Self-Compacting Fiber Reinforced Concrete for Precast Industry

Paulo A. L. Fernandes
Department of Civil Engineering, CERIS, Polytechnic Institute of Leiria, Leiria, Portugal
Email: paulo.fernandes@ipleiria.pt

João Veludo*+, Hugo Rodrigues**+, Nuno Almeida+, João Baptista*+
* CERIS; +Polytechnic Institute of Leiria/ Department of Civil Engineering, Leiria, Portugal
** RISCO; Polytechnic Institute of Leiria/ Department of Civil Engineering, Leiria, Portugal
Email: joao.veludo@ipleiria.pt; hugo.f.rodrigues@ipleiria.pt; nuno.f.almeida@ipleiria.pt; joao.baptista@ipleiria.pt

***Abstract*—The Self-Compacting Fiber Reinforced Concrete (SCFRC) is a composite cementitious matrix, with an added amount of discrete fibers. The increase in tensile strength, the inherent ability to control cracking and the consequent increase of the absorbed energy are the main properties benefited from the introduction of fibers. Regarding the consistency of the concrete, there is a decrease in its workability with the increased addition of fibers. Given this problem and due to the need to build lighter, slenderer elements and still meet the precast industry requirements, in particular its production cycles, it is required the use of a self-compacting concrete. This paper describes an experimental study to obtain a self-compacting fiber reinforced concrete formulation, suitable to develop new solutions of non-structural precast elements in buildings.**

The work focused on studying the influence of several parameters on fresh and hardened SCFRC properties. Based on Faury's reference curve various mixtures have been developed, , with a water / cement ratio ranging from 0,30 to 0,35. In all mixtures, the dosage of steel fibers and the volume of cement remained constant.

For all the compositions, the slump flow and the compression strength were evaluated and analyzed.

***Index Terms*— Self-compacting concrete, fiber reinforced concrete, precast**

I. Introduction

The prefabrication concept is based on the construction method and speed of construction, where the various elements are produced in factory environment and later transported and assembled on-site, thus representing economic gains and improving the quality and safety of on-site work [1]. The need to standardize production methods and geometry of the elements means less freedom for designers and owners to make changes to, this being a major commitment to achieve. Also relevant are the aspects related to connections, assembly on site and regulations inferring directly with the final quality and durability of the structure. Currently prefabrication provides a wide range of solutions (structural or non-structural) covering housing, industrial buildings, bridges, retaining walls, reservoirs, culverts, tunnels, among others.

In this study, the speed of production cycles implying demolding the elements shortly after casting, combined with the required reduced thickness for the walls, a good finish level and minimal strength allowing transporting and assembling the walls are the main concern on the choice of the type of concrete to be used. For these reasons, the authors developed a self-compacting concrete (SCC) that allows the concrete to fill the mold without the need for vibration, obtaining a better surface finish of the elements, allowing to manufacture more complex geometries, reduced manpower and noise (by absence of vibration) and increasing the life of the molds for casting. SCC also shows an increase in maximum compression strength when compared with a normal concrete, for identical water/cement ratios (W/C) and an increased resistance to the action of chlorides because it is more compact than regular concrete [2].

Furthermore, the inclusion of fibers in concrete has been done for a long time, being used to improve the mechanical properties of the concrete in terms of strength (tensile and compressive), Young ́s modulus, cracking behavior, durability, shrinkage, among others. The type of fibers included in a fiber-reinforced concrete (FRC) is varied: metal, glass, synthetic and natural fibers [3].

The main aim is to benefit from the advantages of these two types of concrete (SCC + FRC) and formulate a self-compacting fiber reinforced concrete (SCFRC).

It is important to point out some limitations and precautions considered for this study:

- The fluidity and workability achieved with an SCC are easily compromised by exudation and segregation phenomena [2];
- The workability of the concrete is easily affected by the type of the fibers, dosage, length, length/diameter ratio (l/d) and shaped configuration) [3];
- The choice of the concrete constituents should be easy to obtain and ensure the most economical solution.

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II. Self-Compacting Fiber Reinforced Concrete

When combined with fibers, SCC provides a better distribution of these fibers throughout the concrete paste due to its fluidity resulting in a more uniform and more consistent element. The SCC is more compact than regular concrete, leading to the improvement of the adhesion between the concrete and the fibers, an overall better structural behavior and improving the durability [4]. The dosage of fibers to include and their aspect ratio (l/d) must however be limited so that balling or loss of fluidity doesn't occur [3]. Dosage must be higher than 25 kg/m^3 and their aspect ratio should range between 45 and 70.

