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ORIGINAL ARTICLE

Experimental study of the influence of different types of surface treatments on the local repair of columns by jacketing

Estudo experimental da influência de diferentes tipos de tratamentos de superfície na recuperação localizada de pilares por encamisamento

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Abstract: Material deterioration, changes in the use of buildings or incorrect initial structural system may result in the need of structural repair or strengthening. Jacketing of the structural element is a widely used technique for structural repair due to its relatively low cost and relative ease of execution. The present research proposes to experimentally investigate, through the sleeve test, the influence of different surface treatments on the connection between the concrete of an existing structural element and the concrete used in its repair. Comparative study of the observed results allows a better understanding of the influence of surface treatment regarding the restoration of the resistant capacity of columns through the jacketing technique, highlighting the one that presents the best performance.

Keywords: repair, strengthening, jacketing, sleeve test, surface treatments.

Resumo: Deterioração material, alterações nas formas de uso de edificações ou dimensionamento inicial incorreto da estrutura pode acarretar necessidade de recuperação ou reforço estrutural. O encamisamento do elemento estrutural é uma técnica amplamente utilizada para recuperação estrutural devido ao seu custo relativamente baixo e à sua relativa facilidade de execução. A presente pesquisa propõe investigar experimentalmente, por meio do ensaio de luva, a influência de diferentes tratamentos de superfície na ligação entre o concreto de um elemento estrutural existente e o concreto utilizado em sua recuperação. Estudo comparativo dos resultados observados permite compreender melhor a influência do tratamento de superfície no que diz respeito à restauração da capacidade resistente de pilares por meio da técnica de encamisamento, destacando-se o que apresenta melhor desempenho.

Palavras-chave: recuperação, reforço, encamisamento, ensaio de luva, tratamentos de superfície.

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1 INTRODUCTION

The research presented in this paper proposed to investigate the influence of different types of surface treatments on the connection between concrete of an existing column with localized damage (old concrete) and concrete that will be used in its repair (new concrete) in the context of the sleeve test developed by Piancastelli [1]. The main goal of this research is to expand part of the knowledge regarding the connection between concrete of different ages through an experimental study that aims to provide comparative information between different types of surface treatments in this connection – in particular, the surface treatments of sanding, chipping (achieved with a drill) and bonding with epoxy adhesive – that can guide repair designs using the concrete jacketing technique, especially the localized jacketing.

The experiments were divided into 6 (six) series, distinguished by the surface treatment and nominal compressive strength of the old concrete (10 or 20MPa). Additionally, the influence of the thickness of the repair jacket (2.2 or

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Conflict of interest: Nothing to declare.
Data Availability: The data that support the findings of this study are available from the corresponding author, [A. H. Miranda], upon reasonable request.

4.6cm) and height of old-new concrete interface (10, 14 or 17.5cm) is investigated. For each series, in addition to the sleeve tests, tests were performed according to ABNT standards, for the characterization of both old and new concrete mechanical properties (compressive strength, tensile strength, and elasticity modulus). Based on the Mohr-Coulomb failure criterion, the coefficient of friction and adhesion achieved in the connection in each series are determined.

2 LITERATURE REVIEW

As the column is the element responsible for transporting actions to the foundations, failures in its operation can generate a significant reduction in the performance of the building. In addition, the repair of this structural element "is the one that requires the greatest care, precision and safety" (Piancastelli [1]).

Repair can occur through various techniques. A technique widely used today is concrete jacketing due to its relative lower cost and simplicity of execution. This technique consists of increasing the cross-section of the column, as shown in Figure 1, through total or partial involvement with concrete, usually, with reinforcement. To reduce the thickness of the jacket, Reis [2] and Enami [3] suggest the use of high-performance concrete. It should be noted that the jacketing can occur along the entire length of the column or only in portion of the column whose resistant capacity is compromised.

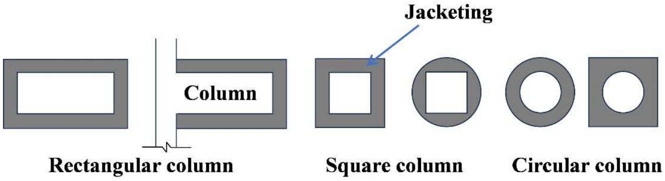


Figure 1. Geometry of columns and jacketing

To achieve satisfactory results in the jacketing, the connection between the concrete of the column to be repaired and the concrete that will be used in the jacket is of potential interest, since, without efficiency of this connection, the transfer of forces between the column and the jacket is compromised, affecting the restored resistant capacity.

2.1 Bonding tests (adhesion and friction)

For the analysis of the connection between concrete and structural repair materials, four technical standards are referred to here: ASTM C 1583 [4] which addresses the Pull Off Test; ASTM C 496 [5] that addresses the Splitting Tensile Test; and ASTM C 882 [6] and BS EN 12615 [7] which address the Slant Shear Test. The last two technical standards aim to evaluate the adhesion between concrete and epoxy resins; however, the slant shear test began to be used to evaluate the bond between concrete and different structural repair materials.

Piancastelli [1] proposes the use of the sleeve test to characterize the connection between concretes. In the specimens of this test, the load is transferred from one concrete to the other as shown in Figure 2. In this test, it is possible to quantify adhesion and friction.

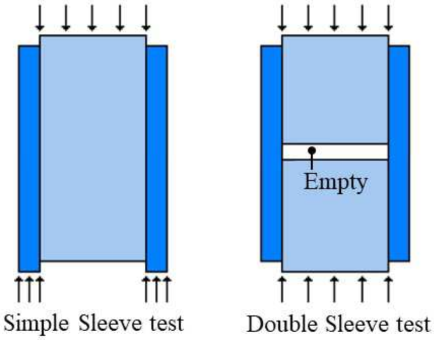


Figure 2. Input and output load on specimens in sleeve test

2.2 Strengthening of columns – mechanical characterization of the connection

Adhesion is responsible for the transfer of stresses between materials, being the property responsible for preventing or minimizing relative displacement in contact. Friction, in turn, is a force that arises opposing movement between two surfaces.

Of significant importance in the jacketing of columns, friction promotes greater security in the contact between the old and new concrete. In this way, the high roughness on the surface of the concrete can generate greater use of the normal stress existing in the column/jacket contact (confinement). Therefore, surface treatments that bring greater roughness can be presented as advantageous for promoting greater effectiveness in the connection between concretes of different ages, thus increasing the restored resistant capacity.

According to Piancastelli [1], there are no technical standards, whether Brazilian or foreign, as far as the author's knowledge goes, that provide reliable information about adherence and friction between old and new concrete aimed at structural repair.

