MECHANICAL AND BOND BEHAVIOR OF CARBON TEXTILE REINFORCED CONCRETES UNDER TENSILE LOADING

Rebecca Mansur de Castro Silva [1] and Flávio de Andrade Silva [1]

(1) Department of Civil and Environmental Engineering, Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro, Brazil

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Abstract

In the last years the use of textile reinforced concrete (TRC) has grown considerably. Several types of fibers can be used in the form of textiles. Carbon fabrics have become an interesting reinforcement for TRC due to their excellent mechanical properties. However, the bond between carbon textile and cementitious matrix is not elevated. There are methods that can modify the textile-matrix bond, improving the mechanical behavior of the composite. In this paper the mechanical behavior of carbon textile reinforced concretes under tensile loading is discussed. Two types of carbon fabrics were studied: a flexible and a rigid one. The influence of the use of a coating made with an epoxy resin and sand in the response of the composite was investigated. Various stages of loading corresponding to initiation, propagation, distribution, opening, and localization of a crack system in the specimen were discussed. Pull-out tests were performed in textile's yarns to characterize and compare the interface between the two types of carbon reinforcement and the cementitious matrix. The results obtained showed that the TRC with rigid carbon fabric achieved superior mechanical response under tensile loading. The addition of the coating made with an epoxy resin and sand was able to improve the tensile mechanical response of these composites, suggesting an enhancement in the bond between the fabric and the matrix. This improvement was more significant in the TRC with the flexible carbon fabric.

1. INTRODUCTION

The research of new materials that allow the construction of thinner, lighter and less expensive structures has grown considerably in the last years. An interesting example of these materials is the cementitious matrix reinforced with fibers composites. The fibers control the matrix cracking, modifying the mechanical behavior of the composite after the first matrix crack and improving its ductility [1].

Textile reinforced concrete (TRC) is a cementitious matrix composite reinforced with multiple layers of 2D or 3D fabrics [2]. Several fibers can be used to fabricate this type of reinforcement, such as natural, glass, polypropylene and carbon. Among these materials, carbon fibers show elevated mechanical and durability properties [3,4,1,5].That poses as one of the reasons why the use of carbon textile as reinforcement in cementitious matrices is becoming extremely attractive. Recent studies [6–9] show the elevated mechanical behavior of the carbon TRC under tensile loading and bending.

The mechanical behavior of TRC is influenced by the properties of the matrix, reinforcement, and mostly the interface between them. The bond between the reinforcement and the matrix is one of the main characteristics of the interface [10]. However, the bond between fabrics constituted of multifilament yarns, as carbon textiles, is not elevated [1]. Studies [6,8,11,12] show that there are methods to improve the bond between the fabric and the cementitious matrix, enhancing the mechanical behavior of the composite.

This work presents a study of the mechanical and bond behavior of carbon textile reinforced concretes under tensile loading. Direct tensile tests were performed in TRC with two types of carbon fabrics (flexible and rigid) to evaluate their mechanical behavior. The influence of the addition of a coating made with and epoxy resin and sand on the tensile mechanical response of the carbon TRC was also investigated. In order to analyze the interface between the reinforcement and the cementitious matrix, pull-out tests were performed in carbon yarns.

2. EXPERIMENTAL PROGRAM

2.1 Cementitious matrix

The matrix used in this research was a fine-grained concrete with compression behaviour shown in Figure 1. The mix proportion used was 1:1:0.3 (sand:cementitious material:water by weight). Portland cement CPII F-32, defined by the Brazilian standard [13], and river sand with maximum diameter of 1.18 mm were used. Glenium 51 (MS) with content of solids of 30% was used as superplasticizers. Table 1 presents the compositions of the fine-grained concrete matrix.

