

MECHANICAL BEHAVIOR TO SHEAR OF REINFORCED CONCRETE BEAMS REINFORCED WITH CARBON FIBERS BONDED WITH EPOXY ADHESIVE

COMPORTAMENTO MECÂNICO AO CISALHAMENTO DE VIGAS DE CONCRETO REFORÇADAS COM FIBRAS DE CARBONO COLADAS COM ADESIVO EPÓXI

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Abstract: In Brazil, the concrete structure is widely used in civil construction. In this field, there is a common need to reinforce the structural elements, either by increasing the load, for calculation errors, flaws in the execution or modifications of use conditions. This experimental work aims to compare two reinforcement techniques with carbon fiber blanket on reinforced concrete beams submitted to shear stress. The tests will compare the results of reinforced concrete samples without any reinforcement, with shear reinforcement using carbon fiber blanket with techniques and materials popularly spread on the market. In this case using the structural adhesive S&P 220, and with shear reinforcement using carbon fiber blanket glued with structural adhesive NVT 201E.

Keywords: Reinforced concrete. Reinforcement. Carbon fiber. Shear.

Resumo: No Brasil, é muito utilizada a estrutura de concreto na construção civil. Neste ramo, é comum haver necessidade de reforço dos elementos estruturais, seja por aumento da carga, por erros de cálculo, vícios na execução ou modificações das condições de uso. Este trabalho experimental tem como objetivo comparar duas técnicas de reforço com manta de fibra de carbono em vigas de concreto armado submetidas ao esforço cortante. Os ensaios irão confrontar os resultados de corpos de prova de concreto armado sem reforço algum, com reforço ao cisalhamento utilizando manta de fibra de carbono com técnicas e materiais popularmente difundidos no mercado. Neste caso utilizando o adesivo estrutural S&P 220, e

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com reforço ao cisalhamento utilizando manta de fibra de carbono adesivada com o adesivo estrutural NVT 201E.

Palavras-chave: Concreto Armado. Reforço. Fibra de carbono. Cisalhamento.

1 INTRODUCTION

Although its use is very popular, concrete is not exempt from any factors that could compromise its useful life. The unexpected increase of loads in projects may impair the structural capacity for transferring efforts. Unfavorable environmental conditions and the aging of the structure can also contribute to the degradation of its use in service. Through the application of an external reinforcement, it is possible to restore the capacity to support loads of concrete structural elements (MUKHTAR; FAYSAL, 2018).

Expansion projects that are not foreseen in buildings also change the requests in the structural system already executed, that must be analyzed making new considerations regarding the actions and efforts acting. In certain cases, design errors occur, as well as, the execution of the reinforced concrete structure, being feasible to perform the structural reinforcement in the affected elements instead of the demolition and reconstruction of the structure already built. (BEBER, 2003).

Therefore, the need of civil construction technicians to know several techniques for reinforcements available at market today and their procedures, costs, advantages and deadlines. A relatively current option is the use of Fiber Reinforced Polymer (PRF). In relation to other more traditional materials, the choice of PRF is based on attractive factors such as high mechanical strength and stiffness, durability in chemically aggressive environments, low weight, ease and speed of installation (FRIGIONE; LETTIERI, 2018).

2 OBJECTIVE

Due to the increased use of carbon fiber as an intervention in civil construction, this experimental work will discuss the application of the use of structural adhesive NVT 201E (adhesive developed at the IPRJ's Adhesion and Adherence Laboratory used to repair pipes and sheet metal) to shear reinforcement and will address the execution method, advantages and

disadvantages, so that one can finally compare to the conventional technique widespread in Brazil.

In this work, will discuss important concepts for the application of reinforcement on concrete structures using external pasted of laminated composite materials. Materials, test procedures and shear reinforcement techniques will be presented, and finally the results will be discussed based on a statistical analysis to compare the influence of the adhesives NVT 201E and S&P 220 on the shear strength in concrete substrate.

3 MATERIALS

3.1 Laminated Composite Material

Composites consist of a thermoplastic matrix or a matrix with thermal curing (thermosets) and continuous fibers arranged randomly or in defined directions. The strength of the matrix is less than that of fibers. These fibers must withstand loads in order to obtain a greater gain in the strength of the composite as a whole. However, there is a drawback that should be pointed out regarding the sudden rupture of the fibers (MACHADO, 2010).

