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Experimental Investigation of Steel-Concrete Bond for Thin Reinforcing Bars

Abstract

The steel-concrete bond is a fundamental property in reinforced concrete structures. Although there are several studies on the steel-concrete bond, few of them have evaluated the performance of reinforcing bars with diameters less than 10.0 mm, which includes 5.0, 6.3, and 8.0 mm diameters, which are normally used in reinforced-concrete elements. This study experimentally evaluates the bond between thin steel bars and concrete of 25MPa compression strength. Three types of methods of testing the bond-strength were performed: confined bar test, pull-out test and beam test. It was compared the adequacy of the tests to calculate the conformation coefficient of the bars. The results of the confined bars tests show that this test may be inadequate to determine the surface conformation coefficient of reinforcing bars thinner than 10 mm, especially for notched (CA-60) steel bars. The pull-out test resulted in better results in terms of evaluating the bond behavior. Regarding the specimens for the pull-out tests, a modified model with an anchorage length equal to 10 times the bar diameter is suggested. Therefore, the main contribution of this study, based on the results obtained and the methodology used, is to present a proposal for the evaluation of steel-concrete bond for thin rebars.

Keywords

bond, surface conformation, thin rebars.

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1 INTRODUCTION

The foundation of reinforced concrete is primarily based on the bond mechanism between steel bars and concrete. The characteristics of steel-concrete interface are influenced by an extensive range of parameters related to both steel and concrete, besides the interactions between them. This diversity of aspects, detailed in Angst et. al. (2017), results in heterogeneities in the whole steel-concrete interface influencing, among other aspects, the steel-concrete adhesion. Also, as a phenomenon influ-

enced by many variables, it is a challenge to establish how the steel-concrete adhesion can be described in standards used for reinforced concrete design. Scientific studies on this property have been performed since the 1940s, as in Rehm (1968) which investigated the factors that influence the bond between steel bars and concrete. Other relevant studies are those by Watstein (1941), Mains (1951), Ferguson et al. (1954), Perry and Thompson (1966), Goto (1971), Mirza and Houde (1979), Kemp (1986), and Jiang et al. (1984). These fundamental studies were all carried out using steel rebars with diameters greater than 12.0 mm.

Research on the steel-concrete bond has followed the materials evolution, such as high-compressive strength concretes, concrete with additives, and self-compacting concretes (Barbosa (2001), Barbosa et al. (2004), Almeida Filho (2008), Araujo et al. (2013), Michael and Catherine (2016)). Steel-concrete bond is also a subject associated to the quality control of reinforced-concrete structures (Lorrain et al. (2011), Silva et al. (2013) and Jacintho et al. (2014)) and the performance of reinforced concrete under extreme conditions, such as in high-temperatures environments and under corrosion (Caetano (2008) and Márquez et al. (2016)). However, although there are several studies on the steel-concrete bond, few of them have evaluated the performance of reinforcing bars with diameters less than 10.0 mm, which includes 5.0, 6.3, and 8.0 mm diameters, which are normally used in reinforced-concrete elements. In addition, the concrete evolution is making possible the design and production of slender reinforced concrete components, especially by the precast sector, applying predominantly thin rebars. On the other hand, the small number of scientific studies on the bond of thin bars casts doubts on the parameters used to calculate the anchorage length of these bars in reinforced concrete elements, that is proposed by Brazilian standards ABNT-NBR 7480 (2007) and ABNT-NBR 6118 (2014).

According to Brazilian standard ABNT-NBR 6118 (2014), the basic anchorage length (l_b) of reinforcing bars can be calculated by equation 1:

$$l_b = \frac{\phi}{4} \cdot \frac{f_{yd}}{f_{bd}} \tag{1}$$

In which:
ϕ – bar diameter
f_{yd} – bar yield strength and
f_{bd} – reinforcement bond strength.