As stated in previous studies [5][6][7] the dosage of fibers in the concrete has a beneficial influence on the compressive strength up to a certain value. TABLE I presents three compositions where the compressive strength increases to a maximum value with a certain dosage of fibers (optimum dosage marked as bold in TABLE I), decreasing after that. After a certain dosage, the workability is affected as well [7].

TABLE I. Effect Of Fiber Dosage on Compressive Strength from Previous Studies

Concrete Type	Fiber dosage (% Volume)	Compression Strength (28 days) (MPa)
High Strength Fiber Reinforced Concrete [5]	0	85
	0,5	91
	1,0	95
	1,5	**98**
	2,0	96
Fiber Reinforced Concrete [6]	0,25	67,50
	0,51	**73,64**
	0,76	66,96
Fiber Reinforced Concrete [7]	0,5	42,34
	1,0	43,67
	1,5	44,50
	2,0	44,67
	2,5	45,33
	3,0	**46,00**
	3,5	45,00
	4,0	44,67
	4,5	44,33

III. Experimental Program

The experimental program was performed to access the workability and compressive strength for six different compositions developed to obtain an adequate self-compacting fiber reinforced concrete to use in precast panels and to evaluate the influence of the concrete constituents in each mixture. Prior to these six mixtures, two exploratory mixtures where performed to evaluate the self-compacting behavior of the concrete.

The mixtures were made using a vertical shaft mixer with a capacity of 100 liters. Once the final objective is dealing with precast elements, the uniformity of the constituents and processes are considerably more controlled and rigorous when compared to concrete made *in situ*, so it is important to provide some degree of variability in these parameters so that the result is always within the desired objectives. The mix procedure was: at first the aggregates were mixed for a few minutes; then the powder (cement + filler) was added and mixed until uniformity of the mixture; the next step included joining the liquid faction (water and admixture) while mixing until the paste was homogeneous; the final step was the addition of the fibers (when used).

Due to needs of production cycles, the concrete must reach high strength at early ages, suitable to be demolded and moved 24 to 48 hours after casting.

To fulfill all these conditions, it was decided to use a 600 kg/m^3 dosage of cement + filler, keep the compactness between 0.80 and 0.83 and the water/binder ratio in the interval 0.31 to 0.33.

All tests were conducted at the Laboratory of Structures and Reinforced Concrete (LEBA) of the School of Technology and Management of the Polytechnic Institute of Leiria.

A. Materials

In this study, the constituents selected for the base formulation of the FRSCC are presented in TABLE II. Since this self-compacting concrete is being developed for use in non-reinforced elements, subject to compression and bending, in addition to the usual constituents (cement, aggregates, and admixtures), it was necessary to introduce fibers. Some constituents have changed as consequence of the optimization process.

TABLE II. Constituent Materials of the Concrete

Material	Description
Cement	CEM I – 42.5R
Coarse Aggregate 1	Limestone nº1 (6.3/12.5 mm)
Coarse Aggregate 2	Limestone nº0.5 (2/6.3 mm)
Sand 1	River sand 0/4 mm
Sand 2	Dune sand 0/2 mm
Admixture 1 (Superplasticizer)	Sika Viscocrete 20HE
Admixture 2 (Superplasticizer)	BASF MasterGlenium SKY 526
Fiber 1	Steel Fiber 35/0.75
Fiber 2	Polypropylene Fiber
Filler	Limestone Powder

B. Concrete Mix Design

The design methodology used to formulate the SCFRC mixtures was based on the following principles:

- Limit the maximum aggregate size according to the size of the mold and the SCC characteristics - in this framework this parameter was defined at less than 15 mm;
- Use aggregates with a wide range of particle sizes to maximize the compactness and the self-compacting behavior of the mixture;
- Formulate the concrete using Faury's reference curve by adjusting the parameters of the curve at the most appropriate values to obtain an SCC;

- Adopt a low water/cement ratio to obtain appropriate strength;
- Use of a 3rd generation superplasticizer to compensate the low W/C ratio and ensure the required fluidity and workability;
- Control the admixture (superplasticizer) dosage to control unwanted phenomena of segregation and exudation, thereby obtaining a homogeneous paste;
- Use of steel fibers and (optionally) polypropylene to improve the mechanical properties of the concrete and its durability;
- Adopting a dosage of the binder paste adequate to promote the desired consistency and workability, once the paste reduces the friction between particles.

