STEEL FIBERS ADDITION EFFECT ON TENSILE STRENGTH OF CONCRETE

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https://doi.org/10.21452/bccm4.2018.02.24

Abstract

This paper is an experimental study on a concrete class C50, reinforced with steel fibers (1,5% by volume) and assessment its properties in the resistance to direct and indirect traction. Uniaxial tensile, splitting and flexural tensile tests were performed with and without fiber reinforcement. The standard axial compression strength of the two concretes was found. To perform the direct tensile tests, prismatic specimens with a cross section of 25 x 100 mm and a length of 400 mm were made. Plates made of metal were glued to the ends of the concrete samples with epoxy adhesive to couple them to the press in order to obtain tensile forces. The Splitting Test and Flexural Tensile test were performed according to Brazilian standards. It was verified that the direct tensile strength is the lowest found for both concretes, and it varies around 20% in relation to the tensile tests by splitting and flexural traction in the simple concrete and 30% for the reinforced one. No significant differences were found in the strengths obtained between the Splitting test and the Flexural Tensile test for simple and reinforced concrete. As expected, the test results indicate the positive influence of the fibers on the tensile strength of the concrete. Gains of around 40%, 50% and 60% were obtained with steel reinforcement in uniaxial tensile, splitting and flexural tensile tests, respectively. Also as expected, it was observed that the fibers played their role in increasing the ductility and control of composite cracks.

INTRODUCTION

The concrete presents compressive strength as the main mechanical property from the structural point of view, however, when subjected to tensile stresses, it behaves in a fragile manner and with little deformation at rupture. An alternative to overcome this behavior is to add steel fibers to the matrix, which modify this fragile material behavior, significantly improving properties such as impact strength, crack propagation, ductility and toughness [1-2-3-4-5].

So, by reinforcing a concrete with steel fibers, it is possible to revert its brittle character due to the stress transfer bridge formed through the fiber, causing the concentration of stresses at the ends of the concrete to be minimized and the speed of crack propagation reduced [6]. However, it is common the occurrence of dispersions and significant differences in the results, which can be generated by variations in orientation, embedded volume, geometry and uniform distribution of fibers in the composite [7].

To the extent that the benefits in the use of fibers stand out through tensile tests, it should be emphasized that these have low reproducibility and are not standardized and because of this, and other methods are often used to acquire this data. Indirect results are achieved through the splitting test and flexural tensile test, but present great variability among them [8]. In order to correct this fact, since these results differ from the reference and traction value of the direct traction (fct), the conversion coefficients 0,9 and 0,7 are applied for the results of splitting test and flexural tensile test respectively [9]. According to the same source, if these tests cannot be performed, the results of uniaxial tensile can still be obtained through the compressive strength of the concrete (fck) by equation 1.

$$f_{ct,m} = 0{,}3fck^{2/3} \tag{1}$$

Therefore, the present study aims to evaluate mechanical behavior of concrete samples with and without addition of steel fibers in terms of tensile strength measured in three different ways, uniaxial tensile, splitting and flexural tensile tests. The correlation between these different test methods is conferred in comparison with standards and bibliography. Moreover, it is sought to quantify the effect of fiber addition on the results obtained by these three methods.

MATERIALS AND METHODS

2.1 Methods

Two mixtures of concrete were executed. The simple or reference concrete (SC) with the mixture proportion of: 43% gravel, 14% sand type 1, 17% sand type 2, 18% cement, 0.24% superplasticizer and 8% (water / cement ratio of 0.44). For the (CRFA) the previous trace was reinforced with 1.5% of steel fibers. The cement used was the Brazilian Portland Cement CP-V ARI. The gravel has a maximum aggregate diameter of 12.7 mm and a fineness modulus of 6.77. The sands used were of natural origin (sand 1 and sand 2), and their granulometry were classified as averages, which presented characteristic diameters and modulus of fineness respectively of 0.425 mm and 1.16 for sand 1 and 0.6 mm and 1.38 for sand 2. A superplasticizer additive (MC-PowerFlow, company MC-BAUCHEMIE) with a density of 1.05 g / cm was also added. The metal fibers have a length of 30 mm with hook at each end, and aspect ratio of 65.