2.3 Strengthening of columns – influence of surface treatment on the connection

Since, in Brazil, there are still no technical standards for structural repair and strengthening projects, studies devoted to investigating the influence of surface treatment on the connection between concretes in structural repair by jacketing are still necessary.

The interface between new concrete and old concrete plays an important role in the overall success of any repair. A good bond ensures long-term durability and monolithic action, i.e., the repair contributes to both the stiffness and load-carrying capacity (Chilwesa et al. [8]). Research has shown that the substrate roughness, which is highly dependent on the surface preparation method, has an influence on the interface bond strength, though there is no consensus in literature on the extent of this effect and, consequently, practical recommendations, e.g., scarifying the substrate, applying adhesion “bridges” (such as, for example, a layer of epoxy resin), creating grooves approximately 3cm deep, among others (Cánovas [9], Takeuti [10], Júlio [11], Takeuti [12], Takeuti et al. [13], Zaiter and Lau [14]), still require investigation and validation.

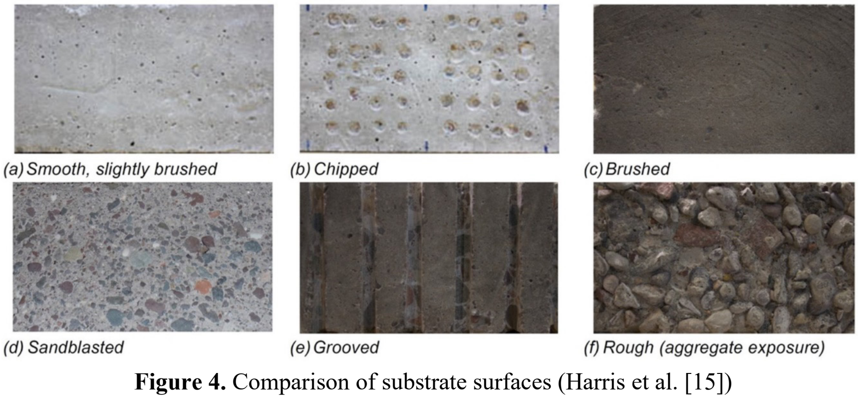
Chilwesa et al. [8] sought to evaluate the connection between concretes by varying the types of substrate concrete surfaces, considering smooth, wire-brushed (with a steel brush) and grooved surfaces, as illustrated in Figure 3.


(a) Grooved and Smooth (b) Smooth and Wire-brushed

Figure 3. Comparison of substrate surfaces (Chilwesa et al. [8])

The authors observed that substrate surface roughness is an important parameter affecting interface bond strength, observing an increase in bond strength with an increase in substrate surface roughness, with the biggest increase in bond strength recorded for changes in roughness from smooth (as-cast specimens) to rough (brushed specimens) as compared with changes in roughness from rough (brushed specimens) to very rough (grooved specimens). According to the authors, this suggests that there might be an optimum roughness index beyond which no substantial changes in bond strength can be obtained.

Harris et al. [15] present an experimental and numerical study focused on the connection between normal and ultra-high-performance concrete considering six different types of surface treatments, presented in Figure 4.


(a) Smooth, slightly brushed (b) Chipped (c) Brushed

(d) Sandblasted (e) Grooved (f) Rough (aggregate exposure)

Figure 4. Comparison of substrate surfaces (Harris et al. [15])

The authors conclude that excellent bonding between concretes can be achieved with limited surface preparation and in the absence of bonding agents such as epoxies or latex emulsions that are commonly used in overlays. However, the authors are unclear regarding the definition of "a limited surface preparation" as well as the applicability of this conclusion.

Additionally, the authors highlighted that, although the bond performance appears to be adequate for overlay applications, the experimental program highlighted several challenges related to characterizing the interfacial bond between concretes.

Another study that stands out for the conclusion observed, highlighting the lack of consensus regarding surface treatment in the connection between concretes, is the study developed by Júlio [11] in which the influence of the interface on the behavior of columns strengthened by reinforced concrete jacketing is investigated and whose main conclusion contradicts the current practice in several countries, which consists of increasing the roughness of the original column, followed by the application of epoxy resins, that is, it was concluded that there is no need to carry out any type of surface treatment of the interface in terms of roughness, nor is there any need to apply any type of adhesion agent. This lack of consensus is the reason for the study developed here, whose experimental program is presented below.

3 MATERIALS AND EXPERIMENTAL PROGRAM

Naturally, the older a building is, the greater the need for repair or structural strengthening. It is observed that older buildings are commonly made of lower-strength concrete, in accordance with the technical standards of the time. As the focus of this work is the repair of columns in old buildings, the nominal compressive strengths of the concrete element to be repaired, f_c, were defined as 10MPa (mix ratio: 1:3.25:5.87, w/c = 0.92) and 20MPa (mix ratio: 1:3.87:4.2, w/c = 0,86). The consideration of two strengths for old concrete aims to investigate the ability to restore the strength of the structural element as a function of the strength to be restored. The term old concrete (OC) was assigned to the concrete present in an element to be repaired. The test specimens were made with CP V cement, natural coarse sand, gneiss gravel from 9.5mm to 19mm and plasticizer additive Muraplast FK 830 with a dosage of 0.8% relative to the mass of the cement. The concrete used in the repair jacket was called new concrete (NC). MC-Bauchemie's non-retractable, high-performance, cementitious based Emcekrete 40 grout with a water/binder factor of 0.11 was used.

3.1 Preparation of old concrete specimens

The molds for making the old concrete specimens, used in the sleeve and characterization tests, consist of cylindrical plastic molds with a diameter of 10cm and a height of 20cm. The demolding process was carried out at a minimum age of 7 days. After curing the old concrete specimens, prior to making the sleeve test specimens, the specimens were rectified to regularize the load application surface.

3.2 Surface preparation of old concrete specimens

Before making the jacket covering the sleeve test specimens, the lateral surface of the old concrete specimens was prepared through the considered surface treatments.

3.2.1 Sanding surface treatment

The sanding of the surface of the old concrete specimens was carried out with a steel brush. The Figure 5 allows viewing the surface of these specimens.

Figure 5. Sanding surface treatment

3.2.2 Mechanical chipping surface treatment (holes with drill)

The surface treatment of the mechanical chipping type considered here was performed through holes in the lateral surface of the old concrete specimens, carried out with the aid of a drill with drill bit for concrete with 6.25mm diameter. Aiming to standardize the surface achieved after applying this treatment, it was established that the spacing between holes would be around 2cm and the hole depth of approximately 5mm. The Figure 6 illustrates the surface of the specimens after this treatment.

