence of setting accelerator in setting times of concrete is studied, and its effect on the acquisition of strength to short and long term.

2 EXPERIMENTAL METHODOLOGY

Ultra-High performance concrete is made from an initial dosage (Table 1), based on previous studies carried out by the research group of the ICITECH. On this concrete the influence of the variation of the dosage in setting accelerating additive is analyzed, taking into account the behavior of this concrete over time, in fresh (workability) and hardened (compressive and flexural strength). The experimental test is performed in two phases: the first phase consist on determining setting accelerator content and the second one is to study the effect of fiber incorporation.

2.1 Materials and Dosage

The dosage of the analyzed concrete is shown in table 1. The selection of the setting accelerator additive is justified in previous studies (Torres Remón 2016). In the sections in which flexural strength is analyzed, the fiber dosage is set at 2% over the total volume of the mixture. High yield stress steel fiber of 13/02 mm (length / diameter) is used.

Table 1. Concrete dosage.

Materials	Concrete Dosage (kg/m^3)
Cement CEM I 52.5R	800
Water	170
Superplasticizer	4
Silica Sand 0-0.8 mm	562
Silica Sand 0-0.4 mm	302
Quartz	225
Micro-silica	175
Setting accelerator	variable
Fibers	variable

2.2 Experimental Program

In the he first phase of tests, dosages with amounts of setting accelerating additive 0, 1.5 and 3% of the weight of the cement will be analyzed. In the second phase, the dosage that has given the best results in the previous phase will be used, and 2% of fibers will be added over the total volume of the mixture.

The developed concretes are made (Table 2) with the equipment and the technology characteristic for the manufacture of mortars, according to UNE-EN 196-1: 2005 (AENOR 2005).

Table 2. Manufacture of concrete.

Introduced in the mixer	Solids (without additives	Water	Superplasticizer	Setting accelerator	End of Mixing
Mixing time	0 s	30 s	150 s	600 s	Variable

2.2.1 *Evolution of workability*

The methodology used is based on the determination of the workability of the mixture in a similar way to that indicated in UNE-EN 12350-2: 2009 (AENOR 2009). These tests consist of pouring the concrete into a mold immediately after finishing the mixing, considering t = 0 this instant. After waiting for the set time for the test, the mold is lifted and the concrete is allowed to flow. Once the flow has stabilized, the result is the increase in diameter (in mm) above the initial theoretical diameter of the mold base.

We have used a rigid PVC mold with a cylindrical shape (25 mm high and 30 mm diameter), smaller than the standardized mold (figure 1). The change in the type of the mold is justified by the need to increase the sensitivity of the measurement.

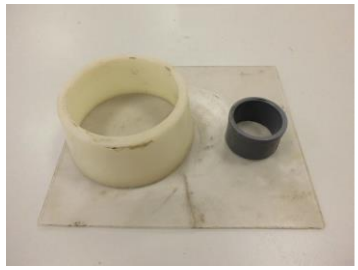

Figure 1. Standardized and non-standardized mold.

2.2.2 *Evolution of mechanical properties*

For these tests 40x40x160 mm specimens are manufactured according to UNE-EN 196-1: 2005 (AENOR 2005). The test samples are filled with a single layer and compacted with 30 strokes. Curing takes place in a humid chamber at 20ºC and 100% humidity. Three specimens are made from each mixture and tested for flexural and compressive strength.

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Workability

A total of 42 trials were performed to determine the workability of the concrete. This corresponds to 14 tests for each type of mixture (control dosage, dosage with 1.5% setting accelerator and dosage with 3% setting accelerator).

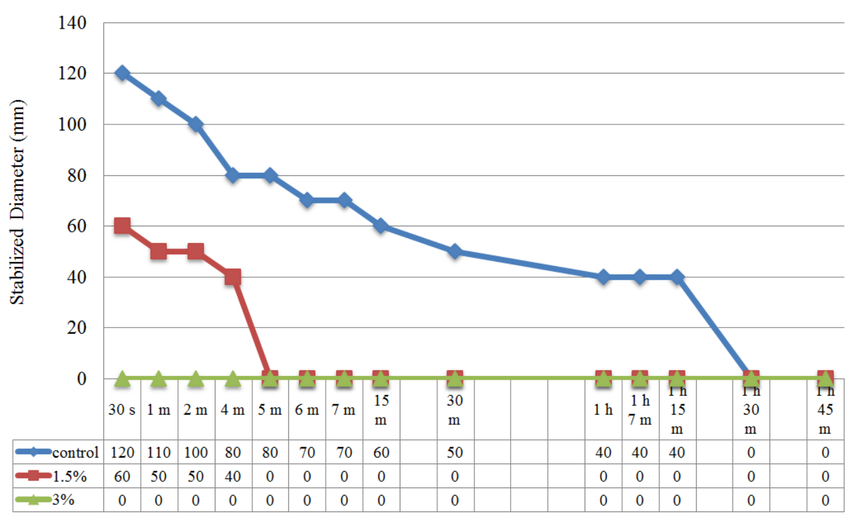

Figure 2. Evolution of workability with different percentages of setting accelerator.