The definition of laminate according to Reddy and Miravete (1995) refers to a set of layers, called sheets, stacked so that the desired mechanical and physical properties are achieved in the finished material. These layers can contain fibers aligned in a unidirectional or multidirectional way and the way they are ordered is responsible for giving different properties to each type of laminate. There is also the possibility that a laminate can be manufactured with layers composed by fibers of different materials.

The matrix of composites with fibers has several functions. At principle, it is responsible for the union of the fibers that make up the composite, acting as the means by which external requests are transmitted and distributed to the fibers (HOLLAWAY, 1993; CALLISTER, 1997).

The growth in interest to the use of structural reinforcement systems with fiber-reinforced composites can be attributed to some factors, like its quick application. Although the costs of fibers and resins used in composites are relatively high if compared to traditional materials, like steel and concrete, the cost of labor and equipment to run this type of system are usually lower (AMERICAN CONCRETE INSTITUTE, 2008).

3.1.1 Carbon Fiber

Carbon fibers are characterized by a combination of low weight, high strength and high rigidity. Its high elasticity modulus and, by a way, high strength, depend on the degree of fibers orientation, that is, the parallelism between the axis of the fibers (SCHWARTZ, 1984). The use of this material has been increasing in civil construction, because its constitution leads to having low weight, resistance to corrosion, and good resistance when compared to other types of reinforcements, essential characteristics for reinforced concrete structures.

The production of these fibers requires exposure to air from the base fibers, followed by high temperature processing (in order of 1000° C to 1500° C) of organic polymer fibers. How bigger temperature of this process, most bigger the elasticity modulus of resulting material, ranging from 100GPa to 300GPa (MACHADO, 2010).

3.1.2 Epoxy Resin

The resins have the function of involving and agglutinating the fibers to ensure an adequate transfer of tensions between them and to protect them from environmental aggressions and wear. Its properties must also lead to a perfect adhesion between the concrete and reinforcement material interfaces and provide adequate durability and applicability to the composite (CARNEIRO, 2008). Epoxy based resins are more expensive than resins based on vinylester

or polyester. However, it has better characteristics such as greater resistance to the attack of bad weather and has a longer useful life.

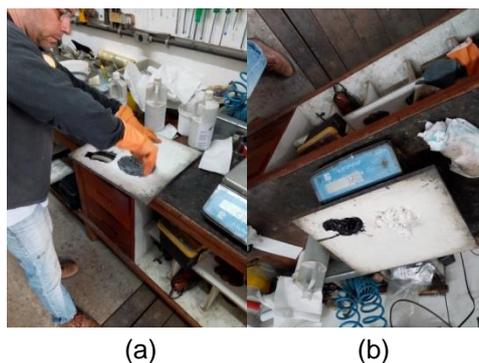
Regarding structural adhesives, those that cure at relatively low temperatures, such as epoxy resins, has been widespread in civil construction applications, mainly in relation to the repair or increase of load by bonding Fiber Reinforced Polymers (FRP). After mixing the resin with the agent and its cure, a period of time must be waited until the cure is complete so that maximum bond strength is achieved, enough for the transfer of loads to take place properly (MICHELS et al., 2016).

Structural reinforcements with composite materials, mainly CFRP, have become popular in Brazil due to their excellent properties for this purpose. However, premature failure of the reinforcement has been observed, characterized by its detachment from the concrete substrate. This kind of failure is extremely undesirable because it occurs without warning and anticipates the collapse of the reinforced beam, making it impossible to take full advantage of the CFRP's tensile-resistant properties (FERRARI, 2002).

3.1.2.1 Adhesives

In the experiment, bonding was carried out using two types of structural adhesives on the concrete substrate, the S&P 220® adhesive provided by S&P Reinforcements Clever Solutions, and the NVT Pipe Fix® adhesive provided by Novatec Repairs Solutions, both made available by the Laboratório de Adesão e Adherencia (LAA) - IPRJ, shown in the Figures 1-a) and 1-b).

Figure 1: Structural adhesives used: (a) NVT Pipe Fix® (b) S&P 220®.