The reinforcement bond strength (f_{bd}) can be obtained by equation 2:

$$f_{bd} = \eta_1 \eta_2 \eta_3 f_{ctd} \tag{2}$$

According to this expression, the bond depends on the concrete's tensile strength (f_{ctd}) and on factors attributed to dimensionless coefficients: $\eta 1$ is related to the rebars' surface conformation, $\eta 2$ is related to the rebars' position during concrete casting, and $\eta 3$ is related to the bars' diameter (ϕ). Among these parameters, $\eta 1$ is directly related to the surface conformation coefficient of steel bars (η), which is specified by ABNT-NBR 7480 (2007). The minimum surface conformation values (η) obtained in bond tests are prescribed by this standard (Table 1), and tests must be performed according to ABNT-NBR 7477 (1982).

ABNT-NBR 7480		
η		Bar Type
$\Phi < 10.0$ mm	$\Phi \geq 10.0$ mm	
1.0	1.0	Plain
1.0	1.2	Notched(CA-60)
1.0	1.5	Ribbed(CA-50)

Table 1: Surface conformation coefficients (η) according to standard ABNT-NBR 7480 (2007).

According to Table 1, the minimum surface conformation coefficient of bars thinner than 10.0 mm must be equal to 1.0. However, several authors have evaluated the values of these coefficients, and the studies by Barbosa (2001) and Barbosa et al (2004) verified that bars thinner than 12.5 mm may not meet Brazilian standards requirements, with conformation coefficients lower than the specified minimums.

These issues, together with the small number of studies on the bond of steel rebars thinner than 10.0 mm, raise the following concerns: a) Does the performance of thin bars meet the minimum conformation coefficient specified by ABNT-NBR 7480 (2007)?; b) Is the surface conformation coefficient test proposed by ABNT-NBR 7477 (1982) adequate for thin bars?

Regarding the tests, it was verified in the literature that most of the tests used to evaluate steel-concrete bond are: pull-out tests RILEM-CEB RC6 (1983), beam tests RILEM-CEB RC5 (1982) and confined bars tests ABNT-NBR 7477 (1982). The pull-out test consists of extracting a steel bar placed in the center of a cubic concrete specimen. The pulling force is measured at one end, and the displacement is measured at the other end, as shown in Figure 1. The bond strength is obtained through equation 3.

$$\tau = \frac{P}{\pi \cdot \phi \cdot La} \tag{3}$$

With:
τ – bond strength;
P – applied load;
ϕ – rebar diameter and
L_a – anchorage length.

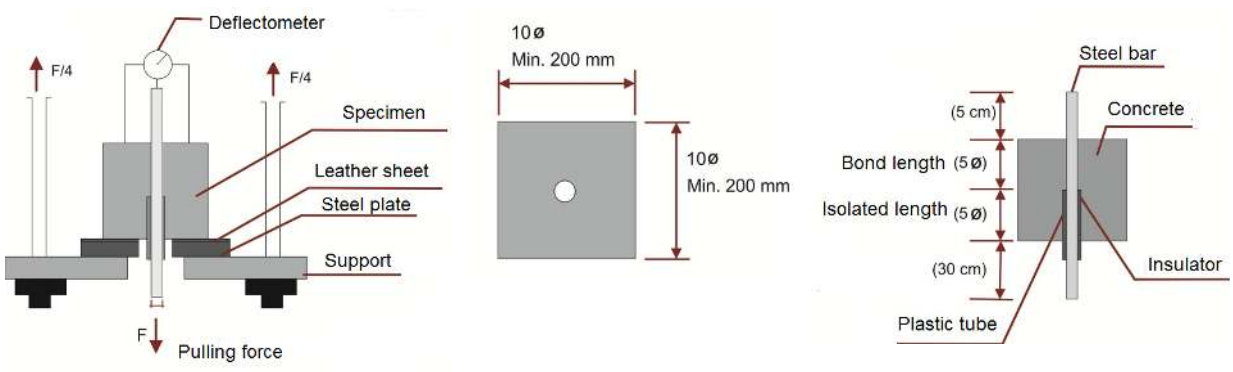

Figure 1: Pull-out test set-up (RILEM RC6).

According to Figure 1, the anchorage length was 5 times the steel rebar diameter, and the non-bonding length was insulated with a rigid PVC conduit.
Beam test set-up is basically a 4-point beaming test for a determination of the bond-strength for bent concrete girders (Figure 2).

