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To cite this article: J Carrillo *et al* 2021 *J. Phys.: Conf. Ser.* **2118** 012014

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Durability assessment of concretes reinforced with steel and synthetic fibers in Colombia

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Abstract. In recent years, the use of steel fibers has increased in Colombia, optimizing structure designs, quality specifications and mechanical behavior. However, the concrete durability and resistance to aggressive environments such as sulfates and chlorides are not commonly evaluated. This paper includes results of durability analysis for 21 MPa compressive strength concretes reinforced with steel and synthetic fibers. Performance parameters measured during tests include sulfate resistance, chlorides penetration, and carbonation according to technical standards. The Variables of experimental program were fiber type and fiber dosage. Dosages for synthetic fibers were 1.5 kg/m³, 3.0 kg/m³ and 5.0 kg/m³, and for steel fibers were 5.0 kg/m³, 9.0 kg/m³ and 18 kg/m³. Results of the study were used to propose recommendations for reducing concrete deterioration when exposed to these aggressive environments and for extending the durability service life.

1. Introduction

Currently, the term durability includes fundamental aspects to obtain an ideal concrete, that is described in American Concrete Institute Standard (ACI), ACI 318R-19 [1], the most important are exhibition and resistance by the action of environmental aggressive agents (sulfates, chlorides (CO₂) etc.) [2,3].

It is well known that the fiber-reinforced concrete (FRC) improved plastic retraction characteristics; also increases strength tension and energy absorption, decrease thicknesses of fissures in specimen reducing permeability. These mechanical characteristics of the FRC can improve construction processes that cannot be obtained by reinforcement bars or welded wire mesh, but even like that it is not achieved to measure the impact that could have the structure exposed normally before the action of some aggressive agent [4-6].

Colombia is in a great process of development, and the civil engineering has turned into one of their engines to achieve it. The implementation of new technologies of construction like the use of fibers of steel or synthetic fibers in the fiber-reinforced concrete, which achieves resistance to aggressive environments and mechanical ideal properties, offers to the engineer a new perspective of new designs. In this paper the assessment of use of fibers in concrete specimen subjected to aggressive agents is accomplished.



2. Experimental program

The fiber-reinforced concrete durability evaluation with steel and synthetic fiber was realized by means of the test of 66 specimens by 3 dosages for fiber type and 11 specimens without fiber as comparison standard.

2.1. Characteristics of the specimens

In the experimental program there was included durability tests as ion chloride resistance, and ion sulfate resistance. Additional mechanical tests were done to evaluate the compressive strength. In different specimen there was had variation of steel and synthetic dosages fibers. The dosages assigned are according to the Colombian standard, “Normas sismo resistentes (NSR), NSR-10”, [7] which allows the use of 60 kg/m³ fibers for girders as dosage, but not for other types of concrete elements. For this reason, this investigation chose dosage to 18 kg/m³ for industrial floor slabs, and it was reduced proportionally to the half for both types of fibers as is specified in the Table 1. Each specimen was named in agreement to its content of fibers (type and dosage) as 1-2, where 1 indicates the type of fiber (S = synthetic, A = steel) and 2 indicates the dosage used in kg/m³. In specimen without fiber, the classification assigned were the letter T. The different cylinders were tested to evaluate durability to an age of 28 days; to evaluate compressive strength, specimens were tested to 3, 14 and 28 days. The quantity of tested specimens by ages is shown in Table 2.

Table 1. Study variables.

Variable		Description			
Type of fiber	Steel	Length (lf) mm			50.0
		Diameter (df) mm			1.1
		Aspect relation			45
	Synthetic	Length (lf) mm			5.5
		Thickness (ef) mm			0.3
		Aspect relation			18.3
Dosages for type of fiber	Steel	Df, Kg/m ³	1.50	3.00	5.00
		Volume fraction (Vf) %	0.15	0.30	0.51
	Synthetic	Df, Kg/m ³	5.00	9.00	18.00
		Volume fraction (Vf) %	0.51	0.91	1.83

2.2. Concrete properties

The nominal concrete compressive strength (f_c) was 21 MPa, the maximum nominal aggregate size was 1 inch and minimal slump was 7 inches. In addition, the water/cement relation (W/C) was 0.57 and the relation of sand and gravel was 80% and 20% respectively. The specimens were processed in a special room with temperature not bigger than 25 °C and continuous humidity.

2.3. Test setup

All mechanical and durability tests were realized in the Argos Colombia Laboratory's, Puente Aranda Plant, located in Bogota, Colombia.

