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Selection of steel fibers dosage in concrete for repository containers

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ABSTRACT

The use of nuclear energy, as well as all human activities, generates wastes that have to be suitably treated, in order to avoid any risk to the public and the environment. Currently in Brazil, CNEN is responsible for the project to construct and to commission a national repository for the final storage of low and intermediate level wastes. This repository will be a near surface one, where the radioactive waste will be disposed, using the concept of multiple barriers, i.e. the waste packages will be placed in concrete containers, these ones will fill the modules, which will be closed and covered by natural materials. In this work, Steel Fiber Reinforced Concrete (SFRC) was studied as a substitute for the conventional reinforced cement concrete (RCC) in the production of the cited containers. Compressive and tensile strength tests were performed in specimens of concrete with two types of fibers (A and C). The characterization and the evaluation of steel fibers were also carried out. The best results were obtained with the addition of 1.5% vol. of type A fibers. The carbon and sulfur quantification showed that the steel used in the manufacture of fibers was low carbon, and it was confirmed after the folding test that the fiber material achieve the quality requirements.

Keywords: **steel fibers, Steel Fiber Reinforcement Concrete, repository, concrete containers.**

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1. INTRODUCTION

In Brazil, the RBMN Project has the objective to build and to commission the national repository to store low and intermediate level radioactive wastes [1]. The disposal concept follows the multiple barriers approach, i.e. the waste package are placed in concrete containers, these containers in concrete cells, which are closed and covered by natural materials. The concrete container is basically produced with cement, water, fine and coarse aggregates and additives. The concrete is used because it has high water resistance, easy execution, variety of shapes and sizes, low cost, among other properties [2].

However the concrete has fragile behavior, but this can be solved using conventional armature. Nowadays an alternative is the use of steel fibers, which act as a source of stress transfer in the cracks, giving ductility to the concrete, resulting in a pseudo-ductile behavior. This concrete is called Steel Fiber Reinforced Concrete (SFRC) [3, 4].

According to the Brazilian standard NBR 15530:07 steel fibers are "discontinuous steel filaments specifically produced for use on concrete" [5]. The length of these fibers ranges from 30 to 60 mm, they can have different cross- sectional shapes and they are made with low carbon steel. They can be classified referring to the production process and to the geometric conformation. The second classification is more usual, and it divides the fibers in hooked-end (type A), crimped (type C) and straight (type R) ones [5, 6].

2. MATERIALS AND METHODS

2.1. Determination of concrete proportioning

Initially, a review of literature was conducted about concrete, steel fibers and Steel Fiber Reinforced Concrete (SFRC), in order to understand the importance and the critical points about these issues. From this review, the concrete compressive strength was selected and established in the range from 30 to 40 MPa at 28 days. Then the concrete proportioning was calculated, using the ABCP/ACI method [7]. The types and amounts of steel fibers were selected based on the literature and their commercial availability. The Table 1 shows the experimental design adopted. The types of steel fibers used were hooked-end (A) and crimped (C), with the dosages 0.8% (-) and 1.5% vol (+).

Table 1: Experimental design for the SFRC study.

Variables		**Experiment**	**Answers**	
Type of steel fiber	**Dosage**		**Test**	**Age**
A (-)	-	Control (without fibers)	Compressive strength	7
		- -		28
C (+)	+	- +	Tensile strength	7
		+ -		28
		+ +		

Figure 1 and Figure 2 show the types of steel fibers selected. These figures have a comparison between the size of the fibers and a coin of one Real.

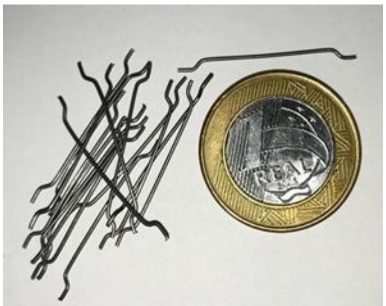

Figure 1: *Comparison of size between the hooked-end steel fiber and a coin of one Real.*

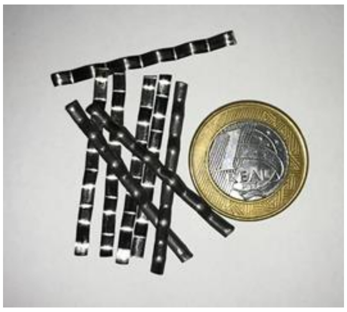

Figure 2: *Comparison of size between the crimped steel fiber and a coin of one Real.*

2.2. Preparation of the concrete and specimens

The concrete was prepared as the following procedure: the mixture of the coarse aggregate and 80% of the water was carried out in a mixing drum for 30 s; the cement was added and the materials were mixed for more 30 s; then after the addition of the fine aggregate this coumpound was mixed for additional 3 min. After that, the mixing drum spade and wall were scraped for 1 min. The last 20% of the water was added and the product was mixed for 7 min. In this concrete 1/3 of the total of the steel fibers was added in the mixing drum after the procedure above described and mixed for 3 min. After this, the 2/3 remaining steel fibers were added and mixed for 3 min, obtaining the Steel Fiber Reinforced Concrete. This concrete was poured in 12 cylindrical moulds (10x20 cm), which were put on the vibrating screed for 3 min to reduce the amount of voids. Some concrete without steel fibers (control) was made in order to varify the effect of the fiber addition.