(a) (b)

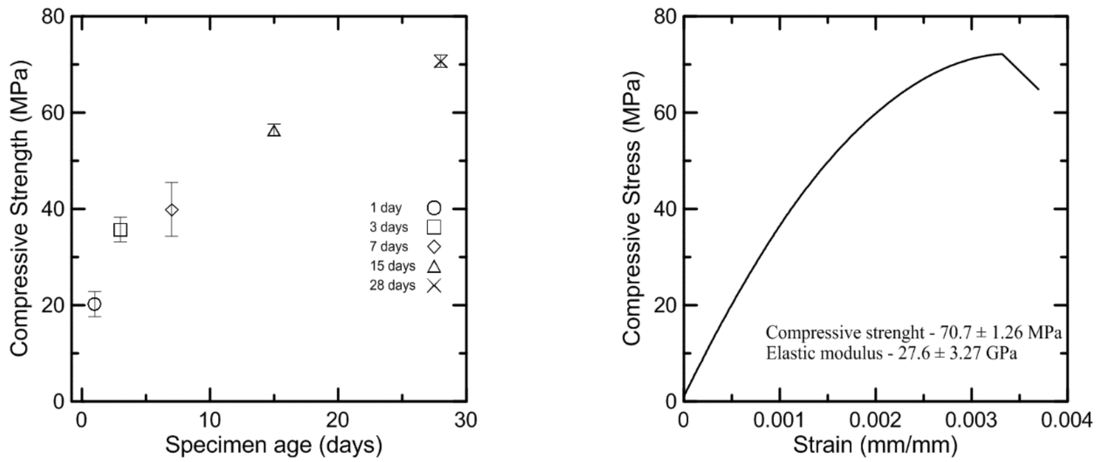


Figure 1: (a) Strength evolution and (b) compressive behavior of the cementitious matrix.

Table 1: Cementitious matrix composition.

Composition	
Sand (kg/m³)	947
Cement CPII F-32 (kg/m³)	750

Fly ash (kg/m³)	265
Silica fume (kg/m³)	50.5
Water (kg/m³)	279.7
Superplasticizer (kg/m³)	6.31

2.2 Carbon fabric

Two types of carbon fabric were used as reinforcement: a flexible, provided by V.Fraas GmbH, and a rigid one, provided by Solidian GmbH. Both fabrics present an open mesh layout, as shown in Figure 2, and were coated during their fabrication process. According to the suppliers, the rigid fabric has an epoxy resin coating and is tensile strength corresponds to 4000 MPa, and the flexible fabric, has a styrene butadiene resin (SBR) coating and tensile strength of 1700 MPa.

A coating made with epoxy resin, Sikadur®-32, and sand with the same grain size of the one used in the matrix were applied to the fabrics. The resin were spread on both sides of the textiles and then sand were sprinkled over it.

(a) (b)

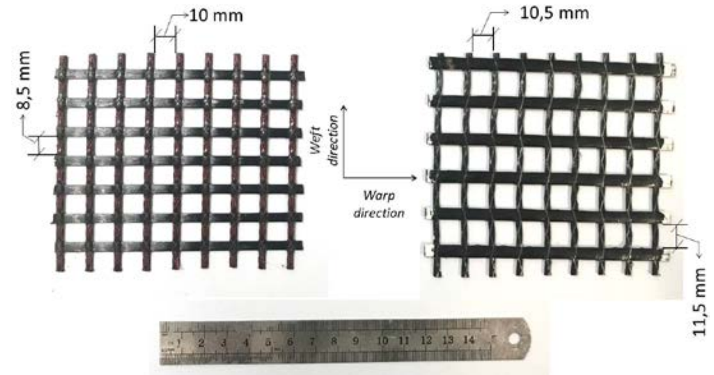


Figure 2: (a) Flexible and (b) rigid carbon fabrics.

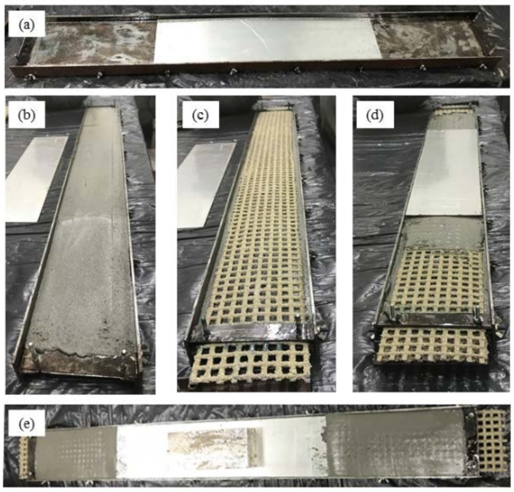
2.3 Composite manufacturing

The matrix was produced using a bench-mounted mechanical mix of 20 L capacity. The cementitious materials and sand were dry mixed for 60 s. The water was added and the mix was homogenised for 4 min. Then, the superplasticizer was incorporated and the mix was blended for additional 5 min.

