STUDY OF FIBER-CONCRETE REINFORCED WITH CFRP SHEETS

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Abstract: One of the applications of composites in civil construction regards the recovery of structures that suffer continuous action of aggressive agents, for instance like acid rain, and/or when they are submitted to a load that is beyond the strength limit they have been designed for, which might be a consequence of the alterations on their initially proposed design. In the present work a carbon/epoxy matrix composite sheet for structural application was bonded to the tensile surface of a concrete specimen submitted to a flexure test whose average compressive strength is 35 MPa. In order to avoid cracking and simultaneously increase the toughness related to pure concrete, 2 $kg.m^{-3}$ of synthetic microfiber, 54 mm long, were added to its composition. The tensile samples were tested according to ASTM C 1609 - Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete. Comparing the concrete specimens that weren´t reinforced with the ones reinforced with composite sheets, the tenacity increase from 4796 to 15186 J and the fracture toughness from 1.84 to 5.82 MPa.

Keywords: *reinforced concrete, synthetic microfiber, carbon fiber*

1 Introduction

Frequently some pathologies in structures require solutions with lowest possible waste during the stages of his recovery. In general, these damages are the result of exposure to chemical or physical agents, and such damages often require the change in using the structure. In both cases, the solution may result in the application of external reinforcements on the damaged structural element, which restores the load capacity of the concrete elements in order to extend the useful life of these structures.

Repairs using CFRP (carbon fiber reinforced polymers) initially met specific needs of certain countries. In the European countries, for instance, it was the rehabilitation of historical heritages that motivated such use. In North America, the focus was on the durability of buildings, while in Japan the goal was to resist earthquakes, according Juvandes [1]. Currently, this type of reinforcement is already widespread and is applied all around the world.

Mukherjee and Rai [2] investigated the flexural behavior of concrete beams that were reinforced with pre-stressed CFRP. In their study, the concrete structure was loaded up to the appearance of initial cracks. After that, there was the rehabilitation of the structure with CFRP laminate. The usage limit in this case was the load that the strengthening broke by debonding, which could be further increased since the laminate was anchored at its end with sheets of carbon fiber. The study shows that the load carried by the beam was higher after bonding the CFRP laminate and that reinforcement reduced the strain proportionally to the rate of pre-stressing.

The increase resistance in structures due to natural deterioration and increased traffic led Gheorghius et al. [3] to study the long-term effects on the interface between the external CFRP reinforcement and the concrete structure. Models scaled beams were subjected to fatigue loads to the various cycles and then tested in 4-point flexure with constant load. The beam was 1215 x 150 x 100 mm and it was manufactured of a 50 MPa concrete with a minimum armor, according to Canadian standards. The bars of the armor were 6.35 mm in diameter, tensile strength of 600 MPa and Young modulus of 200 GPa. The researchers found cracks in the cyclic phase of high intensity, in which there is a greater occurrence of reinforcement debonding. However, the final loading was not affected by the fatigue due to cyclic loading

Gorji [4] presented an analytical method to predict the deflection of rectangular beams fiber reinforced, applied to its bottom side. His study was based on three assumptions: the sections remain flat throughout the loading with the stresses being distributed linearly in the vertical direction of the piece; no slip occurs between steel, concrete and external reinforcement; it works only on the concrete compression zone and the stress-strain relationship is linear. The authors concluded that the variation method of energy can be considered viable in predicting deflection anywhere on the reinforced beams.

The objective of the present study is evaluate the tenacity and fracture toughness of concrete mixed with polypropylene microfibers specimens reinforced with carbon epoxy sheet composite.

2 Materials and Method

2.1 The concrete matrix

The concrete matrix is, by itself, a composite of three phases, which are cement and two aggregates: sand and gravel. Their physical characteristics are directly related to the mix proportions, the water volume in the mixture and to the additives. These amounts will change, depending on the strength and geometry designed for each structure. As a brittle material, the concrete was initially reinforced with a mixture of synthetic microfibers, defined as the first reinforcement, and after curing (28 days), the samples were further reinforced externally by sheets of carbon fibers.

The samples were prepared to achieve mean compression (f_{cm}) of 35 MPa and tensile mean strength (f_{ctm}) of 4.5 MPa. The mix proportion for molding the specimens is showed in Table 1.