The specimens were covered with a plastic for minimize dehydration. After 7 days, the moulds were removed and 6 specimens were submerged in water for curing. The other 6 specimens were tested at 7 days. In Figure 3 is possible to see the specimens already prepared for compressive strength tests.

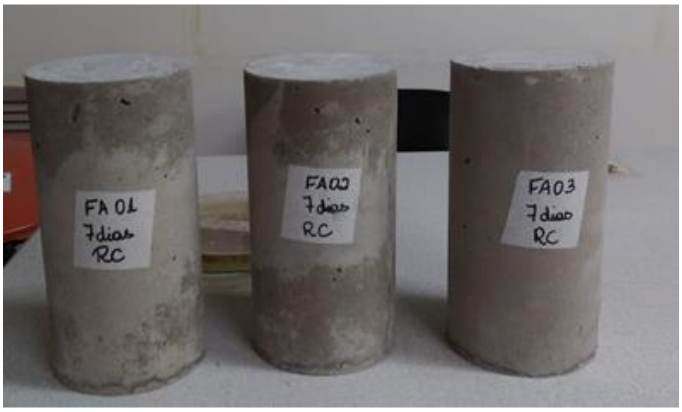

Figure 3: *SFRC specimens with 0.8% vol. of type A fibers prepared for compressive strength tests.*

The tests to determine the compressive and tensile strengths were performed at the Cementation Laboratory (LABCIM) of the CDTN. The compressive strength test followed the standard method ABNT NBR 5739 (2018), after 7 and 28 curing days [8]. The tests were carried out using a compression testing machine with a load capacity of 150 t. The maximum force reached was given in Newton (N) and to obtain the compressive strength was used Equation 1:

$$f_c = \frac{4 \, x \, F}{\pi \, x \, D^2} \quad (1),$$

being f_c the compressive strength, expressed in MPa, F the maximum force obtained, in N, and D the specimen diameter, in mm.

The tensile strength was determined by the method of ABNT NBR 7222 (2011) [9]. These tests were made after 7 and 28 curing days in the same described testing machine. The maximum force obtained is given in Newton (N) too. Equation 2 was used to calculate the tensile strength:

$$f_{ct,sp} = \frac{2 \; x \; F}{\pi \; x \; d \; x \; l} \quad (2),$$

being $f_{ct,sp}$ the tensile strength, expressed in MPa, F the maximum force obtained, in N, d and l the specimen diameter and length, respectively, in mm.

2.3. Tests for characterization and evaluation of steel fibers

Two methods were used to characterize and to evaluate the steel fibers: folding test and carbon and sulfur quantification using LECO™ equipment. The folding test was performed at the Mechanical Testing Laboratory of the CDTN, according to the method proposed by ABNT NBR 15530 (2007) using a pin of diameter equals to 3.11 mm [5]. The folding test was performed using the apparatus shown in Figure 4.

Figure 4: *Apparatus used performing the folding test.*

To evaluate the quality of the material used in the manufacture of steel fibers, the standard ABNT NBR 15530 (2007) establishes that the folding test should be performed on 10 samples, and they must be folded at a 90° angle and at least 90% of them can't break [5].

The carbon and sulfur quantification was used to verify if the steel of the selected fibers was low-carbon. This analysis was performed in the LECO™ equipment of the Nuclear Fuel Laboratory (LABCON) of the CDTN. In the test with the hooked-end steel fiber it was necessary to use two flux, one containing tungsten and tin and another with iron. In the case of the crimped steel fiber the flux containing tungsten and tin was sufficient to melt the material. Analyses of both types of fibers were performed in triplicate.

3. RESULTS AND DISCUSSION

3.1. Concrete proportioning

Using the ABCP/ACI dosage method presented by Rodrigues (1990), the following concrete proportioning was determined: 1.0: 1.75: 2.43: 0.44, relating cement, fine aggregate, coarse aggregate and water, respectively [7]. Hooked-end steel fibers (type A) and crimped (type C) were selected for use in this work. The straight steel fiber (type R) was not used because of its low commercial availability of on the market.