For the direct tensile tests, rectangular plates were casted in a steel mold measuring 1000 mm x 120 mm x 18 mm (length x width x thickness). Figure 3.a shows the specimens production using a lamination technique. A thin concrete layer was placed on the bottom of the mold and the carbon textile reinforcement was positioned over the fresh concrete. Another thin layer of concrete was placed over the fabric. To avoid bending and slippage during the casting, the fabrics layers were attached into screws at the ends of the mold. In order to reduce the section of the specimen in the mid-span, two aluminum plates measuring 500 mm x 120 mm x 1,5 mm (length x width x thickness) were used, one at the bottom of the mold and the other at the top of the mold. The thickness of the samples varied according to the type of carbon fabric used and the presence or not of a coating made of epoxy resin and sand. The specimens were covered in their molds for 24 h. After that period they were wetted and involved in plastic film and stored in a room with controlled temperature (20ºC ± 2ºC) and humidity (55% ± 5%) for 28 days.

For the pull-out tests, cylinders were casted in PVC molds with 25 x 20 mm (diameter x high) supported on an acrylic plate (Figure 3.b). The matrix was put on the molds and a yarn of the carbon fabric, with embedded length of 20 mm, was positioned in the center of the cylinders (Figure 3.b). The specimens were removed from the molds after 24 h and stored in a wet chamber with 100% of humidity and temperature of 21ºC ± 2ºC for 7 days.

(a)



(b)

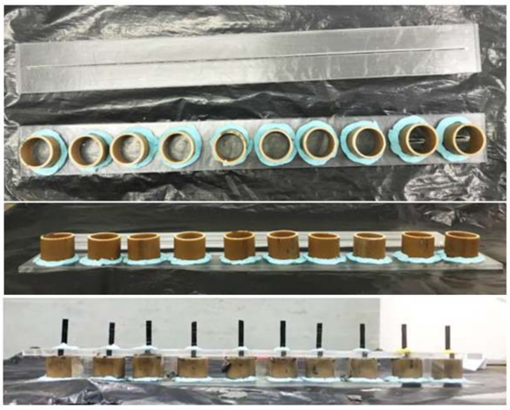


Figure 3: Fabrication of carbon TRC composites for (a) direct tensile and (b) pull-out tests.

2.4 Direct tensile tests

Direct tensile tests on the carbon TRC plates were performed in a MTS 311 universal testing machine with capacity of 1000 kN. The tests were controlled by the actuator displacement at a rate of 0.5 mm/min. The specimens were tested using a gage length of 500 mm with fixed-fixed boundary conditions. The specimens were fixed in steel plates at their ends with screws (Figure 4). The screws were tightened with a torque wrench and emery papers were glued at the surfaces of the specimens that were in contact with the steel plates, in order to avoid slippage between the specimens and the steel plates. The boundary conditions (number of screws, torque and contact surface between the specimen and the steel plate) varied according to the type of the composite (Table 2). To obtain the displacement of the specimens, two linear variable differential transducers (LVDTs) with reading capacity of 250 mm and a extensor made of aluminum attached to them were used. At least four specimens for each variation were tested.

The tensile stress was obtained dividing the load recorded from the load cell by the composite area (width x thickness). The strain was obtained by the division of the average displacement measure by the LVDTs and the gage length of the specimen (500 mm).

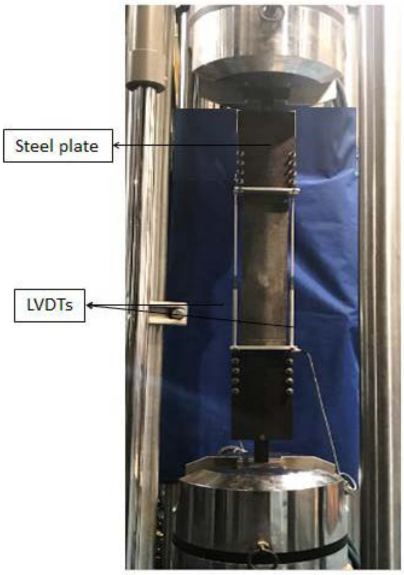


Figure 4: Direct tensile test setup.

Table 2: Boundary conditions for the carbon TRC submitted to direct tensile tests.