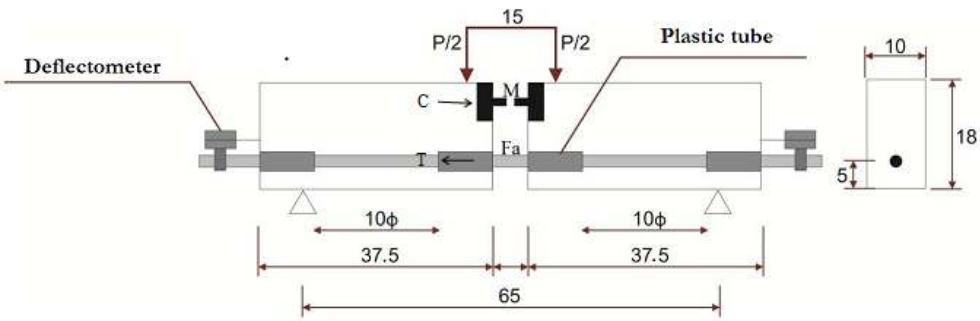

Figure 2: Beam test set-up (RILEM RC5).

Two separate concrete blocks are, at the bottom, connected by a reinforcement whose bond-strength is to be measured. The reinforcement bar is set into tubes to ensure a precise bond length. The top parts of the blocks are connected by a separating hinge. After setting the test beam, a force is applied to the top part of the girder, symmetrically to both blocks. The force is applied continuously and the shift of the bar towards the inside of the block is measured. The test continues until exceeding the bond-strength between the concrete and the reinforcement. The bond strength is obtained through equation 4.

According to Figure 2, the anchorage length was 10 times the steel rebar diameter, and the non-bonding length was insulated with a rigid PVC conduit.

$$\tau = \frac{F_a}{\pi \cdot \phi \cdot La} \qquad and \qquad F_a = 1,25 \times P \tag{4}$$

With:
τ – bond strength;
F_a – rebar load;
P – applied load;
ϕ – rebar diameter and
L_a – anchorage length.

The confined bars test is used to determine the surface conformation coefficient of steel bars. In this test, the bar is pulled in tension gradually transferring normal tensile stress to the surrounding concrete cover, as shown in Figure 3. At the end of the test, the specimen must present at least six cracks (Figure 4).

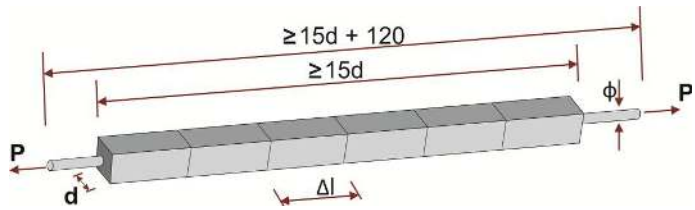

Figure 3: Confined bars test specimen.



Figure 4: Cracked specimen.

The surface conformation coefficient (η) is calculated from the average distance between the cracks through equation 5:

$$\eta = \frac{2.25 \cdot d}{\Delta l_{average}} \qquad d = \sqrt{\pi\phi\left(\frac{\phi}{4} + 7\right)} \tag{5}$$

With:
d – specimen cross sectional length (cm) and
$\Delta l_{average}$ –average distance between cracks, which considers the four faces.

As already mentioned, the tests cited are used to evaluate the steel-concrete bond. However, there are important considerations to be made:

- The confined bars test results in an indirect measure of the bar's bonding capacity and has unsatisfactory values for thin bars;
- The pull-out test has been widely adopted in studies in Brazil and other countries to evaluate the bond strength of a bar submitted to direct pull-out. However, there are few studies that have used the pull-out tests for thin reinforcing bars;
- Beam tests more accurately represent the steel concrete bond in bent concrete elements, but it is much more laborious to perform.
- The methods produce quite different results which make an objective assessment of the concrete-reinforcement bond-strength difficult.

Given all of the aforementioned reasons, this study presents the results of bond tests carried out using thin reinforcing bars, conducted according to the confined bars, pull-out and beam models. This research contributes to: a) better understanding of the steel-concrete bond for thin steel bars; and b) providing key information for definition of future standards for bond tests to thin reinforcing bars.