In the present study, the dosages of steel fibers were of 0.8 and 1.5% vol. As suggested in the literature, in SFRC the used percentage of steel fibers varies in the range between 0.38 and 2.80% vol. [3].

3.2. Compressive and tensile strength results

A summary of materials and tests is organized in Table 2.

Table 2: Summary of materials and tests.

Concrete proportioning		**Types of steel fibers**	**Dosage**	**Experiment**
Cement	1.0	A (-)	0.8% vol (-)	Control (without fibers)
Fine aggregate	1.75			- -
Coarse aggregate	2.43	C (+)	1.5% vol (+)	- +
				+ -
Water	0.44			+ +

The compressive strength tests were made in triplicate and the results were calculate using Equation 1. The average and the standard deviation values are presented in Table 3 and Figure 5.

Table 3: Compression and tensile strength results.

Curing time (days)	Experiment	Compression strength (MPa)	Tensile strength (MPa)
7	Control	25.06 ± 3.65	2.62 ± 0.45
	- -	30.53 ± 3.52	2.85 ± 0.24
	- +	28.60 ± 8.49	4.61 ± 1.72
	+ -	23.35 ± 1.75	2.76 ± 0.39
	+ +	29.69 ± 3.12	4.14 ± 0.21
28	Control	29.04 ± 6.05	3.66 ± 0.54
	- -	34.51 ± 1.93	4.57 ± 0.18
	- +	47.20 ± 5.15	5.74 ± 0.79
	+ -	23.63 ± 5.46	3.52 ± 0.23
	+ +	30.89 ± 0.62	4.54 ± 0.38

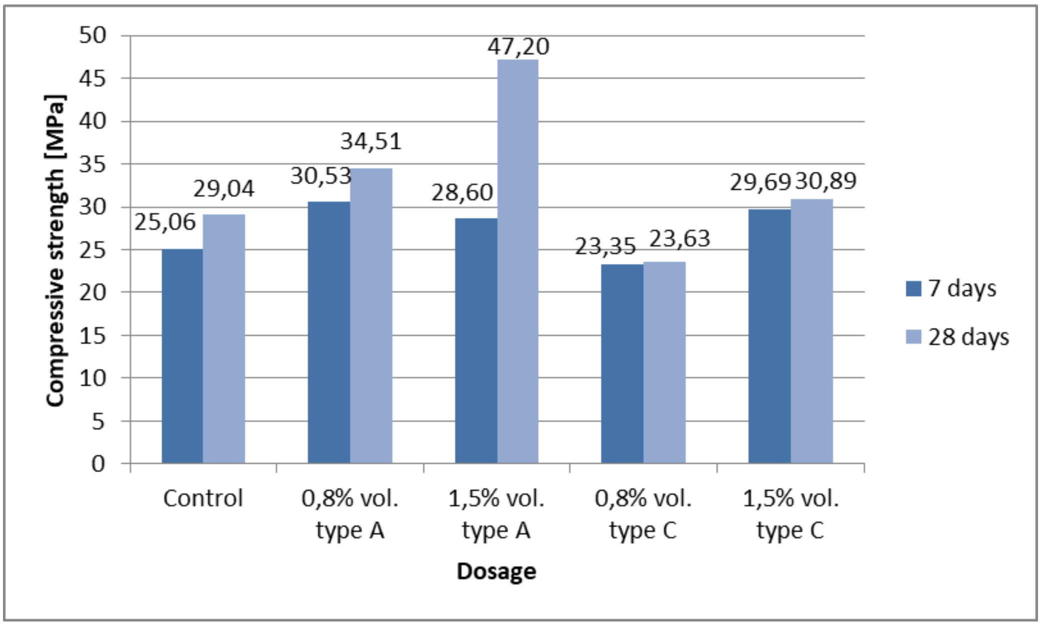

Figure 5: *Results of the compressive strength tests at 7 and 28 curing days.*

Based on the results, at 7 curing days the highest effect was observed with addition of 0,8% vol. of type A steel fibers, yielding a compressive strength of (30.53 ± 3.52) MPa with a confidence interval of 95%. At 28 curing days, the highest value was also obtained using the type A steel fibers, but with an addition of 1.5% vol, being (47.20 ± 5.15) MPa with a confidence interval of 95%.

The Equation 2 was used to calculate the tensile strength. The Table 3 and Figure 6 shows the average of these results.