4 METHODOLOGY

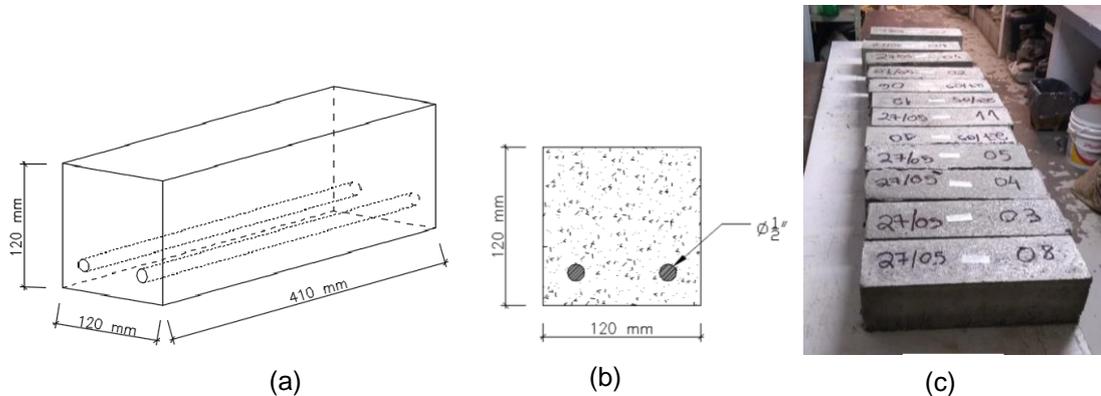
For the elaboration of this article, some procedures were made that will be described in more detail. Some steps can be mentioned, such as concrete dosing, sizing of bodies test, the dimensioning of the laminated composite reinforcement, reinforcement application's, the axial compression test of the concrete and mainly the 4-point bending test for reinforced concrete. Which will be used as a basis for a statistical analysis of comparison between the use of two structural adhesives.

4.1 Execution of Bodies Test

4.1.1 Reinforced Concrete

The dosage of the concrete used in the test bodies was dimensioned to obtain with $f_{ck} = 30$ MPa at 28 days of age, slump test from 80 to 100 mm and a/c factor equal to 0,52. The dosage of the concrete used was 1:1,42:3,12:0,52 (Cement: Sand: Gravel: Water/Cement). Cylindrical and prismatic test bodies were made, following the procedure of ABNT NBR 5738/2015. The diagram represented in Figure 2 shows the dimensions of the prismatic test bodies made at the Laboratório de Ensaios Físicos (LEFI) - IPRJ, for the 4-point bending test, according to the ABNT NBR 12142/2010.

Figure 2: Scheme of prismatic test bodies: (a) perspective, (b) cross section with two ½” rebars, (c) image of the test pieces made at LEFI.



4.1.2 Laminated Composite Material

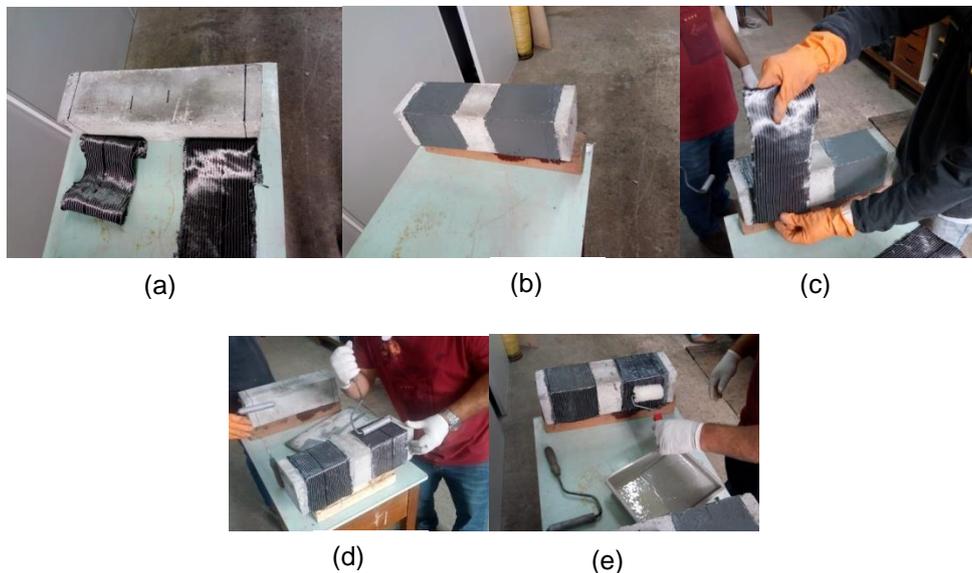
The laminated composite materials used to reinforce the beams of the experiment were composed of structural epoxy adhesive, a layer of carbon fiber and laminating resin. This composition is approximately 1 mm thick and a carbon fiber layer. The American standard ACI Committee 440 (2002) was used for this dimensioning. The adhesives used (NVT 201E and S&P 220) respected the composition recommended by the manufacturer. Was used the carbon fiber LT450-C10-C, produced by Devold AMT® and was used Resin Pipe Fix® for the lamination of composite with the composition indicated by the manufacturer.