Figure 6. Mechanical chipping surface treatment (holes with drill)

3.2.3 Epoxy adhesive surface treatment

The epoxy resin-based structural adhesive was formulated for bonding concrete surfaces and other materials, providing high adhesion, high strength, impermeability, and fast hardening. In this research, Tecbond TIX Quartzolit was used, which has 60 minutes of open time at 25ºC and compressive strength of 40MPa in 24 hours and 50MPa in 7 days. Prior to the application of the epoxy adhesive, the lateral surface of the specimen was sanded. The Figure 7 illustrates the epoxy adhesive application process, in a layer of approximately 2mm.

Figure 7. Epoxy adhesive surface treatment

3.3 Confection of the new concrete jacket (grout)

Using the molds handmade by Piancastelli [1], in PVC tubes with MDF base, as shown in Figure 8, the jacket was made in new concrete (grout), as shown in Figure 9, by gloving a pair of piled up of old concrete specimens separated by a 2cm polystyrene layer (see Figure 10 in Section 4).

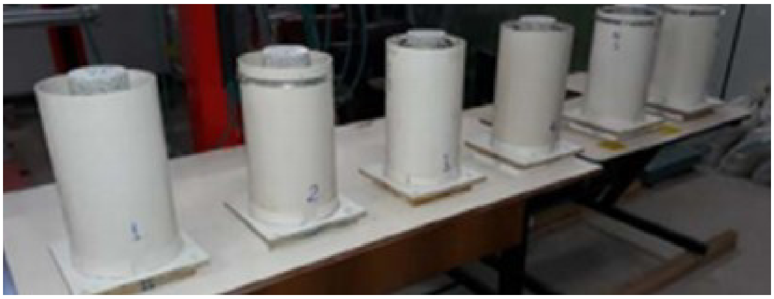


Figure 8. Molds of the sleeve test specimens

After preparation, the grout was added to the mold until reaching the mark for the established jacket height.

Figure 9. Sleeve test specimens with new concrete jacket (grout)

4 SLEEVE TESTS - SERIES AND SPECIMENS

To organize the experimental study, the test series were defined according to the type of adopted surface treatment, with the compressive strength of the old concrete being the secondary factor considered for the characterization of the series. Based on the variables defined for this study, the following series of sleeve tests were established, where "t" and "H" are, respectively, the thickness and height of the jacket:

- Series 1: epoxy adhesive; f_c = 20MPa; t = 2.2 or 4.6cm; H = 10, 14 or 17.5cm
- Series 2: epoxy adhesive; f_c = 10MPa; t = 2.2 or 4.6cm; H = 10, 14 or 17.5cm
- Series 3: holes with drill; f_c = 20MPa; t = 2.2 or 4.6cm; H = 10, 14 or 17.5cm
- Series 4: holes with drill; f_c = 10MPa; t = 2.2 or 4.6cm; H = 10, 14 or 17.5cm
- Series 5: sanding; f_c = 20MPa; t = 2.2 or 4.6cm; H = 10, 14 or 17.5cm
- Series 6: sanding; f_c = 10MPa; t = 2.2 or 4.6cm; H = 10, 14 or 17.5cm

4.1 Sleeve tests - specimens of each series

4.1.1 Concrete characterization tests

On the same date on which the sleeve test was carried out for each series, tests were carried out to characterize compressive strength, tensile strength, and elasticity modulus of old and new concrete, following the technical standards of ABNT NBR 5738:2015 [16], NBR 5739:2018 [17], NBR 7222:2011 [18] e NBR 8522-1:2021 [19].

4.1.2 Sleeve tests

The jackets of the specimens to be tested were 2.2cm or 4.6cm thick, leading to an external diameter of the sleeve test specimens of 14.4cm or 19.2cm, respectively. Subjected to normal compression with load applied continuously and increasing until rupture, the specimens for the sleeve tests were made up of two old concrete specimens, with a 2cm layer of polystyrene between them – simulating the localized loss of resistant capacity of the structural element – coated with a sleeve made of grout (Figure 10 and Figure 11). At rupture, the value of the load reached was recorded.

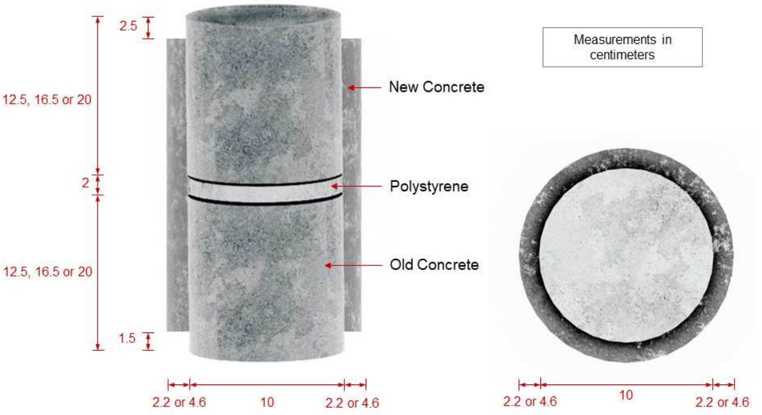


Figure 10. Characteristics of the sleeve test specimens

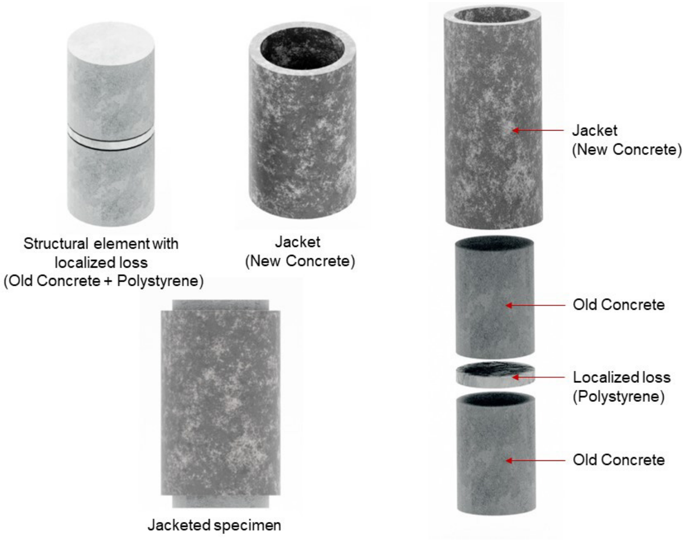


Figure 11. Schematic drawing of the sleeve test specimen elements

5 SLEEVE TESTS RESULTS AND DISCUSSIONS

As a way of better identifying the characteristics of the specimens analyzed in each series, a standard nomenclature was adopted as shown in Figure 12.