2 MATERIALS AND METHODS

The methodology of this work consisted of confined bars, pull-out tests and beam tests. The primary objective of the confined bars tests was to determine the surface conformation coefficient of the

steel bars. The pull-out tests and the beam tests were performed to determine the maximum bond strength between the steel bars and concrete. The planning of the tests is shown in Table 2.

Test type	Bar type	Diameter (mm)	Number of specimens per diameter (N)
Confined bars	Notched CA-60	5.0	9
		8.0	9
		9.5	9
	Ribbed CA-50	6.3	9
		8.0	9
		10.0	9
Pull-out	Notched CA-60	5.0	5
		8.0	5
		9.5	5
	Ribbed CA-50	6.3	5
		8.0	5
		10.0	5
Beam Test	Notched CA-60	5.0	5
		8.0	5
		9.5	5
	Ribbed CA-50	6.3	5
		8.0	5
		10.0	5

Table 2: Tests planning.

According to this table, notched (CA-60) and ribbed thin bars (CA-50) were used. For each bar type and each diameter, nine specimens were tested in the confined bars tests and five specimens in the pull-out and beam tests, which resulted in 54 confined bars tests, 30 pull-out tests and 30 beam tests.

Deformed steel bars (notched and ribbed) with 5.0, 6.3, 8.0, 9.5 and 10.0 mm diameters were used in the specimens, as show in Table 2. The notched bars had a yield point of 693 MPa and a tensile strength of 768 MPa. The ribbed bars had a yield point of 639 MPa and a tensile strength of 721 MPa.

The test samples for all test methods were produced from the concrete that had a target compressive strength of 25 MPa. The cement used was Portland high early strength (CP V). The concrete was mixed in the ratio of cement/sand/coarse aggregate = 1:3.45:3.56 at a water/cement ratio of 0.78 and superplasticizer/cement ratio of 0.0074. Concrete cylinders with dimensions of 200x200x100 mm^3 were also cast for the test of concrete compressive strength.

After casting, the concrete specimens, both test specimens and cylinders for compressive strength, were kept in the water tanks for 21 days. This date was chosen for the tests schedule could be performed in a shorter period. The 21-day cured specimens had an average measured strength of 29 MPa.

The confined bars tests were performed according to standard ABNT-NBR 7477 (1982). The specimens were cast in wood moulds, as shown in Figure 5 and Figure 6. Before the tests, the specimens were painted with lime to make cracks more easily observable.

The tests were performed in a universal testing machine at a constant displacement rate of 1.0 mm/min, up to a load equal to 80% of the yield strength, established for the rebar (Figure 7). The number of cracks in the specimens and the space between them were measured at the end of the test (Figures 8 and 9).



Figure 5: Mould for confined bars specimens.



Figure 6: Confined bars specimens.



Figure 7: Set-up of confined bars test.

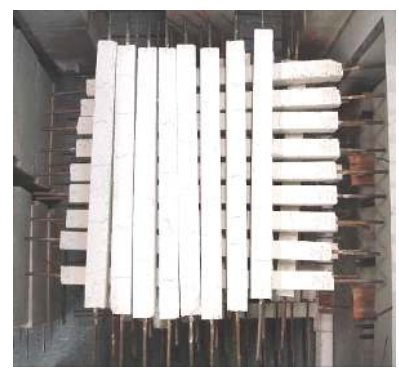

Figure 8: Cracked specimens after the test.



Figure 9: Detail of crack opening.

The surface conformation coefficients were also calculated according to ABNT-NBR 7477 (1982), equation 5.

Pull-out tests were conducted according to the recommendations of RILEM-CEB RC6 (1983). Figures 10 and 11 show a detail of the mould used to cast the specimens.



Figure 10: Moulds for Pull-out specimen.



Figure 11: Casting mold- pull-out specimen.

After being cured for 21 days, the specimens were tested in a universal machine with a steel support to fix the model, as shown in Figure 12.