4.1.3 Reinforcement Application to the Concrete Substrate

For the experiment, reinforcements were made on 3 beams using the structural adhesive NVT 201E, on 3 beams using structural adhesive S&P 220 and 3 other beams remained without reinforcement, so they could be used as a reference. For the 3 beams reinforced with NVT 201E, 321.5 g of Component A and 169.21 g of Component B were used. After applying the adhesive, a layer of carbon fiber LT450-C10-C was fixed, and subsequently the Pipe Fix Resin

was applied to make the lamination, the measure used was 250.0 g of Component A and 43.85 g of Component B. For the 3 beams reinforced with S&P 220, 540.0 g of Component A and 135 g of Component B were used. After applying the adhesive, a layer of the LT450-C10-C carbon fiber was fixed, and subsequently the Pipe Fix Resin was applied to make the lamination, the measure used was 250.0 g of Component A and 43.85 g of Component B. Figure 3 shows a schematic of methodology to applying reinforcement to the concrete substrate.

Figure 3: Reinforcement application steps to concrete substrate: (a) Application template, (b) Structural adhesive applied, (c) e (d) Carbon fiber fixing and (e) Lamination process.



4.2 Tests

4.2.1 Axial Compression Test

Cylindrical test bodies with a diameter of 10 cm and a height of 20 cm were tested, as stipulated in ABNT NBR 5738, all 28 days old. The test was performed on June 27, 2019 and the types of rupture were mostly sheared and tapered. The test load was applied continuously, without shocks and at a speed

of 0.5 MPa / s, according to ABNT NBR 5739; figure 4 shows the Solotest® hydraulic press. The dosage of these test bodies was dimensioned to have 30 MPa at 28 days and was the same as that of the beams that were reinforced by shear, including from the same batch. Table 1 presents tests results.

Figure 4: Hydraulic press used for tests.



Table 1 – Resistance to axial compression of concrete at 28 days.

Reference	Load (tf)	Compressive Strength (MPa)
L1CP1	24,38	31,04
L1CP2	22,83	29,07
L1CP3	26,02	33,13
L1CP4	22,23	28,30
L1CP5	23,64	30,10
L1CP6	20,37	25,94
L1CP7	24,09	30,67
L1CP8	22,42	28,55
L1CP9	25,05	31,89

Source: Research Data.

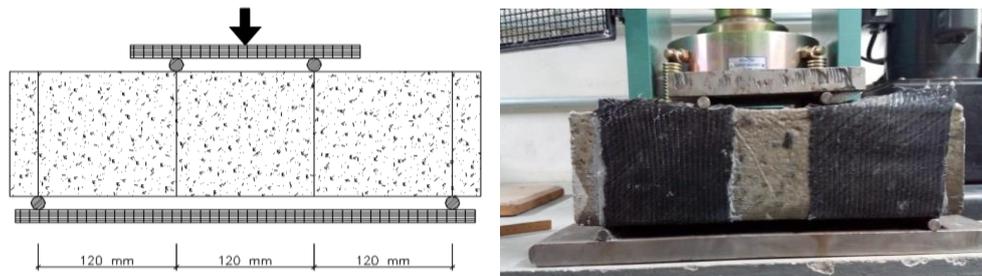
4.2.2 Shear Strength Test

11 composed beams of rectangular section were made and formed with positive armor of steel ½” CA-50, as outlined in Figure 2. For the tests, the structural adhesive NVT 201E composed of carbon fibers was used in 3 of these beams (reinforcing shear), the S&P 220 adhesive composed of carbon fibers was used in 3 of these beams (reinforcing shear) and 5 beams without shear reinforcement.

