CONCRETE REINFORCEMENT WITH CARBON FIBER RODS –A STUDY OF FIBER/CEMENT MATRIX INTERFACE

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ABSTRACT

There is an increasing trend of using metal fibers or synthetic fibers, such as polypropylene, strengthening cement, creating favorable conditions for its use. An important application, mostly using carbon fibers, is one in which beams and columns of buildings and bridges are supported by the outer casing of fabrics of this material, avoiding a possible demolition of the structure.

In the present study continuous carbon fiber sticks were inserted in concrete blocks and pullout tests were performed to analyse the fiber/cement matrix interface. The test apparatus were designed for this work and the specimens were modified and adapted to the operational systems according to the present technical standards.

Typically, polymer composites exhibit good adhesion at fiber/matrix interface because the fibers present a surface sizing that is compatible with the polymer matrix to be used in the manufacture of the composite, thus promoting adhesion of the two materials. However, cement is an inorganic material and there is no mechanism that creates the compatibility of cementitious matrices with glass or carbon fibers.

Thus, to promote a good mechanical adhesion between fiber and cement matrix, it was developed a technique that changed the surface of the carbon fiber and some surface roughness was created to ensure its adherence to the cement. The interface performance was evaluated by pull out tests.

1 INTRODUCTION

In the mid last century, the use of non-metallic fibers associated with mortar, bricks and floors began to be effectively studied to obtain composites that would offer advantages over steel rebar structures [1].

Today there are an increasing number of studies regarding applications of synthetic macro fibers, fabrics or carbon fibers mats in civil construction, to compensate axial, flexural and shear requirements [2]. From such knowledge, propositions arose for using different types of fibers to reinforce structural elements, such as beams and pillars that had undergone some kind of damage by excessive overload, to make some structural adequacy in commercial buildings or to restore architectural features of historic buildings [3].

In this innovative study, the insertion of a reinforcement element in the concrete cube was experimented in order to replace the traditional metallic bar. So, rods containing continuous carbon fiber filaments were manufactured in order to provide a structure that resisted both to electrolytic corrosion, due to leakage electrical current, and to electrochemical corrosion, caused by acid rain or by sea environment, and also to chemical corrosion, which regards the action of some material directly over the reinforcement element. The shear stresses on the fiber/cement matrix interface were determined by pullout tests. Since no similar papers were found in the literature, the results were compared to those obtained in equivalent tests applied to specimens made with corrugated steel bars that are daily used in civil construction.

2 FIBER/MATRIX INTERFACE

The fiber/matrix interface can be defined as the area that is close to the fibers surface and next to the matrix that involves them. Considering the meaningful difference between the elastic properties of the composite raw materials, it will be up to the interface to make them compatible. It is important to point out that the modulus of elasticity of a cement matrix is 30 GPa, whereas the modulus of elasticity of a high strength carbon fiber is 230 GPa.

Knowledge on the interface properties, which are specific for each fiber/matrix system, is essential to lead to the understanding of physical and mechanical properties of composite materials and it is one of the most important factors regarding the resistance to material fracture [8]. The obtained results in this analysis are important to evaluate the laminate mechanical behavior.

In polymeric composites it is intended to create an affinity between the fiber and the polymer matrix to provide efficient bonding between the materials constituting the composite. This is possible by introducing functional groups in the fiber surface, like in carbon fiber for example, where they are introduced by electrolytical treatment after carbonization. In cement matrix composites, however, there is no feasible way to promote some chemical bonding to the carbon fiber reinforcement. Therefore, a surface finishing was developed in the present study to allow an efficient mechanical bonding between those two materials

3 EXPERIMENTAL

3.1 Materials and processing

In case of concrete structures reinforced with fibers, some roughness must be created on their surface in order to guarantee the adherence between the fiber and the cement matrix since they are different from polymer matrix composites in which there is a chemical affinity between the reinforcement element and the polymer matrix. In cement matrix composites, since it is an inorganic material, there is no affinity between the fiber and the cement matrix, so it is mandatory make some alteration on the fiber surface to guarantee its adherence. Thus, the present study proposes, as a solution, to fixate dry small aggregates on the fiber surface by using a polymer matrix, which will be called rods. Two different groups of rods were made, named as rods with thin roughness (RF), when the aggregates retained in 0.3 to 0.6 mm sieves(45 and 30 Mesh sieves) were used, and rods with thick roughness (RG) when aggregates retained in 0.6 to 2 mm sieves (30 and 10 Mesh sieves) were used. Fig. 1 shows the rods in the oven, placed in the fixation device, which keeps them aligned and pulled to cure the polymer matrix and fixate the small aggregate on the fiber surface.