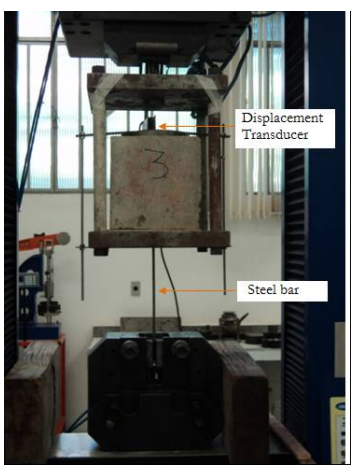

Figure 12: Pull-out test set-up.

The load cell measured the force applied on the rebar and a displacement transducer measured the relative displacement between the steel rebar and the concrete specimen (Figure 13).



Figure 13: Displacement transducer.

The curves of the bond stress versus the slip of the steel rebar were obtained. The maximum bond strength was also determined according to equation 3.

Beam tests were conducted according to the recommendations of RILEM-CEB RC5 (1982). Figure 14 shows a detail of the mould used to cast the specimens. Beam test specimens are shown in Figure 15.





Figure 14: Moulds for Pull-out specimen.



Figure 15: Beam test specimens.

After being cured for 21 days, the beam test specimens were tested in a universal machine as shown in Figure 16.



Figure 16: Beam test set-up.

The load cell measured the force applied on the concrete blocks and a deflectometer measured the relative displacement between the steel rebar and the concrete block (Figure 17).

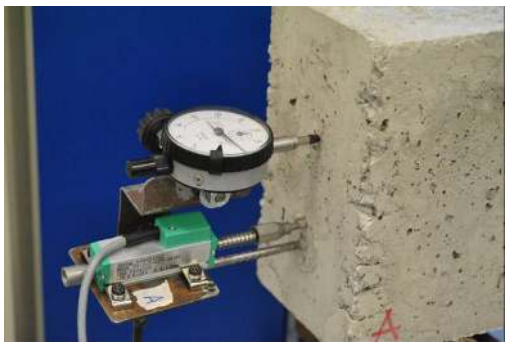

Figure 17: Deflectometer.

The curves of the bond stress versus the slip of the steel rebar were obtained. The maximum bond strength was also determined according to equation 4. Concrete characterization tests were performed on the same day as the bond tests (confined bars, pull-out and beam tests). These tests consisted of simple compression and tensile strength by cylinder splitting test. Cylinder compression tests were performed to determine the compressive strength and modulus of elasticity of the concrete (Figure 18).



Figure 18: Concrete compression test.

The tensile strengths by cylinder splitting test as shown in Figure 19.



Figure 19: Cylinder splitting test.

3 RESULTS

3.1 Confined Bars Tests

One hundred percent of the specimens with notched rebars (CA-60) for 5.0 and 8.0 diameters did not show the minimum of six cracks in their cross-section, which is required by ABNT-NBR 7477 (1982), to calculate the surface conformation coefficient (η). The only case where η met the requirement of standard ABNT-NBR 7480 (2007) was for the only one specimen notched bar with the 9.5-mm diameter. The others eight 9.5-mm diameter bars did not show the minimum of six cracks in their cross-section. In the case of the ribbed rebars, 100% of the specimens had more than six cracks in their cross-section.

Although not all the specimens had the minimum number of cracks required by ABNT-NBR 7477 (1982), the surface conformation coefficients (η) were calculated from the actual number of cracks. The results and the reference values proposed by ABNT-NBR 7480 (2007) are shown in

Table 3. It must be considered that the surface conformation coefficients were calculated by considering the average of the results of the 9 specimens of each rebar diameter.

Bar type	Ø (mm)	η (NBR7480)	$\boldsymbol{\eta}$ (sample average values)	Sample Standard Deviation (S)	Relative Standard Deviation (RSD) %
Notched CA-60	5.0	1.0	0.82	0.10	12
	8.0		0.83	0.24	29
	9.5		0.87	0.14	16
Ribbed CA-50	6.3	1.0	1.04	0.12	12
	8.0		1.18	0.09	8
	10.0	1.5	1.42	0.22	15

Table 3: Surface Conformation Coefficients.