In Table 1 to Table 6, the average values obtained in the characterization tests of the old (OC) and new (NC) concrete in each series are presented, while, in Figure 13 to Figure 18, the compressive strengths obtained with each prototype of the sleeve test in each series are presented, in comparison to the respective compressive strength of old concrete (OC).

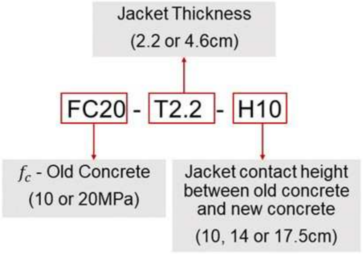


Figure 12. Identification code of the specimens of each series

Table 1. Series 1 – Average characterization values of old (OC) and new (NC) concrete

Characterization Tests	Concrete	
	OC	NC
Tensile strength (MPa)	3.27	3.30
Compression strength (MPa)	24.04	38.96
Elasticity modulus (GPa)	22.36	25.21

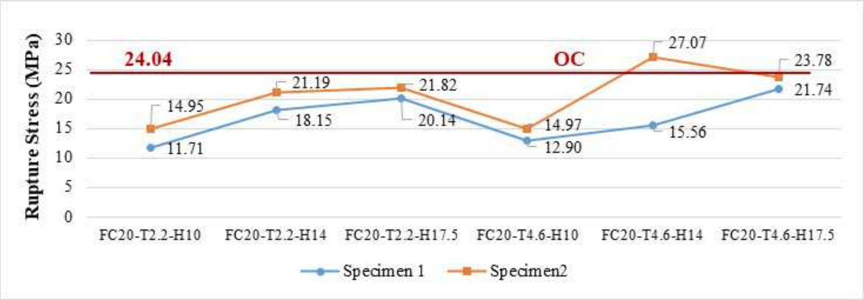


Figure 13. Series 1 – Rupture stress in the sleeve test

Table 2. Series 2 – Average characterization values of old (OC) and new (NC) concrete

Characterization Tests	Concrete	
	OC	**NC**
Tensile strength (MPa)	1.52	4.22
Compression strength (MPa)	15.06	39.86
Elasticity modulus (GPa)	12.38	24.01

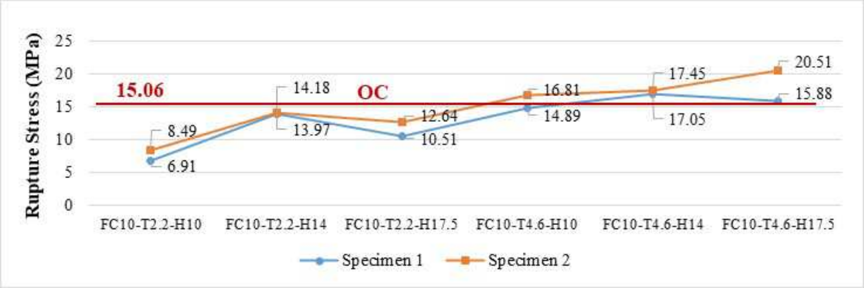


Figure 14. Series 2 – Rupture stress in the sleeve test

Table 3. Series 3 – Average characterization values of old (OC) and new (NC) concrete

Characterization Tests	Concrete	
	OC	**NC**
Tensile strength (MPa)	2.85	2.93
Compression strength (MPa)	23.87	38.76
Elasticity modulus (GPa)	27.18	27.84

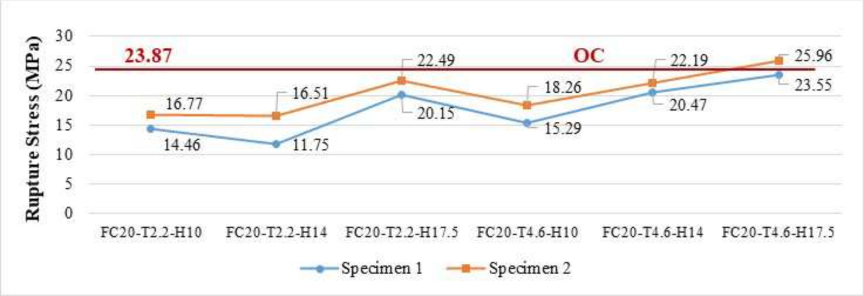


Figure 15. Series 3 – Rupture stress in the sleeve test

Table 4. Series 4 – Average characterization values of old (OC) and new (NC) concrete

Characterization Tests	Concrete	
	OC	**NC**
Tensile strength (MPa)	2.10	2.80
Compression strength (MPa)	18.17	39.40
Elasticity modulus (GPa)	14.56	29.79

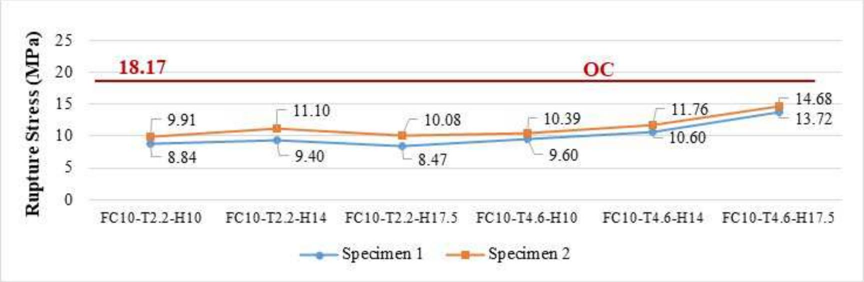


Figure 16. Series 4 – Rupture stress in the sleeve test

Table 5. Series 5 – Average characterization values of old (OC) and new (NC) concrete

Characterization Tests	Concrete	
	OC	**NC**
Tensile strength (MPa)	3.53	3.61
Compression strength (MPa)	29.91	49.29
Elasticity modulus (GPa)	27.97	28.02

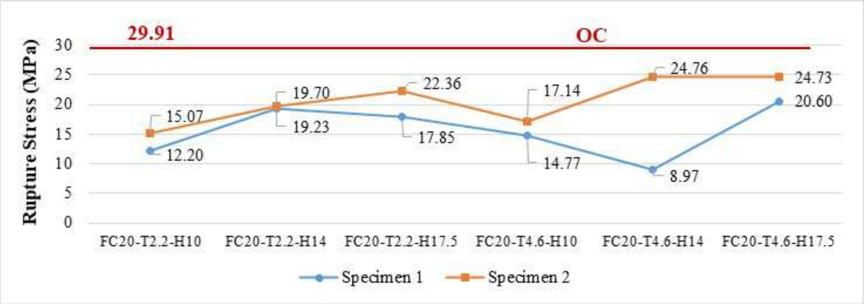


Figure 17. Series 5 – Rupture stress in the sleeve test

Table 6. Series 6 – Average characterization values of old (OC) and new (NC) concrete