2.2 Methods

2.2.1 Molding and curing of concrete

The molding and curing procedure followed the standard NBR 5738 [10], using cylindrical specimens with a diameter of 100mm and a height of 200mm, and prismatic with two cross sections of 25x100mm and 100x100mm, both with length of 400mm. These were left at room temperature for 24 hours for hardening and were subsequently cured in a humid chamber for 28 days.

The tests to characterize the axial compression strength were performed with cylindrical specimens following the procedures described by NBR 5739 [11]. Measurements of displacements through a strain gauge were still made, and these were fixed to the surface of the specimen. The test speed was performed at 0.08 mm / min, displacement of the traverse of the machine.

2.2.2 Uniaxial tensile test

The uniaxial tensile tests were performed on concrete prisms with cross section of 25x100mm and 400mm in length. As shown in Figure 1, steel slabs were glued on both sides at the two ends of the specimens through epoxy adhesive. The metal plates are used for the transfer of charge to the specimens through a rigid system composed of the labeled connection between the steel plates and the machine through a connecting pin.

It should be emphasized that during the process of fixing the plates to the prisms, it was necessary to ensure alignment, not only between plate and prism, but also between the central holes of the plates, which serve as the connection between the system and the machine. This process is taken to minimize or minimize eccentricities in performing the assay. The speed of the tests was 0.5 mm / min of the traverse of the machine.

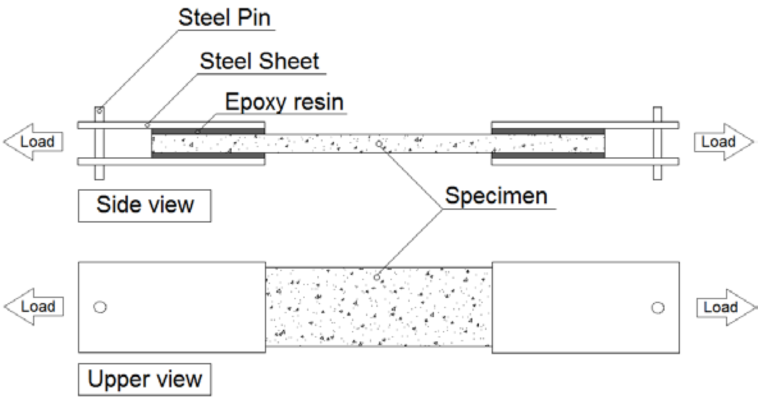

Figure 1: Detail of uniaxial tensile test

2.2.3 Splitting test

The tests were performed according to prescriptions and definitions of NBR 7222 [12]. The "Cumaru" (Dipteryx Odorata) wood, with an apparent density of 1090 kg/m³ and a compressive strength parallel to its fibers of 94,2 MPa [13], were used to perform the responsible wood stripe of the contact between the press and the test piece. The construction of the slabs was carried out according to the specifications of NBR 10024 [14] and the tests performed with a traverse displacement speed of 1.1mm/min.

2.2.4 Flexural tensile test

This test was performed according to NBR 12142 [15], thus imposing two concentrated loads, located at a distance of L/3 to the nearest support. The test was carried out at a speed of 0.5 mm / min of the displacement of the machine beam.

RESULTS AND DISCUSSION

The average compressive strength (fcj28) SC and SFRC, determined by the Uniaxial Compression test with three specimens for each trait, was 49.3MPa (CV = 3.2%) and 48.5MPa (CV = 3, 0%), respectively. Figure 2a shows the typical compressive stress x deformation curves found in the uniaxial compression test. It is observed in this figure that the addition of steel fibers to the concrete provides a relatively low improvement in its ductility and modulus of elasticity, on average 33 GPa.

The typical uniaxial tensile test curves are shown in Figure 2b. It was found that the SFRC obtained a performance in the order of 40% higher than SC against the ability to withstand the axial loads of traction. As mentioned by [6], this occurs due to the fact that the steel fibers arranged inside the matrix act as bridges between the fissures, controlling their propagation.

SFRC specimens also showed an increase in tensile strength obtained by the indirect tests normalized by NBR 7222 [12] and NBR 12142 [15], when compared to SC, 56% higher for the splitting test and 60% in the flexural tensile test. The typical force-displacement curves for the two analyzed traces found in the splitting test and in the flexural tensile test are presented in Figure 2c and Figure 2d respectively.