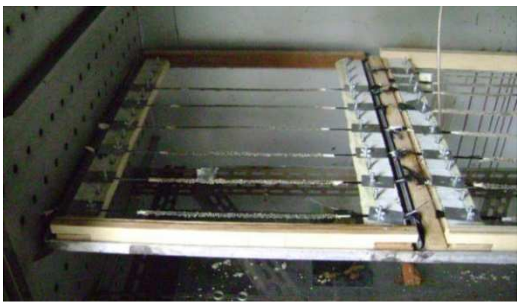

Figure 1.Rods placed in the fixation device to cure the polymer matrix.

3.2 Reinforcement of carbon fiber–rods

Rod, is the name given to a fiber segment that received surface finishing and that will resist to resulting strains from loads acting on a concrete element. It is a composite material consisting of continuous filaments of carbon fiber and polymer matrix and it has, as mentioned above, small aggregates fixated on the fiber surface. Fig. 2 shows the three steps for a rod manufacturing, in perspective and transverse section. A fiber roving segment Fig. 2a, its surface covered with polymer matrix Fig. 2b and finally the rod showing surface roughness Fig. 2c.

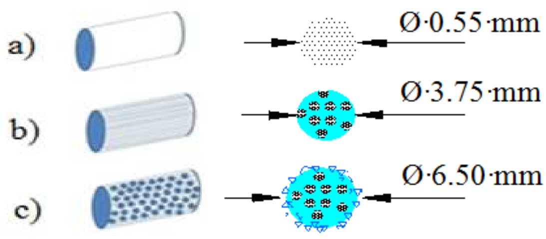

Figure 2.Perspective and schematic cross of the three steps of a reinforcement element: (a) a fiber roving, (b) a section of a rod impregnated with polymer matrix, (c) a section of a rod showing surface roughness

Conceptually, a composite material allows the engineer to quantify the percentages of each constituent material in order to create a material for specific application. In other words, the designer can highlight some desirable characteristics and minimize other undesirable ones through a calculated combination of components. When comparing a carbon fiber rod to a construction steel bar, the composite rod shows advantages since it is resistant to chemical attacks, it is neither magnetic nor conductive, it is light-weighted and it has a high association resistance/weight. Its disadvantage is the low working temperature, below 200ºC, due to the polymer matrix [8]. Fig. 3 shows a rod segment after testing, and on its right, it is possible to notice the coating to increase the surface roughness.

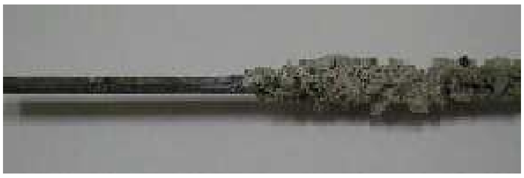

Figure 3. Rod segment after testing.

3.3 Pull out test

The method that is used to determine the resistance to friction was the pullout test. Such method consists of determining the necessary traction force to rupture the bond between the composite phases and move the reinforcement out of the cement matrix. Once the fiber/cement matrix bond is ruptured, the test is interrupted and at that point the pullout force is considered the limit force for that sample. The shear or adherence stress may then be obtained by the relation between the traction force at the sliding moment and the initial fiber friction area inside the concrete cube. The known factors were the average resistance to concrete compression(f_{cm}), the dimensions of the concrete specimen (cm) and the friction area of the fiber/cement interface (cm^2), measured on the rod. During the specimens preparation one of the difficulties was to find the most suitable way to fixate the rod to the testing device grip. At first, a method for rovings test was used, according to ASTM 4018 “Standard test methods for properties of continuous filament carbon and graphite fiber tows”, in which they are fixated by thick cardboard tabs on the tips of the rods, Fig. 4, of a specimen with the thick cardboard tab fixated on the tip of the rod Fig. 4a the apparatus for pullout test with a concrete cube Fig. 4b. Due to the rod diameter, such method proved inefficient. The conical-trunk shape of the grip end generates a progressive lateral compression force on the rod since the beginning of the test, leading to the fiber rupture before reaching the rupture value of fiber/cement matrix bond Fig. 4c.

a) b) c)

Figure **4.** Test according to ASTM 4018: (a) specimen with thick cardboard tab fixated on the tip of the rod, (b) arrangement for testing with a single concrete cube, (c) lateral compression on the rod in the testing device grip.

As a solution, it was attempted to have the rod fixated by two concrete cubes instead of just one. That new apparatus that was developed for the present study, as it is shown in Fig. 5a, brought important advantages since it eliminated the contact between the grip and the fiber, when just the concrete cubes are placed into the metal supports; it also reduced the equipment adjusting steps because the tabs pre-tensioning was no longer necessary, which made the results more reliable; and finally, it decreased the number of wasted tests for fiber damage. In Fig. 5b, it is possible to identify the two concrete cubes with the fiber placed in the center of those cubes and the device to fixate them. Fig. 5c shows a two-cube specimen whose dimensions are 100 x 100 x 100 mm, with a carbon fiber rod in its center.