Characterization Tests	Concrete	
	OC	**NC**
Tensile strength (MPa)	2.00	3.20
Compression strength (MPa)	17.24	35.57
Elasticity modulus (GPa)	10.85	32.89

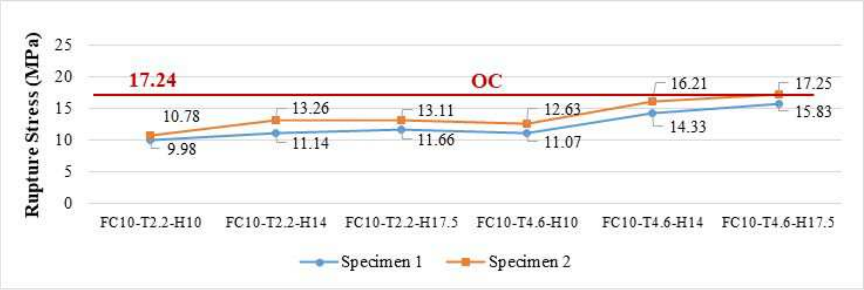


Figure 18. Series 6 – Rupture stress in the sleeve test

5.1 Discussion of the influence of the strength to be restored (10MPa or 20MPa)

5.1.1 Series 1 versus Series 2

In Figure 19, the average compressive strength values obtained in the sleeve test in Series 1 and Series 2 are compared, both series with epoxy adhesive surface treatment, being, respectively, f_c = 20MPa and f_c = 10MPa.

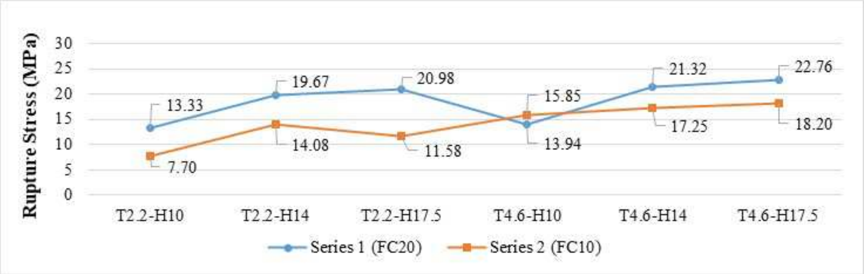


Figure 19. Series 1 x Series 2 – Average rupture stress in the sleeve test

Comparing the results, it is observed that:

- For the case of f_c = 10MPa, there is a significantly greater gain in the restored resistant capacity when increasing the thickness of the jacket from 2.2cm to 4.6cm (on average, 62%), compared to the case of f_c = 20MPa (on average, 7%).
- For the case of jacket thickness of 2.2cm, a greater disparity is observed between the restored resistant capacities as a function of the strength to be restored (on average, 65%), compared to the case of jacket thickness of 4.6cm (in average, 12%).
- In both strengths to be restored, a greater gain in the restored resistant capacity is observed when the jacket height is increased from 10cm to 14cm, than when this height is increased from 14cm to 17.5cm.
- The responses obtained with f_c = 20MPa were monotonic with increasing thickness (t = 2.2 to 4.6cm) and height (H = 10, 14 to 17.5cm) of the jacket, which was not observed for the case of f_c = 10MPa with a jacket thickness of 2.2cm.
- Following the logic, the idealized resistant capacity of 10MPa was more easily restored, as well as exceeded, than the idealized resistant capacity of 20MPa.
- From the standpoint of the idealized resistant capacity to be restored, it can be concluded that the thickness of the jacket of 2.2cm is sufficiently satisfactory when combined with heights of 14cm or 17.5cm for f_c = 10MPa, being the combination of jacket thickness of 4.6cm with heights of 14cm or 17.5cm recommended when dealing with f_c = 20MPa.

5.1.2 Series 3 versus Series 4

In Figure 20, the average compressive strength values obtained in the sleeve test in Series 3 and Series 4 are compared, both series with holes with drill surface treatment, being, respectively, f_c = 20MPa and f_c = 10MPa.

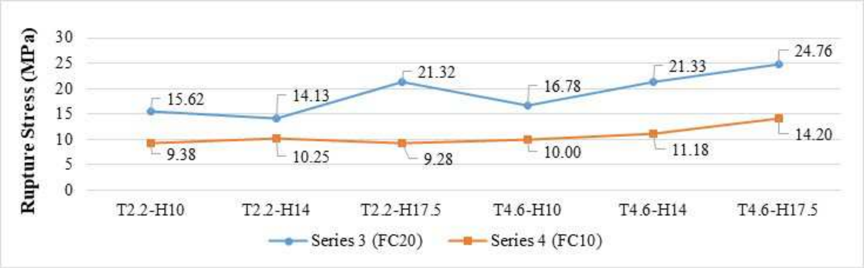


Figure 20. Series 3 x Series 4 – Average rupture stress in the sleeve test

Comparing the results, it is observed that:

- In average values, for both strengths to be restored, there is an almost equal gain in the restored resistant capacity when increasing the jacket thickness from 2.2cm to 4.6cm, that is, f_c = 10MPa: 23%; f_c = 20MPa: 25%.
- In average values, for both jacket thicknesses, an equal disparity is observed between the restored resistant capacities as a function of the strength to be restored, that is, for t = 2.2cm and t = 4.6cm: 78%.
- In the strength to be restored of 10MPa, for the case of a jacket thickness of 2.2cm, no gain in the restored resistant capacity with an increase in the jacket height is observed, whereas, for the case of a jacket thickness of 4.6cm, there is a greater gain in the restored resistant capacity when the jacket height is increased from 14cm to 17.5cm than when this height is increased from 10cm to 14cm. In the strength to be restored of 20MPa, for the case of a jacket thickness of 2.2cm, a greater gain in the restored resistant capacity is observed when the jacket height is increased from 14cm to 17.5cm, than when this height is increased from 10cm to 14cm (in fact, a slight reduction is observed), whereas, in the case of a jacket thickness of 4.6cm, the opposite is observed, that is, a greater gain in the restored resistant capacity when the jacket height is increased from 10cm to 14cm, than when this height is increased from 14cm to 17.5cm, although a gain is also observed.
- The responses obtained with both strengths to be restored were shown to be monotonic with an increase in the jacket thickness (t = 2.2 to 4.6cm), however, they were only monotonic with an increase in the jacket height (H = 10, 14 to 17.5cm) for t = 4.6cm.
- Contrary to logic, there are similar difficulties to restore the idealized resistant capacity of both 20MPa and 10MPa, as well as the same order of magnitude of excesses when these strengths are overcome.
- From the standpoint of the idealized resistant capacity to be restored, it can be concluded that a jacket thickness of 4.6cm is recommended for both strengths combined with heights of 14cm or 17.5cm.