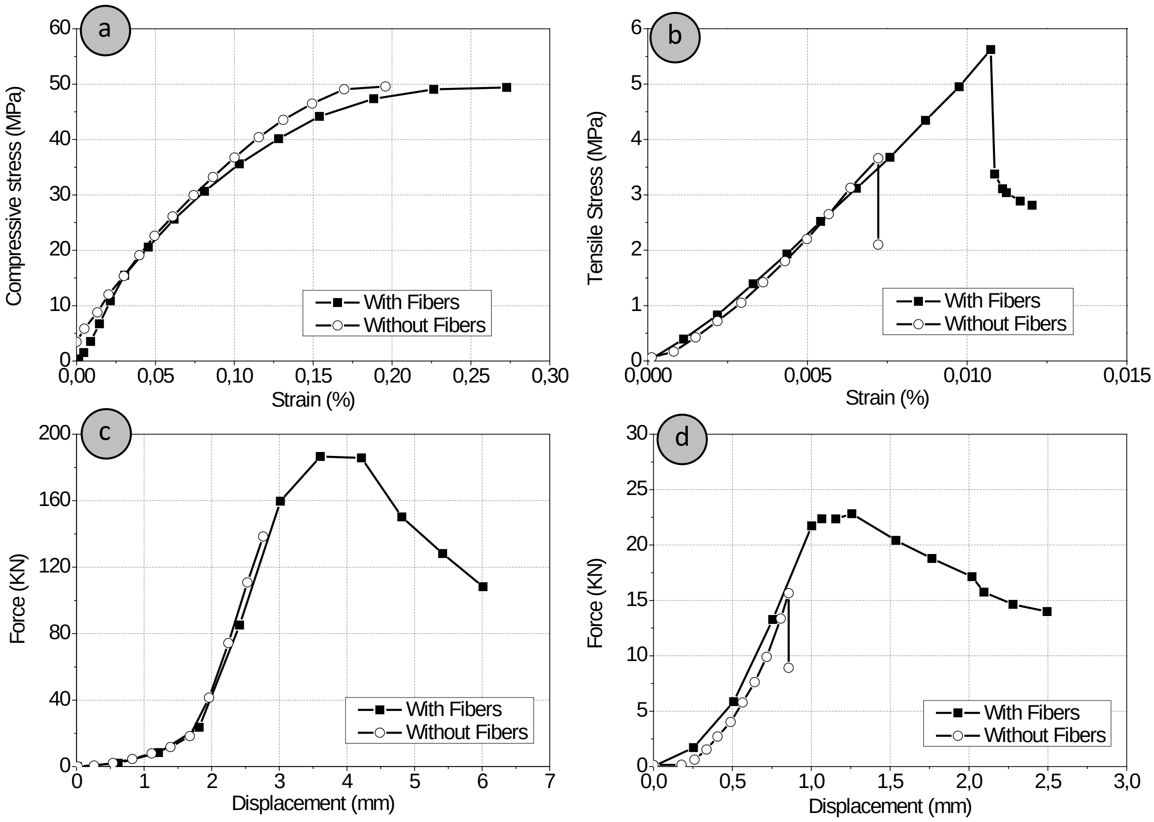

Figure 2: Typical stress-strain curves: a) Uniaxial Compression test and b) uniaxial tensile test and typical force displacement curve for c) splitting test and d) flexural test.

Figure 3 shows the results of the strengths obtained for each test performed on the concrete with and without fibers.