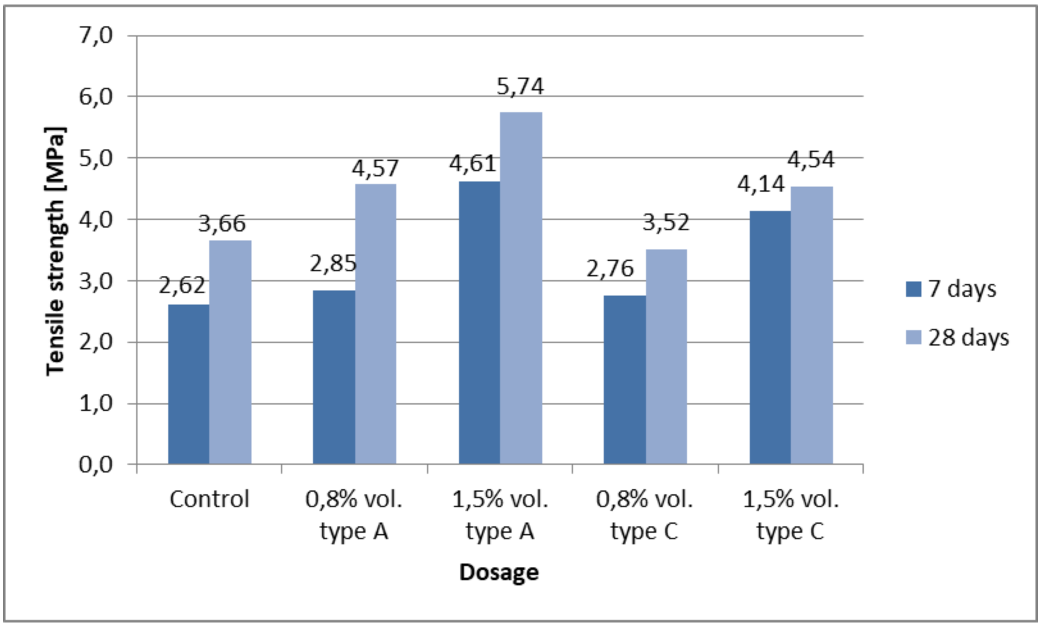

Figure 6: *Results of the tensile strength tests at 7 and 28 days.*

The concrete tensile strength is considerably lower than the compressive strength, which is corroborated by other authors [2]. The addition of steel fibers were also able to increase this property. The steel fibers type A presented the highest results in all cases, being the addition of 1.5% vol. the most effective for both curing ages, 7 and 28 days, with the values of (4.61 ± 1.72) MPa and (5.74 ± 0.79) MPa with confidence interval of 95%, respectively.

The fabrication process of the SFRC needs to be very carefull, since the additon of fibers increases the amount of voids in the concrete (Figure 7) and reduces the workability, making it difficult to apply in the manufacture of pieces, as observed during the moulding of some specimens during this research.

Figure 7: *SFRC specimen with 1.5% vol of type A steel fibers with much voids.*

3.3. Characterization and evaluation of steel fibers

3.3.1 Folding test results

This test was performed following the standard ABNT NBR 15530 (2007) for the type A steel fibers, Figure 8, and type C, Figure 9. All the fibers, 100%, of both types resisted to the folding test without fracture.

Figure 8: *Steel fibers into hooked-end after folding test.*

Figure 9: *Steel fibers crimped after folding test.*

3.3.2 Carbon and sulfur quantification

The carbon and sulfur quantification was used to classify the type of steel used to produce the fibers. The quantification was performed in triplicate and the averages results are presented in Table 4.

Table 4: Results of carbon and sulfur quantification.

Elements \ Type of steel fiber	A	C
Carbon (%)	0.12472 ± 0.01588	0.097075 ± 0.004671
Sulfur (%)	0.045833 ± 0.009885	0.044965 ± 0.005648

Low carbon steels have a maximum of 0.30% carbon, so the steels used in both types of fiber can be classified as low carbon [10]. This is accordance with standard ABNT NBR 15530 (2007) [5]. The results of sulfur content are presented because in the LECO™ equipment gives both results at the same time.

4. CONCLUSION

In this research the steel fibers and their effects on concrete were studied in detail. The most appropriate fiber and the best dosage were determined based in the compressive and tensile strength results.

The best results at 28 days for the compressive and tensile strength tests were obtained using 1.5% vol. of steel fibers into hooked-end (type A), being (47.20 ± 5.15) MPa and (5.74 ± 0.79) MPa with confidence interval of 95%, respectively. Therefore, the SFRC with 1.5% vol of type A fibers proved to be the best option for the production of repository containers. The workability of the concrete was a limiting factor, that can be overcome using self-compacting, which is an improvement of conventional concrete in which super plasticizers are added.

By the steel fibers study following the requirements of standard ABNT NBR 15530 (2007) it was conclude that they are classified as low carbon ones and, after the folding test, that their material complies with this standard [5].

To sum up, as the concrete container aims at long term storage, it should have higher strength, than the use of SRFC with 1.5% vol. of type A is a very good and suitable option for its manufacture.

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