5.1.3 Series 5 versus Series 6

In Figure 21, the average compressive strength values obtained in the sleeve test in Series 5 and Series 6 are compared, both series with sanding surface treatment, being, respectively, f_c = 20MPa and f_c = 10MPa.

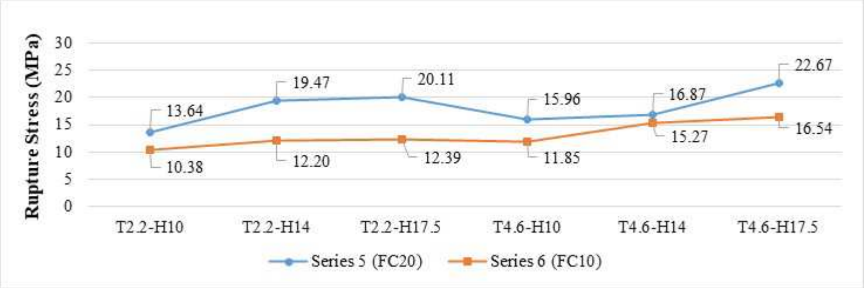


Figure 21. Series 5 x Series 6 – Average rupture stress in the sleeve test

Comparing the results, it is observed that:

- For the case of f_c = 10MPa, there is a greater gain in the restored resistant capacity when increasing the thickness of the jacket from 2.2cm to 4.6cm (in average values, 24%), compared to the case of f_c = 20MPa (in average values, 5%).
- For the case of jacket thickness of 2.2cm, a greater disparity is observed between the restored resistant capacities as a function of the strength to be restored (in average values, 51%), compared to the case of jacket thickness of 4.6cm (in average values, 27%).
- In both strengths to be restored, except for the case of f_c = 20MPa and jacket thickness of 4.6cm, a greater gain in the restored resistant capacity is observed when the jacket height is increased from 10cm to 14cm, than when this height is increased from 14cm to 17.5cm.
- The responses obtained with f_c = 10MPa were monotonic with increasing thickness (t = 2.2 to 4.6cm) and height (H = 10, 14 to 17.5cm) of the jacket, which was not observed for the case of f_c = 20MPa with a jacket height of 14cm.
- Following the logic, the idealized resistant capacity of 10MPa was more easily restored, as well as exceeded, than the idealized resistant capacity of 20MPa.
- From the standpoint of the idealized resistant capacity to be restored, it can be concluded that the jacket thickness of 2.2cm is sufficiently satisfactory, combined with any of the three heights considered, in the case of f_c = 10MPa. For the case of f_c = 20MPa, the combination of jacket thickness of 4.6cm with a height of 17.5cm is recommended.

5.2 Discussion of the influence of the surface treatment

5.2.1 Series 1 versus Series 3 versus Series 5

In Figure 22, the average compressive strength values obtained in the sleeve test in Series 1, Series 3, and Series 5 are compared, all with f_c = 20MPa, with surface treatment, respectively, of the epoxy adhesive type, holes with drill and sanding.

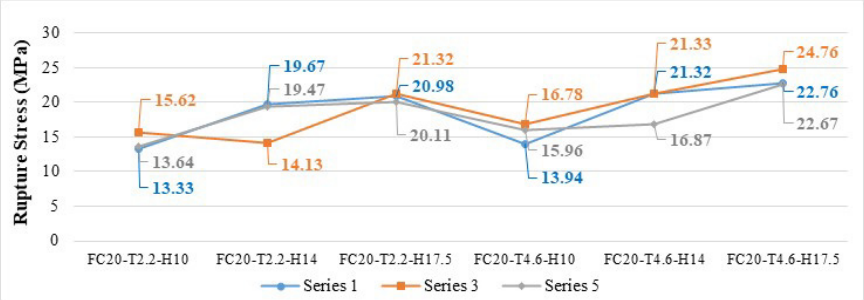


Figure 22. Series 1 x Series 3 x Series 5 – Average rupture stress in the sleeve test

Comparing the results, it is observed that:

- Except for the case of a jacket thickness of 2.2cm combined with a height of 14cm, the holes with drill surface treatment showed better responses of restored resistant capacity.
- Except for the cases of jacket thickness of 4.6cm combined with heights of 10cm and 14cm, surface treatments in epoxy adhesive and sanding showed similar restored resistant capacity responses, contrary to what was expected when interpreting them, respectively, as upper, and lower limits.
- For the case with a jacket thickness of 2.2cm, the three surface treatments were only able to restore the idealized strength (20MPa) for the case with a jacket height of 17.5cm.
- For the case with a jacket thickness of 4.6cm, the three surface treatments were able to restore the idealized strength (20MPa) for the case with a jacket height of 17.5cm, the surface treatments of the epoxy adhesive type and holes with drill for the case with a jacket height of 14cm and none of them for the case with a jacket height of 10cm.
- It can be concluded that, for the case of idealized resistant capacity to be restored of 20MPa, the jacket height of 10cm is not satisfactory regardless of the surface treatment, the height of 14cm is sufficient in the case of thickness of 4.6cm and epoxy adhesive or holes with drill surface treatments, and a height of 17.5cm is satisfactory with the three surface treatments, with a thickness of 2.2cm being sufficient.

5.2.2 Series 2 versus Series 4 versus Series 6

In Figure 23, the average compressive strength values obtained in the sleeve test in Series 2, Series 4, and Series 6 are compared, all with f_c = 10MPa, with surface treatment, respectively, of the epoxy adhesive type, holes with drill and sanding.