For the statistical determination of the comparison of the influence of the shear reinforcement with carbon fibers and with the NVT 201E and S&P 220,

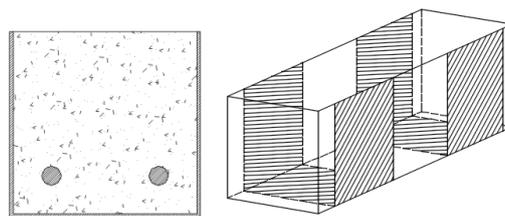
the beam was dimensioned so that the break would happen outside the middle third, where the shear has maximum value. Support was provided by an IPRJ laboratory technician, so that the support points are spaced 120 mm apart, as shown in figure 5.

Figure 5: Representative scheme of the 4-point flexion test of prismatic test bodies.



The shear reinforcement made on the beams corresponds to the one called “U”, as shown in figure 6, and covering only three sides of the concrete element (two sides and the bottom). This arrangement is usually imposed by the existence of a slab at the top of the beam and by the lack of convenience or impossibility of opening slots in it to allow the passage of the fiber. This solution is easy to execute and allows a reasonable increase in the nominal shear strength of the part (MACHADO, 2002).

Figure 6: Representative scheme of carbon fiber reinforcement used in tests.

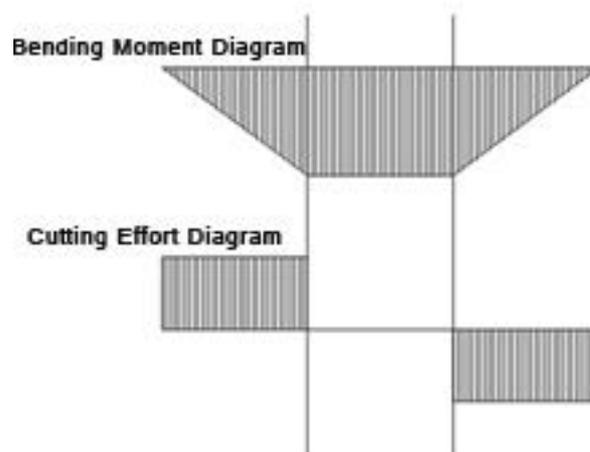


The reinforcement was applied following the manufacturers technical recommendations and the mixture was done manually. The structural adhesive NVT Pipe Fix ® had a mix composition by weight of 1.9: 1.0 and the adhesive

S&P 220® had a mix composition by volume of 4.0: 1.0. The lamination was done directly on the beams, and the curing time of 24 hours was waited with the reinforcement already applied on the beams as specified by the manufacturers.

In the 4-point bending test the central third of the beam is composed of pure bending, whereas in the external thirds there is flexion-shear, as shown in figure 7. The beams were designed with the same parameters for bending, and without shear reinforcement, therefore, the reference beams (which will not be reinforced with laminated composite material) will resist shearing only with the concrete portion and the longitudinal reinforcement portion. Statistical analysis will be made regarding the influence of reinforcements from the breaking load of the beams.

Figure 7: Representation of the stress diagrams suffered by the beams in the 4-point bending test.



The portion resisted by the concrete in the reference beam was calculated, and its value was $V_c = 10.43$ kN. The extra value of shear strength required is approximately 200 kN. For the dimensioning of the reinforcement, the values mentioned above and the calculation methodology described in ACI Committee 440 (2002) were used. It was concluded that a layer of carbon fiber was enough to achieve the extra strength needed, therefore reinforcements were made with a carbon fiber layer approximately 1 mm thick.

Bending tests of 4 points were carried out on 5 reference beams (without shear reinforcement), on 3 shear reinforced beams using NVT 201E and on 3 shear reinforced beams using S&P 220. Breaking loads are shown in Table 2.