2.3.1. Tests in fresh condition. In every dosage, the slump concrete test was done according to “Norma Técnica Colombiana (NTC), NTC-393” [8]. In agreement to European standards in Spanish, UNE-EN 14488-7 [9], which determines the real dosing of fibers by extraction in 3 cylinders per dosage, the procedure was realized after spilling the concrete in the mold to prevent which will act the cementitious paste. The real dosage of fibers was calculated from the volume of the cylinder and the weight of the fibers extracted. Additional tests were done to measure the unit weight in fresh condition (M), and the air content (A), of fiber-reinforced concrete, according to NTC-1926 [10].

Table 2. Test summary FRC (steel and synthetic).

Test type	Age, days																				
	3							7							28						
	T	A-5	A-9	A-18	S-1.5	S-3	S-5	T	A-5	A-9	A-18	S-1.5	S-3	S-5	T	A-5	A-9	A-18	S-1.5	S-3	S-5
Resistance to Strength compressive	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Resistance ion chloride															1	1	1	1	1	1	1
Nord test															1	1	1	1	1	1	1

2.3.2. Compressive strength test. Compressive strength tests in FRC (steel and synthetic), were done according to guidelines of NTC-673 [11]. The tests were carried out in a universal machine MATEST with a maximum capacity of 2000 kN; to ensure uniform load distribution to specimen, sheets of neoprene were used according to NTC-3708 [12]. All mechanical and durability tests were carried out in the Argos Colombia Laboratory's- Puente Aranda Plant, located in Bogota, Colombia.

2.3.3. Chloride ion penetration resistance test. The chloride ion penetration resistance test in fiber-reinforced concrete were done according to American Association of State Highway and Transportation Officials (AASHTO), AASHTO T277, or American Society for Testing and Materials (ASTM), ASTM C1202 [13]. The chemist compounds were NaOH to 0.3 N and NaCl to 3%. The obtained result is the quantity of energy used for the transfer of substances, in Coulombs.

2.3.4. Sulfate ion penetration resistance test; Nord test. The sulfate ion penetration resistance tests were done according to Nordtest, NT BUILD 492 [14]. The setup is similar to chloride ion penetration resistance test, the equipment, cells, specimens sizes used is the same but chemical compounds used in the ionic transfer are different since there is used $\text{Ca}(\text{OH})_2$ replacing the NaOH. In addition, the voltage was constant of 30 V and the measured result is the penetration in millimeters. Details of the experimental program are reported by Garzón [15].

3. Results and discussion

In order to evaluate appropriately the experimental obtained results, this study apply the parameters of classification stipulated in each procedure mentioned previously.

3.1. Fresh concrete properties

The actual specimen dosage obtained for two types of fibers is shown in Table 3. In addition, the measured values for steel fiber of slump, air content, unit weight, are shown in the Figure 1 and Figure 2 for synthetic fiber. In the Figure 1(a) can be observed a softly decrease of slump with addition of steel fiber. An increase of approximately 20 % of air content (A) is observed with addition of steel fibers (Figure 1(b)). The use of steel fibers does not affect specimens' unit weight as shown in Figure 1(c). Also, it can be observed in Figure 1(d) that actual dosage values are over the design content of fiber.

Table 3. Actual specimen dosages of steel and synthetic fiber.

Specimen	Design dosage (kg/m ³)	Actual dosage (kg/m ³)
A-5	5.0	5.5
A-9	9.0	9.7
A-18	18.0	16.4
S-1.5	1.5	1.7
S-3	3.0	3.7
S-5	5.0	6.4