Table. 1. Concrete mix for molding the specimens f_{cm} = 35 MPa and f_{ctm} = 4,5 MPa.

Material	Description/type	Content (kg.m^{-3})
cement	CPV ARI	30,00
sand	particle size 2,0 mm	891,90
gravel zero	Dmax =19mm	1023,00
water	-	131,10
additive	polyfunctiona	1,320 (0,40%)
polymeric microfiber	polypropylene	2,00

2.2 Polymeric Microfiber

Synthetic fibers are made of a structural virgin polypropylene copolymer microfiber mixed with a fibrillated microfiber, whose function is to control the shrinkage of the concrete in the plastic phase. No specific structural function is required of these fibers, that was used only for protection of test equipment and the LVDTs after the rupture of the specimens.
These fibers, whose physical properties are shown in Table 2, were added to the concrete mass and resulted in a secure anchorage to the cement matrix. After the samples were molded, no fibers were found on the surface.

Table 2. Polymeric microfiber properties.

Density	0,91 $g.cm^{-3}$
Tensile strength	570 – 660 MPa
Young Modulus	5,0 GPa
Length	54 mm
Resistance to acid/ alkaline environment	Excelent
Water absorption	Zero

2.3 Carbon fiber sheet (CFRP sheet)

Made by the pultrusion process, the sheets are elements for structural reinforcement that are manufactured with fibers oriented in the longitudinal direction, therefore, resistant to tensile stresses. Their properties are shown in Table 3.

Table 3. Characteristics and properties of the CFRP sheet.

Width	50 mm
Length	1,2 mm
Transversal Section	60 mm^2
Young Modulus	165 GPa
Density	1,60 $g.cm^{-3}$
Volumetric fraction	0,68
Elongation at break	>1,7%
Design elongation	<0,85%

2.4 Adhesive

The joint of the CFRP sheet to the concrete specimen was made by applying a layer of epoxy base adhesive with thixotropic agent. The adhesive is a bi-component material whose mixture of the matrix and the curing agents may be made using a mechanical or manual device with the mixing speed controlled to avoid the formation of bubbles which could compromise the final resistance. This adhesive was prepared according to the manufacturer's instructions establishing the proportion of 3 parts epoxy resin to 1 part hardener.

3 Method of application

Eight concrete specimen of 15 x 15 x 50 cm were manually prepared and molded on a vibrating table. It was added to the concrete mass 2 $kg.m^{-3}$ of polymeric microfiber, as shown in Fig 1.

Fig.1. Polypropylene microfibers.

The adhesive was homogenized and applied on one of the faces of the concrete specimens with a thickness of 1.5 mm. Over this layer was put a sheet of CFRP. The sheets of carbon/epoxy composite were cleaned for removing grease and the concrete surface was prepared by means of brushing followed by aspiration to remove loose particles which could influence the test results.
Initially, the adhesive is gently mixed for 5 min to prevent bubble formation. Then, it was spread over the specimen surface with a thickness of 1 mm on a pre-defined area, respectively illustrated in Fig. 2 and 3.

Fig. 2. Manual steering of the two-component of the adhesive.

Fig. 3 The adhesive is spread over the area of bonding the reinforcement sheet.

In Fig. 4 is shown the CFRP unidirectional sheet with dimensions of 1.2 x 50 x 500 mm longer bonded to concrete surface.

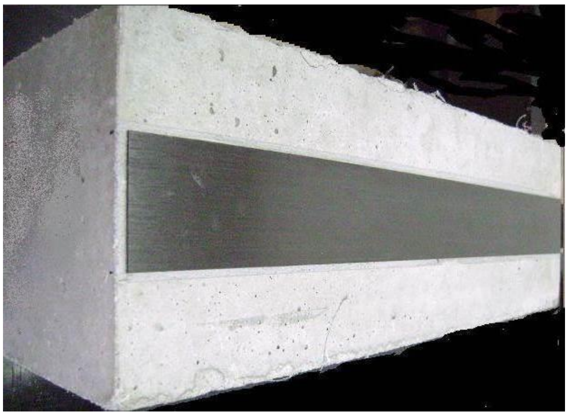

Fig. 4. Unidirectional CFRP sheet bonded to the concrete specimen.