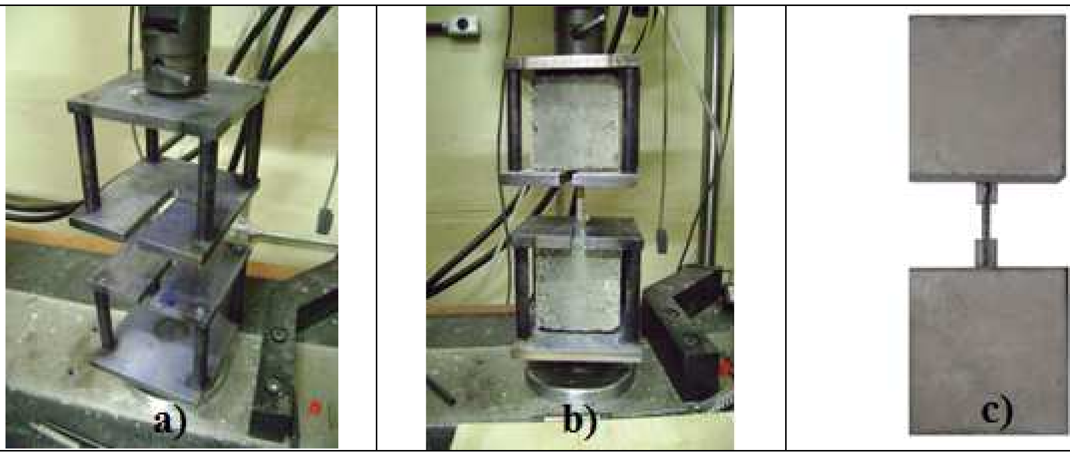

Figure 5**.** Apparatus to fixate the rods with two cubes: (a) detail of the opening for the fiber to go through it and the specimen centralization, (b) arrangement to test the concrete double cube, (c) detail of the specimen with two concrete cubes to determine the shear stress.

The set was pulled at constant speed of 1 mm.s^{-1} and the traction force evolution was measured up to the rupture of the system balance. The contact length of fiber/concrete interface was kept in 50 mm, and 50 mm were isolated by a plastic hose whose diameter was superior to the reinforcement diameter, as it is shown in Fig. 6.

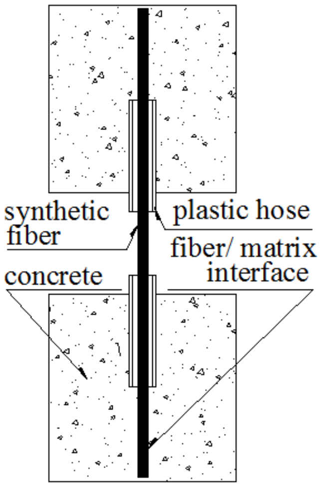

Figure 6. Schematic specimen assembling with two concrete cubes.

The contact surfaces between the cement matrix and the steel bars diameters 6.3 mm (1/4”) and 10 mm (3/8”) show respective areas of 989 mm² and 1575 mm², whereas in the rods of 3 and 9 rovings, they were respectively 393 mm² and 588 mm². Due to the irregular formation of the rods external surfaces, it was difficult to measure accurately the diameters 2.5 mm and 3.75 mm.

4 RESULTS AND DISCUSSION

The adopted value as the strength limit on the fiber/matrix interface was the last measured value before the fiber rod or the steel bar began sliding inside the concrete matrix. From the beginning of the sliding, there is a reduction in the adherence force up to the rupture of rod/matrix interface. The variables that represent the samples and the average results obtained for pullout forces (F_m) and shear stresses (τ) are shown in Table 1.

The tests results showed there was an increase of 85% in the shear stress value by using cement matrix cubes f_{cm}= 30 MPa compared to the values obtained between rods RF Φ = 2.5 mm and steel bars Φ = 6.3 mm, and an increase of 100% comparing rods RF Φ = 3.75 mm and steel bars 10 mm. With cement matrix cubes f_{cm}= 40 MPa, results showed an increase of 87% between rods RG Φ = 2.5 mm and steel bars Φ = 6.3 mm and an increase of 133% comparing rods RG 3.75 mm and steel bars10 mm. Fig. 7 shows the comparison between pullout test curves for concrete C40, varying the roughness and the rod diameter, pointing the force in the rupture moment for each test, and in Fig. 8, the pullout test curves for concrete C40 and the steel bars diameter variation are compared.