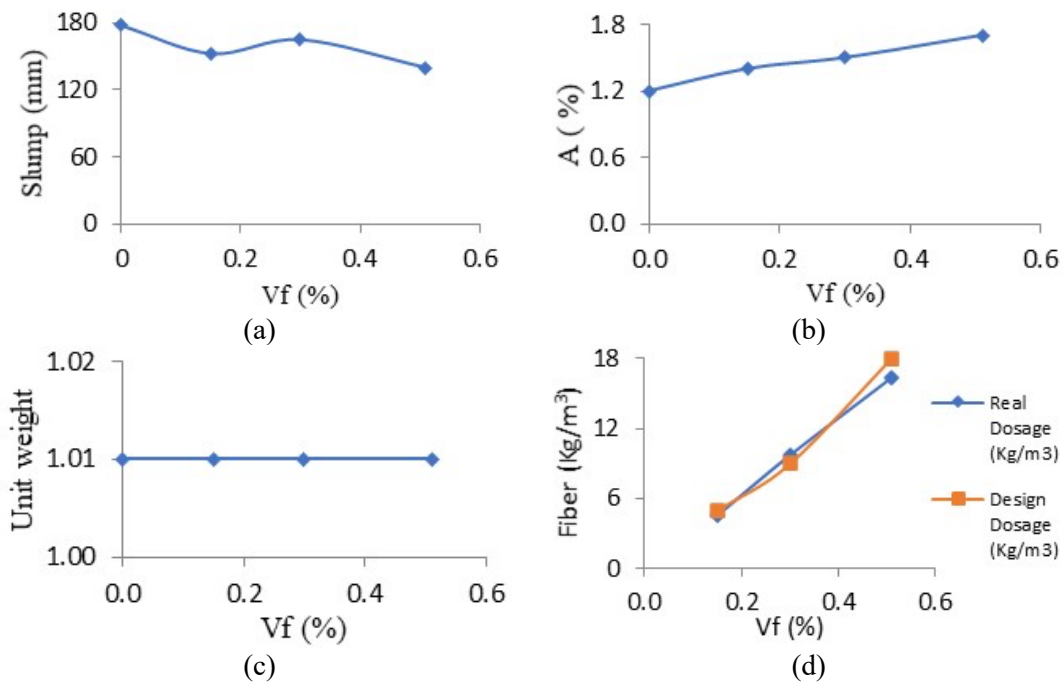


Figure 1. Fresh concrete properties for steel fiber; (a) slump, (b) air content, (c) unit weight, and (d) fiber content.

As can be observed in Figure 2(a), slump curve presents a significant decrease with increase of fiber because the fibers try to keep all the components of the concrete one close. An increase of air content (A) of approximately 30% is observed in Figure 2(b). A slightly change of unit weight it can be observed in Figure 2(c). For the case of the content of fibers, all actual values of dosage were over the values of design dosage, up to 28% for S-5 Figure 2(d).

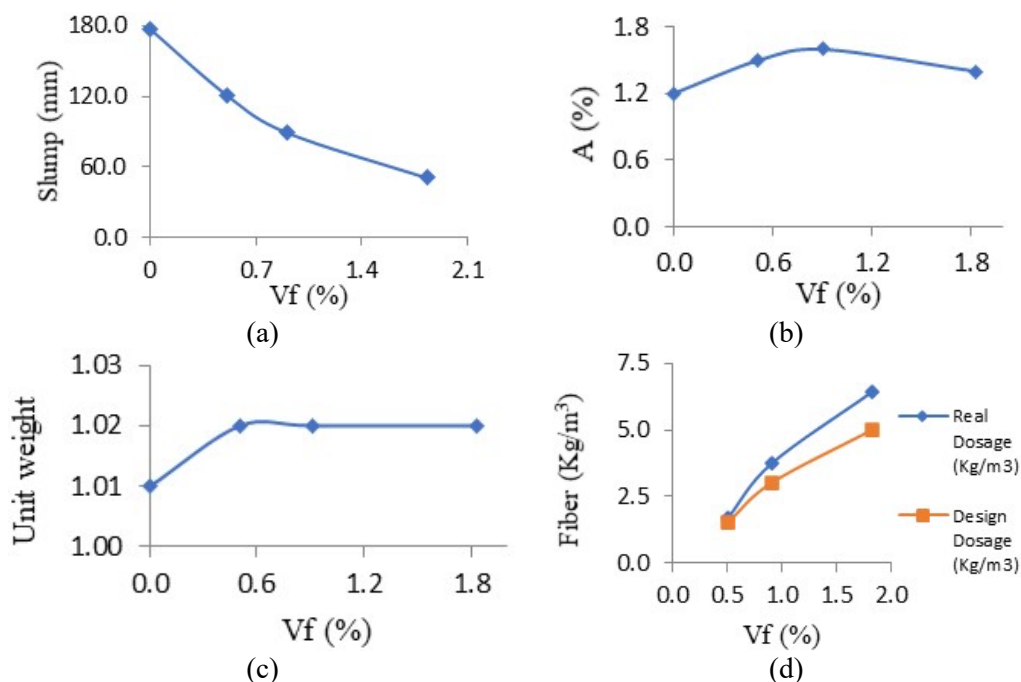


Figure2. Fresh concrete properties for synthetic fiber; (a) slump, (b) air content, (c) unit weight, and (d) fiber content.

3.2. Compressive strength properties

Figure 3 presents compressive strength curves of the fiber-reinforced concrete with steel fiber and synthetic fiber. It can be observed that all compressive strength results at 28 days of fiber-reinforced concrete are below the concrete simple. This result can be due to the distribution of the fiber in the specimen, which believes emptiness's between the fiber and the components of the concrete.