	Plain flexible fabric	Coated flexible fabric	Plain rigid fabric	Coated rigid fabric
Screws/steel plate	8	8	10	10
Torque (Nm)	18	19	18	29
Contact surface (mm^2)	18000	24000	24000	24000

2.5 Pull-out tests

Pull-out tests on the carbon yarns were performed in a MTS 810 universal testing machine with capacity of 250 kN. The tests were controlled by displacement at a rate of 1.5 mm/min. To obtain more accurate results, a load cell with 2.5 kN capacity was used. The specimens were attached to the machine through claws, in a fixed boundary conditions system (Figure 5). The yarns slip was obtained directly from the machine displacement [14]. At least eight specimens for each variation were tested.

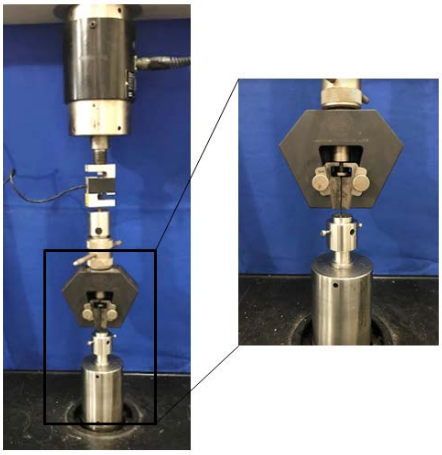


Figure 5: Pull-out test setup.

3. DISCUSSION AND ANALYSES

The carbon TRC with flexible and rigid fabric presented a strain hardening behavior in direct tensile tests. Figure 6 shows representative tensile stress-strain curves obtained from the tests, which present three distinct stages, identified with roman numerals. In Stage I both matrix and reinforcement behave linearly, corresponding to an elastic-linear region. The point where occurs the first matrix crack is known as bend over point (BOP) and represents the limit of State I. In Stage II as the applied strain increases more cracks are formed culminating in a multiple cracking pattern along the composite. Since the fabric provides ways to transfer the stresses through the cracks, after the initiation of crack in the matrix the load-carrying capacity of TRC does not reduce. The Stage III is characterized by the widening of the existing cracks, with no formation of new cracks, leading to a stretching of the fabric, and posterior failure of the composite.

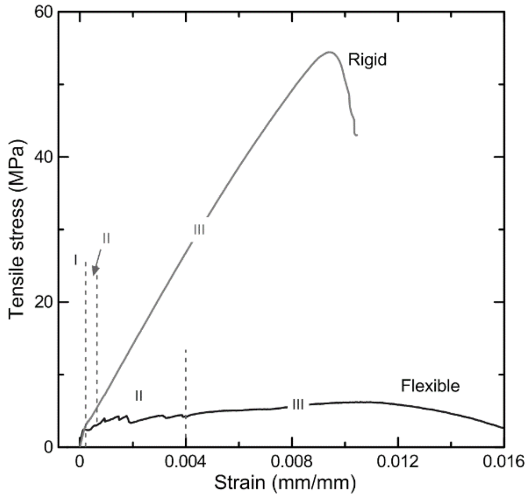


Figure 6: Influence of type of fabric on the tensile stress-strain relation for carbon TRC.

The TRC with rigid carbon fabric showed superior tensile mechanical performance than the TRC with flexible carbon fabric. This could indicate that the bond between the rigid fabric and the cementitious matrix is superior to the bond between the flexible fabric and the cementitious matrix. The difference between the bonds of the two reinforcements with the matrix may be related to the different polymeric coatings used in the fabrication of the textiles. The polymeric coating fills the spaces between the filaments of a yarn, guaranteeing that all the filaments are anchored in the matrix. Therefore, the interaction between the reinforcement and the matrix is improved [8,10,15]. Hence, the coating used in the fabrication of the rigid carbon fabric (epoxy resin) seems to be more efficient in filling the spaces between the filaments than the one used in the fabrication of the flexible carbon fabric (SBR).

Figure 7 shows the influence of the addition of a coating made of epoxy resin and sand on the tensile response of TRC with flexible and rigid carbon fabrics. For both types of composites the impregnation of the reinforcement with epoxy resin and sand improved the mechanical behavior of the material, indicating an improvement in the bond between the carbon textile and the cementitious matrix. Since the plain flexible fabric exhibited lower bond with the matrix than the plain rigid fabric, the effect of the coating with epoxy resin and sand was more significant to the tensile behavior of the TRC with flexible carbon fabric.