3.1 Flexural Test

Fiber reinforced concrete tenacity control is possible by the flexural test, according to ASTM-D-1609 with the controlled deformation. In this case, an electronic LVDT transducer, which was supported in a "yoke" device, to control the displacement was used.
Concrete specimens with dimensions of 15 x 15 x 50 cm were placed over steelrods in an arrangement as shown in Fig. 5 [5]. The steelrods were positioned so that they can rotate freely about its axis in order to eliminate any interference by the friction of the test results.

Fig. 5. Four point bending flexural test.

Support of high-strength epoxy resin (2 cm wide and 4 mm thick) was prepared to allow contact with the steelrods along the top face of the beam to compensate any unevenness in the concrete.

4 Results

The specimens were tested according to ASTM C 1609. Tests results are shown in Tables 4 and in Fig. 6 and 7, respectively for specimens without external reinforcement (WER) and those ones reinforced with CFRP sheet (SR).

Table 4. Results from tests on specimens without and with external reinforcement.

	specimens without external reinforcement	specimens with external reinforcement
tenacity (J) (0-0.35 mm)	4796	15186
fracture toughness in flection (MPa) (0.35 mm)	1.84	5.82

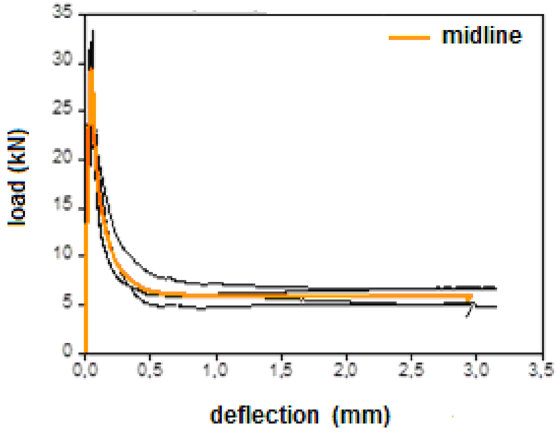

Figure 6**-** Load versus deflection- specimens without CFRP sheet reinforcement.

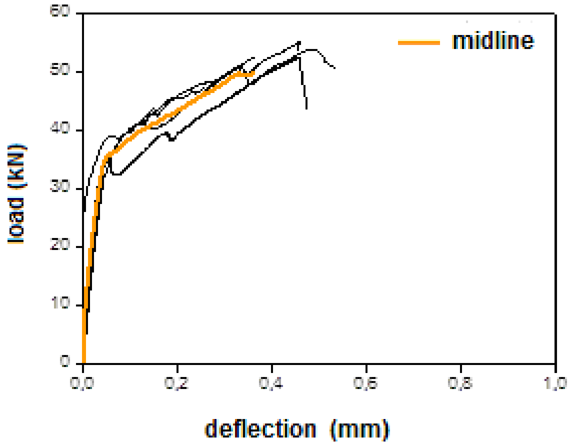

Figure 7- Load versus deflection- specimens strengthened with CFRP sheet.

Both showed a standard curve, that is, a curve with an initial elastic behavior up to the load reaches the first peak. For WER specimens, however, after reach the elastic limit some cracks appeared, decreasing the load capacity of the specimen, but with no instantaneous rupture, maybe due to the microfibers on the concrete, unlike what happened with the SR specimens because instead of relaxation after the elastic limit, the load increased up to a value 3.15 times higher than that of the WER specimens.

All tests with specimens reinforced with CFRP were stopped by the software after the laminate/concrete interface debonding, because the specimens broke sharply, while the limit of deflection used was 0.35 mm.

4 Conclusions

It has been found that the process of the external reinforcement for a CFRP sheets allows the increase of load capacity with a value at least greater than 3.15 times the reference value and also a significant increase in tenacity and fracture toughness.

It was also evident the need to study the behavior of the adhesive in the CFRP sheets/concrete interface, aiming to strike a balance between the external loads and the internal reactions of the specimens or to balance the shortening of the concrete with deformation of the laminate.

Acknowledgments

Sika Brazil for providing the resin and the CFRP sheet and Construquímica by allowing tests to be run on your facilities.

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