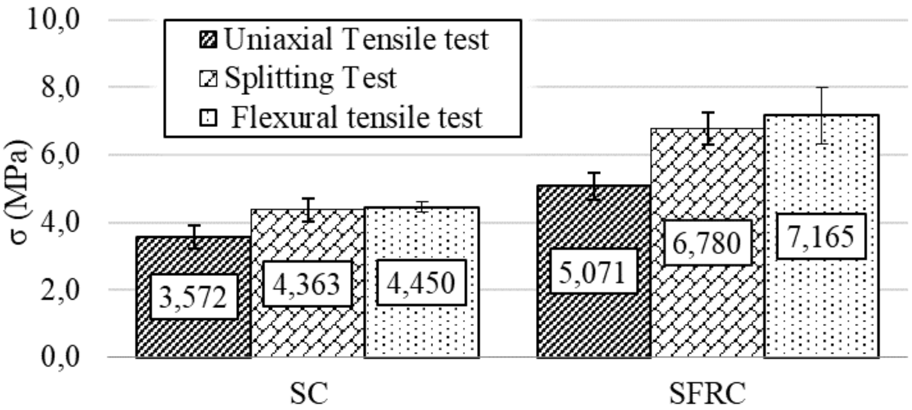

Figure 3: Tensile strength of SC and SFRC obtained with different methods. One standard deviation is plotted in the graphic.

Performing a variance analysis (ANOVA) of the results it was possible to verify that the interaction between the test methods and the use or not of fibers, are not statistically significant factors. However, both the test method performed and the addition or not of fibers modify the results. A comparison of means by the Fisher method [16] found that between the tensile and Brazilian test flexural tests there is no statistically significant variation for both SC and SFRC. These results are presented in Figure 3. Thus, according to the experimental tests carried out in this work, it can be inferred that the use of indirect methods to determine the tensile strength of concrete has an equivalence, independent of the addition or not of steel fibers.

This last observation is in agreement with NBR 6118 [9] which states that the uniaxial tensile test (fct) can be calculated from the uniaxial tensile tests found by the Splitting test (fct,sp) or flexural test (fct,f) applying corrective factors that are worth 0.9 and 0.7 respectively. In this work it was found that the correction factor should be of the order of 0.80 for the two indirect SC-related tests.

When the relationship between indirect and direct resistance to reinforced concrete was analyzed, it was possible to verify that the correction factor is between 0.7 and 0.75, regardless of the indirect method analyzed.

Two observations can be made here. First, the fibers increased the difference between the direct and indirect tensile strengths and, secondly, that the number of tests performed were not sufficient to find a statistically significant difference between the splitting test and the flexural test, but a difference in means was observed. In this way, further testing is necessary to ensure these results.

The analysis of the empirical relations for uniaxial tensile test from the compressive characteristic strength provided by NBR 6118 [9] (equation 1) for simple concrete are shown below (Table 1).

Table 1: Results submitted to stress relationship criteria according to NBR 6118 [9]

fck (MPa)	**f**ctm (MPa)		
	fctm	**f**tk,inf	**f**tk,sup
49,3	4,03	2,82	5,24

A compressive strength of 49.3MPa results in an average tensile strength of 4.03MPa. This value is 13% higher than the experimentally found average (3.57MPa). However, considering the intervals of lower and upper variation of 2.82MPa and 5.24MPa, respectively, all the results found in the direct and indirect tests concerning the simple concrete, would be within the limits of variation imposed by reference to the norm. Also, according to NBR 6118 [9], the value to be used for the calculations that depend on the traction value is fct, inf, that is, before the values found the norm is very conservative, since the (3.57 MPa SC) the difference is 26%, whereas for concrete SFRC it is approximately 80% lower.

It is also emphasized the role of fibers in the control and development of multiple cracks [7], developed by the same ones through the better distribution of the tensions inside the composite [6]. Analyzing the typical curves of the tests (Figure 2), the addition of fibers in the cementitious matrix provides a product with a pseudo-ductile characteristic, with no brittle rupture and with significant increases in resistance to direct and indirect tensile stresses.

The type of rupture resulting from the different tensile tests studied is presented in Figure 4, where the images marked with a1, a2, a3 refer respectively to uniaxial tensile test, splitting test and flexural tensile of SC and the images marked with b1, b2, b3 are referring, respectively, to the same tests already mentioned, but for the SFRC. It is observed in the images of the concrete SC the appearance of practically a main fissure, whereas in the images of the concrete SFRC, multiple fissures appear, and in the surroundings of these main fissures a nucleation of small cracks, provoked by the pulling of the fibers.