The use of a large amount of binder increases the shrinkage, so it was expected that the use of fibers would help to control its effects. The superplasticizer was chosen to increase the concrete's self-compactness for low W/C ratios, adjusting the dosage to minimize segregation and/or exudation. It is important to point that the height to which the concrete is placed in the mold is also important to control the phenomenon of segregation.

Consequently, the concrete displayed characteristics such as high flowability, homogeneity and workability (SCC), when fresh, combined with a high compressive strength at young ages, when hardened, achieved mainly by low W/C ratios, compactness and fibers (SCFRC).

C. Concrete Compositions

For each mixture was registered the behavior during mixing, the occurrence of segregation and the diameter of the mixture spreading, to optimize the workability and the performance of the concrete constituents. Initially it was intended to use a hybrid solution of steel and polypropylene fibers, with different objectives: i) enhance mechanical properties (steel fibers); ii) improve micro-cracking behavior and water absorption/retention in the concrete matrix (synthetic fibers).

When mixing, the polypropylene fibers withdrew a large amount of workability from the fresh mixture thus preventing its use.

In all compositions, the same quantity of fibers was added, corresponding to 5% of the cement in weight. The aggregate's granulometry curves are represented in Fig. 1. The detailed constituents of each mixture are listed in Table III and the water/cement ratios and plasticizer percentages are shown in Table IV.

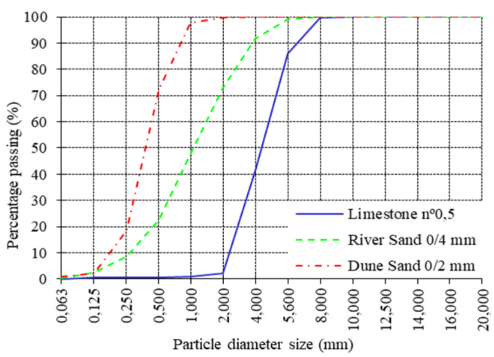

Figure 1. Aggregates granulometry curves

TABLE III. DESCRIPTION OF EACH SCFRC COMPOSITION

Material	Mix. 1	Mix. 2	Mix. 3	Mix. 4	Mix. 5	Mix. 6
Cement	✓	✓	✓	✓	✓	✓
Coarse Aggregate 1 (6.3/12.5 mm)	✓					
Coarse Aggregate 2 (2/6.3 mm)	✓	✓	✓	✓	✓	✓
Medium Sand		✓	✓	✓	✓	✓
Fine Sand	✓	✓	✓	✓	✓	✓
Viscocrete 20HE	✓	✓				✓
MasterGlenium SKY 526			✓	✓	✓	
Steel Fiber	✓	✓	✓	✓	✓	✓
Polypropylene Fiber	✓					
Filler		✓	✓	✓	✓	✓

TABLE IV. WATER/CEMENT RATIOS AND PLASTICIZER DOSAGE

Mix	Water/Cement	% Plasticizer
0.1	0,44	1,6
0.2	0,32	1,6
1	0,51	2,0
2	0,32	2,4
3	0,33	1,3
4	0,31	1,5
5	0,33	1,5
6	0,33	2,0

D. Test Specimens and Test Setup

to evaluate the behavior of the fresh concrete a series of tests were performed with each composition. With the tests of fresh concrete, it is intended to evaluate the fluidity of the mixture (which translates into the filling ability of the self-compacting concrete), the ability of the mixture to pass obstacles (e.g. reinforcement, irregularities in the formwork), and its resistance to segregation, among others.

The evaluation of the fluidity, and the relative viscosity of the mixture, through the t_{500} factor, of each mixture was evaluated with Slump-flow test (EN 12350-8, 2010 [8]) as shown in Fig. 2.

Figure 2. Slump-flow test

For the characterization of hardened concrete, the average compressive strength was evaluated according to EN 12390-1 (2012) [9] at 1, 7 and 28 days.

IV. Results and Discussion

The mixture spreading results and compressive strength at different ages are presented in Table V.