Batch of samples	f_{cm} (MPa)	Kind of roughness	Φ (mm)	F_m (N)	τ (MPa)
1	30	RF	2.50	5188	13
2	40	RF	2.50	5343	14
3	30	RF	3.75	9221	16
4	40	RF	3.75	9766	16
5	30	RG	2.50	5384	14
6	40	RG	2.50	5771	15
7	30	RG	3.75	11444	19
8	40	RG	3.75	12632	21
9	30	groove	6.30	7725	7
10	40	groove	6,30	8351	8
11	30	groove	10,00	11563	8
12	40	groove	10.00	14935	9

Table 1: Values of variable parameters and pullout force (F_m) and shear stress (τ) on carbon fiber/cement matrix interface.

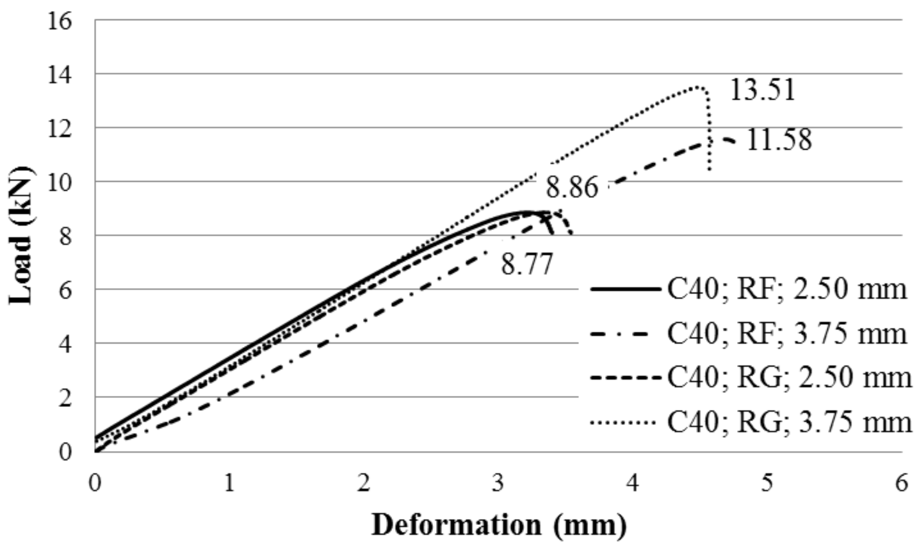

Figure 7**.** Curve of load *versus* deformation of four pullout tests with concrete C40, roughness variation and rods diameter variation.

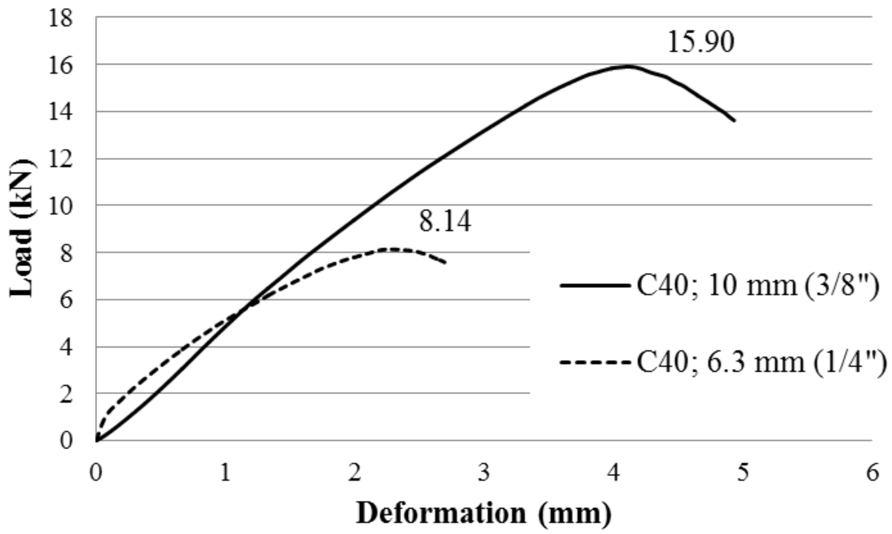

Figure 8. Curve of load *versus* deformation of two pullout tests with concrete C40 and steel bars 10 mm (3/8”) and 6.3 mm (1/4”).

5 CONCLUSIONS

In the present study a carbon fiber reinforcement element was developed to be used in concrete structures as an alternative to the traditional metal frames. The use of carbon fiber reinforcement increased the shear stress significantly when its parameters were changed from f_{cm}= 30 MPa to f_{cm}= 40 MPa, from RF to RG and from Φ= 2.5 mm to Φ = 3.75 mm, compared to the values obtained in tests with corrugated steel bars diameters 1/4” (6.3 mm) and 3/8” (10 mm). The possibility of variation of those three parameters guarantees the designer flexibility to change the reinforcement characteristics and to use specific rods for each structure.

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