The results for the different mixtures are shown in figure 2. In this figure the influence of the content in setting accelerator can be observed with the flow of the mixture.

The x-axis shows the time elapsed until we lift the mold in which we have introduced the fresh concrete. For each time we raise the mold, the increase in diameter after stabilization is represented in the y-axis. The control mixtures achieve stabilization after an hour and a half of having been manufactured. This time is reduced to 5 minutes if the mixture contains 1.5% of setting accelerant. And this time is only 30 seconds in the case of 3% setting accelerator.

In the second phase of tests, no workability test was done, as it was observed that the incorporation of metal fibers in the concrete mixture, favored the stability of the mixture.

3.2 Mechanical Properties

Of the 42 mixtures made to determine the workability of the concrete, 15 are used to make test samples to be tested in flexion and compression. The test is performed at 6, 9, 12 and 24 hours and thereafter at 28 days. Five control mortars and five mortars were made with each of the percentages of setting accelerating additive (1.5% and 3%). Three specimens of each type of mixture are tested, so we tested a total of 45 specimens at flexion and 90 at compression. The results obtained are shown in Table 3.

Table 3. Results of the first phase of tests.

% setting accelerating additive	Age of sample	Flexural Strength (Mpa)	Compressive Strength (Mpa)
0% (control)	6 hours	0.51	1.92
	9 hours	1.05	2.20
	12 hours	2.76	4.70
	24 hours	8.08	51.52
	28 days	22.09	125.77
1.5 %	6 hours	2.45	2.76
	9 hours	3.06	7.37
	12 hours	4.98	18.58
	24 hours	9.34	63.04
	28 days	24.8	137.30
3 %	6 hours	3.37	7.49
	9 hours	3.98	14.20
	12 hours	6.58	28.33
	24 hours	9.34	60.84
	28 days	22.28	129.14

As can be seen in Table 3, the increase in the amount of setting accelerator causes the increase of the strength, mainly compression, at early ages (especially in the first 12 hours). On the other hand, it is also proven that the incorporation of setting additive in these amounts does not negatively influence at the 28 days strength.

In the second test phase, five concrete mixtures with a setting accelerator content of 3% were produced and 160 grams of fibers were incorporated. Five specimens were made from each concrete, a total of 15 specimens were tested at flexion and 30 at compression. As expected the incorporation of metal fibers into the blend has greatly increased the flexural strength of the material (Table 4).

As expected with the incorporation of fibers, we obtain an improvement of the flexural and compressive strength of the mixtures. This increase is detected in the first few hours and is maintained over time. For some ages the flexural strength of the mixtures with fibers doubles the strength of the concrete without fibers.

For concrete with fibers, the increase in compressive strength is more remarkable in the early hours, when the paste has not reached its characteristic strength, but even at 28 days it is still around 20% greater than the concrete without fibers. Therefore, it can be concluded that the addition of setting accelerator in no case has adversely affected in the mechanical resistances.

Table 4. Results of the second phase of tests.

Fibers	Age of sample	Flexural Strength (Mpa)	Compressive Strength (Mpa)
With Fibers	6 hours	7.81	20.34
	9 hours	10.26	32.72
	12 hours	13.63	34.61
	24 hours	22.97	75.85
	28 days	35.22	175.18
Without Fibers	6 hours	3.37	7.49
	9 hours	3.98	14.20
	12 hours	6.58	28.33
	24 hours	9.34	60.84
	28 days	22.28	129.14

4 CONCLUSIONS

In this project, a study on several mixtures of high performance concrete is carried out, from studies previously started at the Universitat Politècnica de València, specifically at ICITECH (Serna Ros *et al.* 2012), (Camacho Torregrosa 2013) and (Torres Remón 2016).

The evolution of the workability and the strength of new concrete mixtures, with the purpose of obtaining concrete that can be compatible to be used with shotcrete. It is important to highlight some aspects obtained after the experimental program:

- It was possible to increase the setting accelerator content up to 3% on the weight of the cement, without altering the workability of the mortar.
- It has been achieved the development of mortars with start of ultra-fast setting (50 s approximately)
- The incorporation of fibers into the mixtures in controlled and adequate quantities, has meant an increase of the initial and final strength, both flexural and compressive.

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