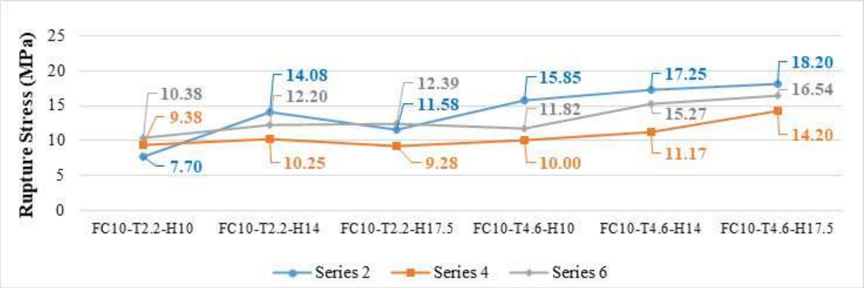


Figure 23. Series 2 x Series 4 x Series 6 – Average rupture stress in the sleeve test

Comparing the results, it is observed that:

- Except for the cases of jacket thickness of 2.2cm combined with heights of 10cm and 17.5cm, the epoxy adhesive surface treatment showed better responses of restored resistant capacity.
- Except for the cases of jacket thickness of 2.2cm combined with heights of 10cm and 17.5cm, the sanding surface treatment was the one that presented the second-best response of restored resistant capacity.
- Except for the case of jacket thickness of 2.2cm combined with a height of 10cm, the holes with drill surface treatment showed the worst restored strength capacity responses, the opposite of what was observed in the case of f_c = 20MPa.
- Only the sanding surface treatment was able to restore the idealized strength (10MPa), regardless of the thickness or height of the jacket.
- The epoxy adhesive surface treatment was only not able to restore the idealized strength (10MPa) for the case of a jacket thickness of 2.2cm combined with a height of 10cm.
- The holes with drill surface treatment was able to restore the idealized strength (10MPa) regardless of the jacket height for the case of a jacket thickness of 4.6 cm. In the case of a jacket thickness of 2.2cm, this treatment was only able to restore the idealized strength (10MPa) for the case of a jacket height of 14cm.
- It can be concluded that, for the case of an idealized strength capacity to be restored of 10MPa, the thickness of 2.2cm combined with any of the three heights is sufficiently satisfactory when using sanding surface treatment or combined with heights of 14cm or 17.5cm when using epoxy adhesive surface treatment. In the case of holes with drill surface treatment, it is recommended to use a thickness of 4.6 cm.

6 FRICTION AND ADHESION IN THE SLEEVE TEST

From the rupture load of two sleeve test specimens with jacket with different thickness or height, it is possible to obtain the coefficient of friction (μ) and adhesion (c). In this research, specimens with different jacket thickness were used.

Piancastelli [1], based on the analysis of fundamental concepts of mechanics of material, equated a linear system through which it is possible to obtain the values of the coefficient of friction and adhesion from the results obtained in the sleeve test, as illustrated in Figure 24.

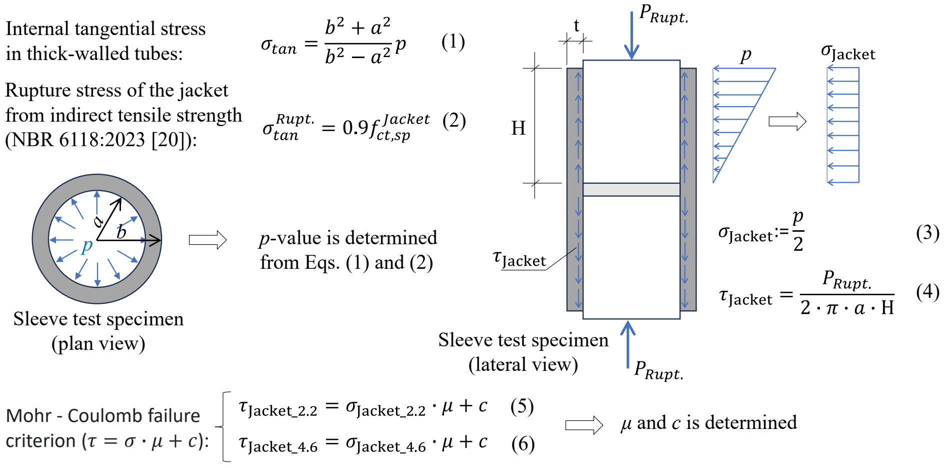


Figure 24. Methodology for calculating the coefficient of friction (μ) and adhesion (c) based on NBR 6118:2023[20]

The validity of the methodology presented in Figure 24 is based on the predominant rupture mode observed in the sleeve tests, illustrated in Figure 25 to Figure 28, in which it is observed that the rupture of the specimen begins with the appearance of longitudinal cracks in the repair jacket (new concrete), resulting from the tangential tensile stress to which it is subjected, with subsequent separation of the core (old concrete) and the jacket, that is, the typical failure mode of confined columns. Similar failure modes were observed in experimental studies by Piancastelli [1] and Enami [3].

Figure 25. Longitudinal crack in a specimen with t = 4.6cm / H = 10cm

Figure 26. Longitudinal crack in a specimen with t = 4.6cm / H = 14cm

Figure 27. Longitudinal crack in a specimen with t = 2.2cm / H = 17.5cm

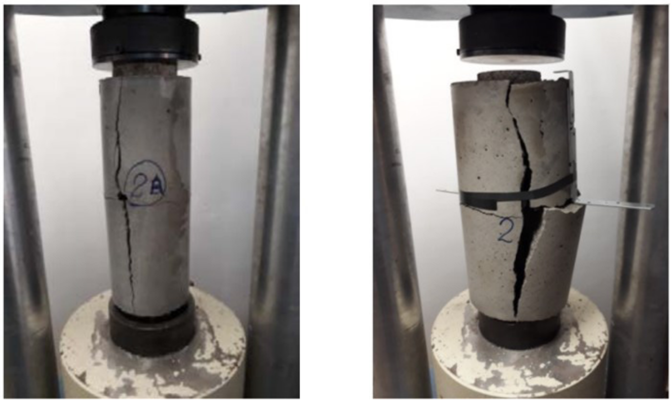


Figure 28. Separation of the core (old concrete) and the jacket (new concrete)

Following the linear system equated in Figure 24, the coefficient of friction and adhesion calculations were performed for each series according to the Table 7 to Table 12.