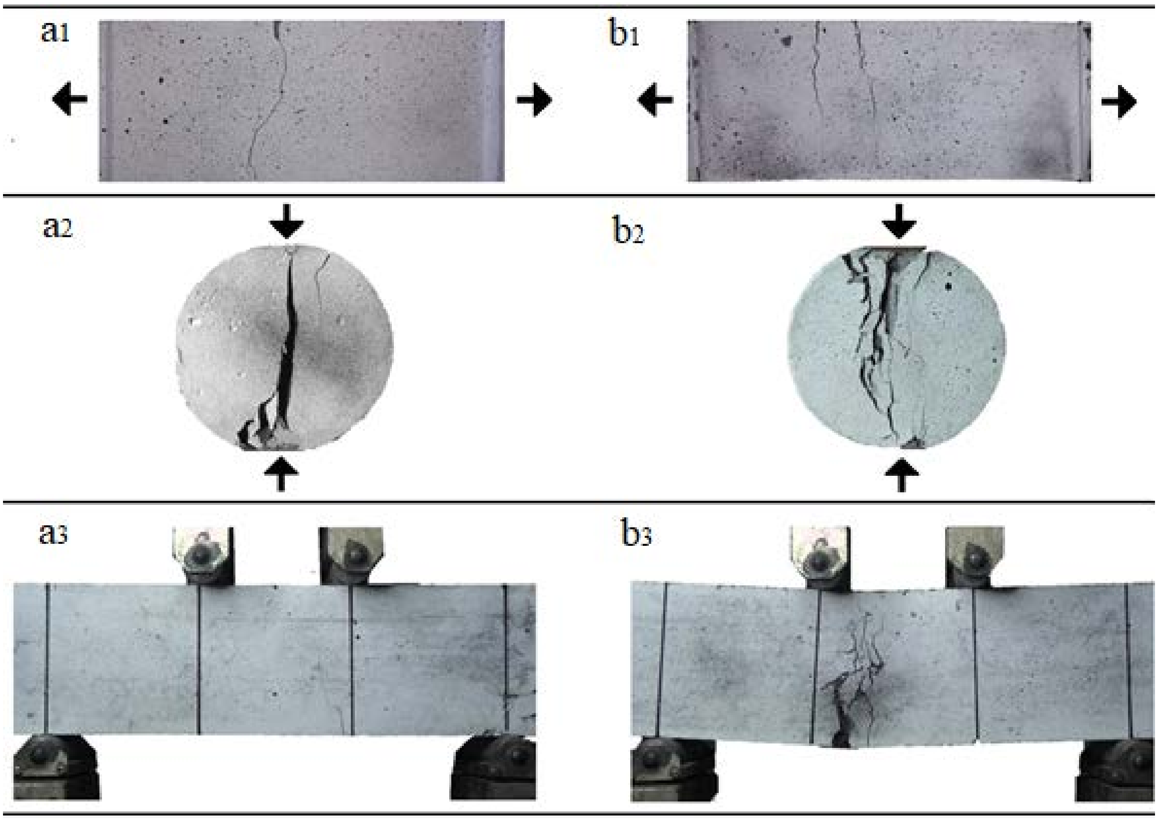

Figure 4: Comparison of (a) SC and (b) SFRC rupture versus (1) direct tensile test, (2) splitting test and (3) flexure tensile test.

4. CONCLUSIONS

In this paper an experimental study under the influence of fiber addition on the tensile strength of the concrete obtained by different methods is presented. The direct tensile strength of SC is 20% lower than the resistance found in indirect tests. The SFRC concrete behaves in the same way, but with a difference of 25 to 30% lower than the other tests.

The addition of steel fiber to the simple concrete followed the expected and contributed to the increase of ductility and control of fissures. This addition also provided positive gains in increasing manner comparing the tests of uniaxial tensile, splitting and flexural tensile. In addition, it was possible to note that two types of indirect tests performed return values without significant variations. Finally, when compared to the values of tensile strength determined by NBR 6118 [9], it is observed that for the concrete containing fibers, the determined value is about 80% smaller, indicating that the standard is quite conservative.

ACKNOWLEDGEMENTS

The authors are grateful for the UNIPAMPA, FAPERGS and CNPQ support, who have made and did their best to carry out our research. they are especially grateful for the support of Pilecco Nobre, a constant partner in the MAEC research group.

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