TABLE V. Mixture Spreading and Compressive Strength at Different Ages

Mix	Mixture fluidity	Compressive Strength (1 day)	Compressive Strength (7 days)	Compressive Strength (28 days)
0.1	537 mm	25,47 MPa	43,65 MPa	48,75 MPa
0.2	775 mm	53,40 MPa	75,17 MPa	84,90 MPa
1	-	21,83 MPa	42,18 MPa	47,07 MPa
2*	700 mm	36,17 MPa	60,00 MPa	66,67 MPa
3	500 mm	53,03 MPa	77,33 MPa	87,58 MPa
4	650 mm	55,20 MPa	85,00 MPa	94,17 MPa
5	720 mm	48,13 MPa	84,77 MPa	93,50 MPa
6[1]	730 mm	41,60 MPa	67,80 MPa	78,00 MPa

[1] segregation was observed

The exploratory mixes performed and the results obtained allowed to draw some conclusions to guide the definition of the parametric study to obtain an optimal formulation for the desired SCFRC that are highlighted as follows:

- The selected aggregates, namely the coarse aggregate 2 (2/6.3 mm), the medium sand and the fine sand, proved to be suitable for the formulation of a SCC;
- The coarse aggregates/fine aggregates particle size ratio most appropriate for the desired consistency is of the order of 0.4;
- The binder dosage should be fixed at 600 kg/m^3, with the cement dosage ranging between 450 and 500 kg/m^3 and the rest assured by a limestone filler;
- Faury's reference curve proved to be suitable for the formulation of a SCFRC by adopting the parameters A>40 and B=2;
- The compactness of the most suitable mixture is between 0.815 and 0.825;
- The admixture (superplasticizer) which showed greater compatibility with cement was MasterGlenium SKY 526 from BASF, without signs of segregation in higher dosages unlike the other tested.

V. Conclusions

In this study, a series of self-compacting concrete compositions were developed. The study of these different compositions allowed to draw the basis for a parametric study to define the optimal dosage and type of steel fibers to design a self-compacting fiber reinforced concrete (SCFRC), suitable to use in the prefabrication of small thickness elements used in precast housing systems.

It was possible to evaluate some important parameters in the performance of self-compacting concrete namely: the coarse aggregates / fine aggregates particle size ratio; the binder dosage; the compactness; and the Faury´s curve parameters.

There was also a clear difference in the performance of two superplasticizer brands, having one the need of a much higher dosage than the other and different probabilities for segregation to occur.

Although the fiber dosage remained the same, by adjusting only the mixture parameters it was possible to achieve very high compression strength not only at 28 days but also at very early ages such as 24 hours. Even though the tensile strength wasn't evaluated, it is believed that this composition has a great potential and is well suited, as a starting point, for upcoming tensile tests.

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Paulo Fernandes is Coordinating Professor at the School of Technology and Management, Polytechnic Institute of Leiria, Portugal, teaching Reinforced Concrete Structures, Prestressed Concrete and Precast Structures. His major research interests are high performance concrete (HSC, SCC, SFRC, SCSFRC), time dependent behavior of concrete, prestressed and reinforced concrete structures (design, assessment and structural rehabilitation), supported by both experimental and numerical programs.

João Veludo is an Adjunct Professor at the School of Technology and Management, Polytechnic Institute of Leiria, Portugal, teaching several topics related with Structural Design and Rehabilitation, and Geotechnical Design. His major research interests are Concrete Building Design and Rehabilitation, Structural Health Monitoring and Foundations Design.

Hugo Rodrigues is Senior Lecturer at the School of Technology and Management, Polytechnic Institute of Leiria, Portugal, teaching several topics related with Structural Analysis, Building Pathology and Rehabilitation. His major research interests are Building Rehabilitation, Structural Health Monitoring and Seismic Safety including experimental and numerical activities.

Nuno Almeida is: Civil Engineer, master student and researcher at the School of Technology and Management, Polytechnic Institute of Leiria, Portugal. His major research interests are Structural Analysis, Structural Strengthening and Retrofitting and Building Rehabilitation.

João Baptista is: Civil Engineer, PhD student at IST- University of Lisbon, Portugal, and researcher at the School of Technology and Management, Polytechnic Institute of Leiria, Portugal. His major research interests are Experimental Testing, Structural Analysis and Concrete Technology.