Table 7. Series 1 – Calculation of the coefficient of friction and adhesion

Jacket height	$\tau_{Jacket\_2.2}$	$\tau_{Jacket\_4.6}$	$\sigma_{Jacket\_2.2}$	$\sigma_{Jacket\_4.6}$	μ	c
(cm)	(MPa)	(MPa)	(MPa)	(MPa)		(MPa)
10.0	3.33	3.48	0.52	0.85	0.45	3.10
14.0	3.51	3.81			0.89	3.05
17.5	3.00	3.25			0.77	2.60

Table 8. Series 2 – Calculation of the coefficient of friction and adhesion

Jacket height	$\tau_{Jacket\_2.2}$	$\tau_{Jacket\_4.6}$	$\sigma_{Jacket\_2.2}$	$\sigma_{Jacket\_4.6}$	μ	c
(cm)	(MPa)	(MPa)	(MPa)	(MPa)		(MPa)
10.0	1.93	3.96	0.66	1.09	4.79	-1.25
14.0	2.51	3.08			1.33	1.63
17.5	1.65	2.60			2.22	0.18

Table 9. Series 3 – Calculation of the coefficient of friction and adhesion

Jacket height	$\tau_{Jacket\_2.2}$	$\tau_{Jacket\_4.6}$	$\sigma_{Jacket\_2.2}$	$\sigma_{Jacket\_4.6}$	μ	c
(cm)	(MPa)	(MPa)	(MPa)	(MPa)		(MPa)
10.0	3.90	4.19	0.46	0.76	0.98	3.45
14.0	2.52	3.81			4.35	0.52
17.5	3.05	3.54			1.66	2.28

Table 10. Series 4 – Calculation of the coefficient of friction and adhesion

Jacket height	$\tau_{Jacket\_2.2}$	$\tau_{Jacket\_4.6}$	$\sigma_{Jacket\_2.2}$	$\sigma_{Jacket\_4.6}$	μ	c
(cm)	(MPa)	(MPa)	(MPa)	(MPa)		(MPa)
10.0	2.34	2.50	0.44	0.72	0.55	2.10
14.0	1.83	2.00			0.59	1.57
17.5	1.32	2.03			2.50	0.23

Table 11. Series 5 – Calculation of the coefficient of friction and adhesion

Jacket height	$\tau_{Jacket\_2.2}$	$\tau_{Jacket\_4.6}$	$\sigma_{Jacket\_2.2}$	$\sigma_{Jacket\_4.6}$	μ	c
(cm)	(MPa)	(MPa)	(MPa)	(MPa)		(MPa)
10.0	3.41	3.99	0.57	0.93	1.60	2.50
14.0	3.48	3.01			-1.28	4.20
17.5	2.87	3.24			1.00	2.30

Table 12. Series 6 – Calculation of the coefficient of friction and adhesion

Jacket height	$\tau_{Jacket\_2.2}$	$\tau_{Jacket\_4.6}$	$\sigma_{Jacket\_2.2}$	$\sigma_{Jacket\_4.6}$	μ	c
(cm)	(MPa)	(MPa)	(MPa)	(MPa)		(MPa)
10.0	2.59	2.96	0.50	0.83	1.14	2.02
14.0	2.18	2.73			1.70	1.32
17.5	1.77	2.36			1.84	0.84

From the results obtained, it is observed that:

- In Series 2, for the case of a jacket height of 10cm, the adhesion value showed a negative sign, which has no physical meaning, except pointing to the fact that friction is more than enough to resist shearing.
- In Series 5, for the case of jacket height of 14cm, the value of the coefficient of friction showed a negative sign, which has no physical sense. From Figure 17, it is observed that this anomaly is a consequence of the poor response obtained with one of the sleeve test specimens that presented an unexpected behavior whose cause was not identified.
- For the idealized strength of 20MPa, the highest value of the coefficient of friction was achieved with the holes with drill surface treatment ($\mu = 4.35$ with H = 14cm).
- For the idealized strength of 20MPa, the highest adhesion value was achieved with the sanding surface treatment ($c = 4.20$MPa with H = 14cm). If this adhesion value is disregarded due to the anomaly observed for the corresponding coefficient of friction, the highest adhesion value will also be that achieved with holes with drill surface treatment ($c = 3.45$MPa with H = 10cm).
- For the idealized strength of 10MPa, the highest value of the coefficient of friction was achieved with the epoxy adhesive surface treatment ($\mu = 4.79$ with H = 10cm). However, this value must be corrected since it is the result of negative adhesion. To do so, one can return to the linear system defined by Equations 5 and 6 – Figure 24 – imposing $c = 0$ and determining μ as the average value, that is,

$$\begin{cases} 1.93\text{MPa} = 0.66\text{MPa} \cdot \mu + 0 \\ 3.96\text{MPa} = 1.09\text{MPa} \cdot \mu + 0 \end{cases} \therefore \mu = \frac{{}^{1.93}\!/_{0.66} + {}^{3.96}\!/_{1.09}}{2} = 3.28$$

- For the idealized strength of 10MPa, the highest adhesion value was achieved with the holes with drill surface treatment ($c = 2.10$MPa with H = 10cm).
- For the idealized strength of 20MPa, the holes with drill surface treatment was the one that presented the highest values of friction angle (60º, in average), followed by the sanding (51º, in average) and, by lastly, the epoxy adhesive (34º, in average).
- For the idealized strength of 10MPa, the epoxy adhesive surface treatment was the one that presented the highest values of friction angle (64º, in average), followed by the sanding (57º, in average) and, by lastly, the holes with drill (43º, in average).

7 CONCLUSIONS

In this work, the influence of different types of surface treatment – namely, sanding, chipping (achieved with a drill) and bonding with epoxy adhesive – on the localized repair of columns by jacketing was investigated through the sleeve test. Some observations are highlighted:

In general, for the case of idealized strength of f_c = 20MPa, the holes with drill surface treatment showed better responses of restored resistant capacity, whereas, for the case of idealized strength of f_c = 10MPa, the epoxy adhesive surface treatment proved to be better.

For the case of f_c = 20MPa, epoxy adhesive and sanding surface treatments showed close restored resistant capacity responses, contrary to what was expected when interpreting them, respectively, as upper, and lower limits, while, for the case of f_c = 10MPa, the sanding surface treatment was the one that presented the second-best response of restored resistant capacity.

Consequently, for the case of f_c = 10MPa, the holes with drill surface treatment turned out to be the worst, the opposite of what was observed in the case of f_c = 20MPa. From these results, it is concluded that the lower the idealized resistant capacity to be restored, that is, the lower the internal forces in the column to be repaired (and the consequent lower Poisson effect), the lower the contribution of the friction force in the connection between concretes, therefore, the contribution of the roughness of the contact surface between concretes will be lower.

In general, the adoption of a jacket with a height of 17.5cm is suggested here, with a thickness of 2.2cm being sufficient. In fact, in the design practice of localized repairs by jacketing, it is recommended that the jacket height be approximately twice the section dimension of the repaired element (Piancastelli [1]). In Zaiter and Lau [21], in which it is concluded that the jacket height must be related to the height of the column, it is also observed that the suggested jacket height is approximately twice the section dimension of the repaired element.

From the perspective of the 17.5cm high jacket, the holes with drill surface treatment stands out here, since this treatment with this jacket height was the one that presented the highest values of the coefficient of friction (f_c = 20MPa: $\mu = 1.66$; f_c = 10MPa: $\mu = 2.50$). The coefficient of friction is the most important parameter in the connection between concretes by jacketing due to the confinement phenomenon.

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