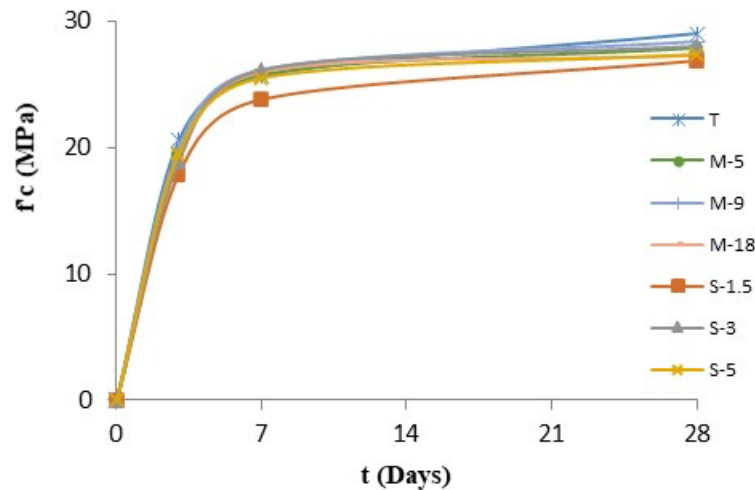


Figure 3. Evolution of strength compressive.

3.3. Chloride ion penetration properties

According to Figure 4 and based on the classification of Table 4, it shows that smaller steel fiber A-5 dosage and dosage of synthetic fiber S-5 exhibit lower loads chloride ion penetration Coulombs. The highest score has the specimen A-18, which is approximately 55% to concrete without fiber and has a high permeability, also the specimen S-3, as classified by ASTM C1202 [13].

Table 4. Classification results and chloride ion penetration resistance.

Specimen	Load Coulombs (C)	Classification according to ASTM-C1202 [13]
T	4001.5	High
A-5	1554.0	Low
A-9	3390.1	Moderate
A-18	6189.3	High
S-1.5	3788.1	Moderate
S-3	4004.5	High
S-5	2183.0	Low

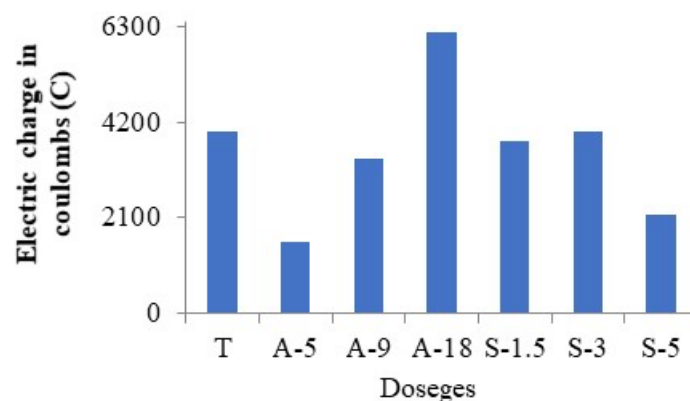


Figure 4. Resistance to chloride ion penetration.

3.4. Nord test properties

As shown in Table 5 the specimen with the highest average penetration was that one without dosing fiber (T), which is important because the change with the addition of fiber, evidenced by optimizing the conditions of durability and reducing the average penetration. It is clear that the specimen S-1.5 is the minimum value of sulfate ion penetration; it was about 93% lower than the highest score recorded. The best performance for the type of fiber, synthetic fiber has, as it has smaller penetration values regarding the results of the specimens of steel fiber.

Table 5. Nord test results test.

Specimen	Penetration (mm)
T	53
A-5	52
A-9	50
A-18	40
S-1.5	4
S-3	46
S-5	46

4. Conclusions

In this paper are presented the results of an experimental program to evaluate the durability of fiber-reinforced concrete with steel fiber and synthetic fiber. Addition of fiber in concrete generates a confinement effect by increasing the fiber content, the latter results in a decrease of penetration of water; this deduction is made by comparing the results of the specimens of each type of fiber with the specimen without fiber. Values of air content are increased with the inclusion of fiber in the concrete, reducing the gaps that were presented and optimizing the mix; all compressive strength test results of steel fiber reinforced, and synthetic fiber reinforced specimens were lower compressive strength without fiber specimen. The results are presented in terms of volume fraction in order to provide professional analysis and compare with other studies.

One of the main limitations of the study were data at different ages in all trials, so it could not perform numerical correlations or propose models to predict the impact of any aggressive agents that exposed concrete. Although the results obtained experimentally for the compressive strength of fiber-reinforced specimens are lower than those of unreinforced specimens, further research on concrete durability should be carried out, as it will allow the construction of structures that require less spending on maintenance and repair. In Colombia, conducting this type of research is important to encourage the use of fibers in concrete structures and optimize them to avoid having only a reactive behavior to pathologies in concrete structures. This is especially important for large infrastructure or housing developments that impact the quality of life of entire communities.

Acknowledgments

The authors gratefully acknowledge “Vicerrectoría de Investigaciones” at the Universidad Militar Nueva Granada (UMNG), Colombia, for financing the research project EXT-INV-3274. The donation of concrete and steel fibers from Argos, Colombia (Diego Velandia) and Proalco, Dramix (Liliana Cardona), respectively, is greatly appreciated. The authors also thank engineer Diego Garzón for his support during data and figures processing.

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