Pull-out tests were performed to analyze the reinforcement-matrix interface. The representative curves pull-out load *versus* slip obtained from the pull-out tests are showed in Figure 8. The TRC with rigid fabric presented higher pull-out loads of the yarn than the one with flexible fabric, indicating that the bond between this fabric and the cementitious matrix is superior. The addition of a coating made with an epoxy resin and sand raised the pull-out load of the carbon yarns. The difference between the pull-out loads of the plain and coated yarns was more pronounced for the flexible fabric. The results obtained from the pull-out tests justify and reinforce the carbon TRC behavior under direct tensile loading.

(a) (b)

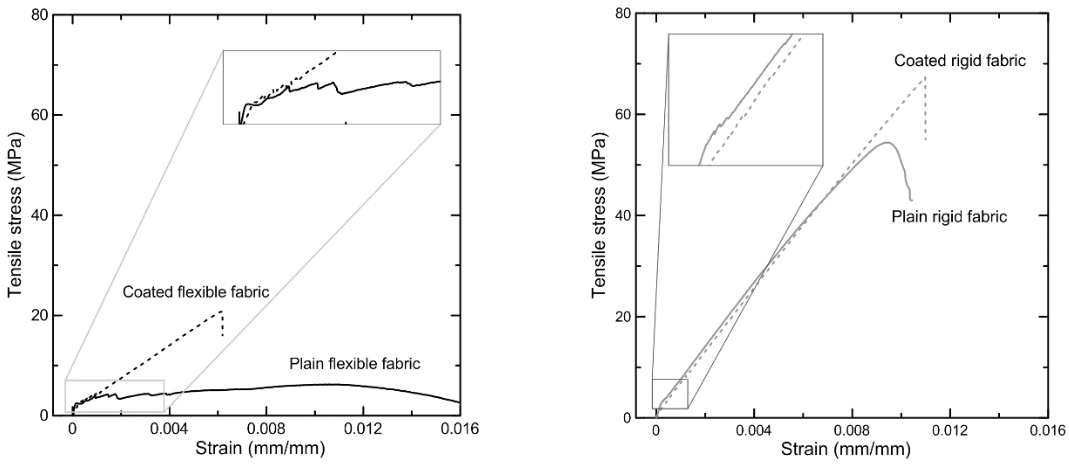


Figure 7: Influence of the coating made of epoxy resin and sand on the tensile response of TRC with (a) flexible and (b) rigid carbon fabrics.

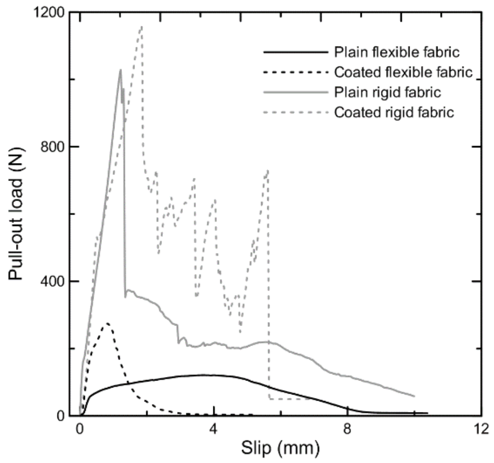


Figure 8: Representative curves obtained from pull-out tests.

4. CONCLUSIONS

A study on the mechanical and bond behavior of carbon textile reinforced concrete under tensile loading was presented. Two types of carbon fabrics, a flexible and a rigid one, were used and the influence of the addition of a coating made with an epoxy resin and sand was investigated through direct tensile and pull-out tests.

All the composites tested showed strain hardening behavior under direct tensile loading, as expected for this type of material. Three typical distinct zones could be observed in the tensile stress-strain curves. The TRC with rigid carbon fabric presented superior tensile performance, indicating that the bond of this textile with the cementitious matrix was higher than the bond of the flexible carbon fabric. The results from the pull-out tests seem to support this assumption.

The addition of a coating made with epoxy resin and sand improved the mechanical response of carbon TRC composites under tensile loading. This improvement was more significant in the TRC with flexible carbon fabric. Once more the results obtained from the pull-out tests confirm the response of the composite under direct tensile loading.

5. AKNOWLEDGMENTS

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