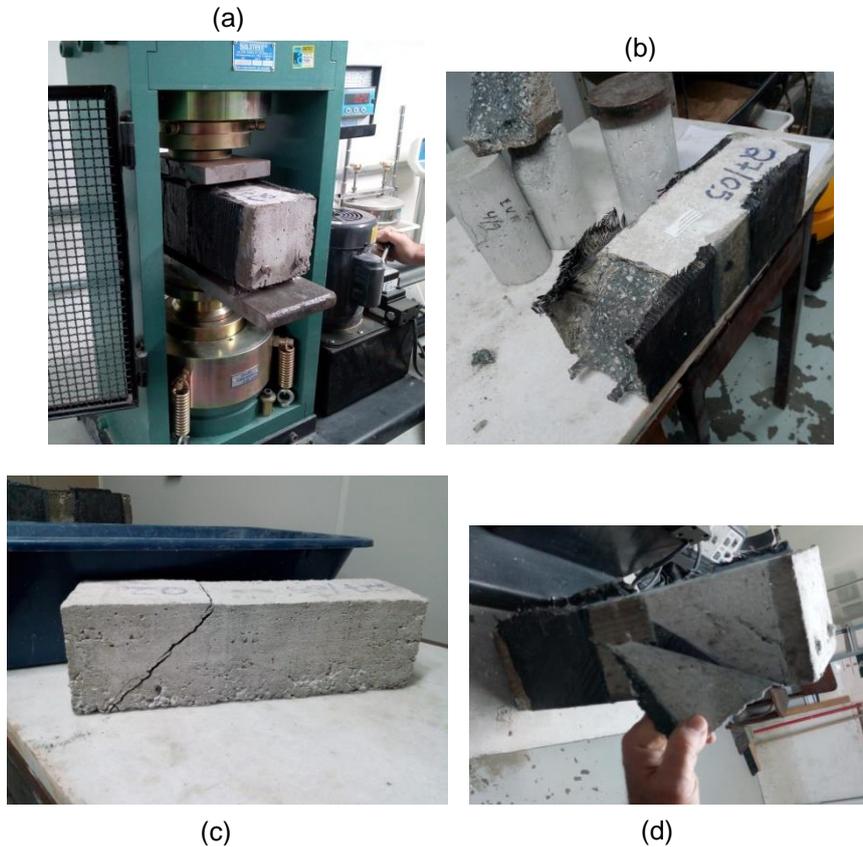
Table 2 – Resistance to axial compression of concrete at 28 days.

Reference Test Bodies	Load (tf)	Shear Strength (tf)
F1CP1	7,37	3,69
F1CP2	6,73	3,37
F1CP3	7,52	3,76
F1CP4	5,12	2,56
F1CP5	6,08	3,04
Test Bodies reinforced with NVT 201E	Load (tf)	Shear Strength (tf)
F2CP1	10,24	5,12
F2CP2	10,41	5,21
F2CP3	10,69	5,35
Test Bodies reinforced with S&P 220	Load (tf)	Shear Strength (tf)
F3CP1	9,75	4,88
F3CP2	9,10	4,55
F3CP3	8,09	4,05

Source: Research Data.

The reference test bodies showed an average shear strength of 3.28 tf. Those reinforced with the NVT 201E adhesive showed an average resistance of 5.22 tf and those reinforced with the S&P 220 adhesive showed an average resistance of 4.49 tf. The beams that used the structural adhesive NVT 201E obtained resistance 59.15% higher than the reference beams and 16.26% higher in relation to beams reinforced with structural adhesive S&P 220. The S&P 220 is the adhesive qualified for use on concrete substrates and widespread in the market. Figure 8 illustrates the test and some results of the test performed at LEFI, such as the arrangement of the test bodies and the way of breaking the reference samples and the reinforced ones.

Figure 8: Images of the 4-point flexion test performed at LEFI: a) Sample positioned for the test; b) Specimen reinforced with NVT 201E fractured by shear flexure; c) Reference beam broken by shear flexure; d) Sample reinforced with S&P 220 showing detachment of the reinforcement after the test.



5 CONCLUSIONS

Beams reinforced with structural adhesive NVT 201E obtained results superior to those obtained in beams reinforced with adhesive S&P 220, which is already established in the market and qualified by regulatory agencies as structural adhesive for use on concrete substrate. In addition to greater resistance in the 4-point bending test, the beams reinforced with NVT 201E showed a lower detachment rate of the reinforcement at the moment of rupture than those reinforced with the adhesive used for comparison. These results favorable to NVT 201E suggest that the adhesive can also be used to repairs in

concrete structures, for that to happen and it can be marketed this way, it is proposed that the other qualification experiments be carried out for structural adhesives on concrete substrates.

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