The results reinforce the above-mentioned concerns: a) Do thin bars present satisfactory bond strength once the performance of thin bars does not meet the minimum conformation coefficient specified by ABNT-NBR 7480 (2007)?; b) Is the surface conformation coefficient test proposed by ABNT-NBR 7477 (1982) adequate for thin bars? It is emphasized that these results are in agreement with studies by Barbosa (2001) and Barbosa et al (2004), who verified that bars thinner than 12.5 mm may not meet Brazilian standards requirements, with conformation coefficients lower than the specified minimums. The results highlight the importance of evaluating the bond performance of thin reinforcing bars using other types of methods of testing the bond-strength. It is important to mention that in Brazil there is no other standardized method of testing the bond-strength and there is a current concern about the results that have been presented according to methodology proposed by ABNT-NBR 7477 (1982), mainly for thin reinforcing bars.

3.2 Pull-Out Tests

The bond stresses vs. the relative displacement curves were obtained from the pull-out tests, from which the ultimate or breakage bond strength (τu) was determined. Table 4 presents the bond strength (τu), which are the average of the results of the specimens of each sample, i.e., each diameter of the steel rebar. Also are present the sample Standard Deviation and the Relative Standard Deviation.

Bar type	Ø (mm)	τ_u (Sample average values) (MPa)	Sample Standard Deviation (S) (MPa)	Relative Standard Deviation (RSD) %
Notched CA-60	5.0	5.29	2.05	39
	8.0	3.99	0.61	15
	9.5	3.16	0.21	7
Ribbed CA-50	6.3	6.93	1.65	24
	8.0	6.47	0.78	12
	10.0	10.55	0.71	7

Table 4: Bond strength values (τ_u) – Pull-out.

Table 4 presents the results of the specimens with anchorage lengths equal to 5 times the bar diameter. It is important to highlight that the bond strength values of specimens of the same sample exhibited high Relative Standard Deviation in some cases (5.0 and 6.3 mm diameters bars). This indicates that the data points are spread out over a wider range of values.

As regards the high Relative Standard Deviation it can be mentioned that: the anchorage lengths that are 5 times the rebars' diameter, equal to 23.0, 31.5, 40.0, 47.5, and 50.0 mm for the 5.0, 6.3, 8.0, 9.5, and 10 mm diameters, respectively, can be considered small, and any interference in the steel-concrete interface may influence the bond behavior during the test. Therefore, the small anchorage length may have contributed to the increase in the Relative Standard Deviation of the results. These results may be indicate that the anchorage lengths of the specimens from the pull-out tests of the thin reinforcing bars must be greater than those prescribed by RILEM-CEB RC6 (1983). Therefore, it is suggested that in the case of rebars thinner than 10 mm, the specimens have anchorage lengths equal to 10 times the rebar diameter.

The variation in the behavior of specimens of the same sample can be verified in the bond stress versus slip curves shown in Figures 20 to 25.

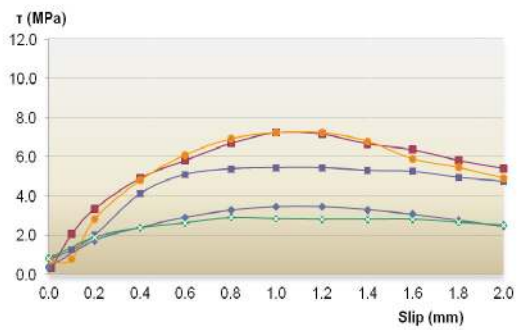

Figure 20: Bond stress-slip (Φ5.0 mmCA-60).

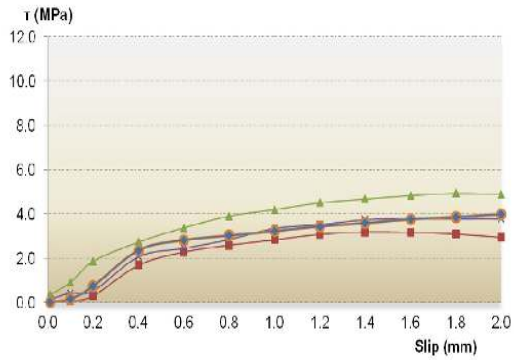

Figure 21: Bond stress-slip (Φ8 mm CA-60).

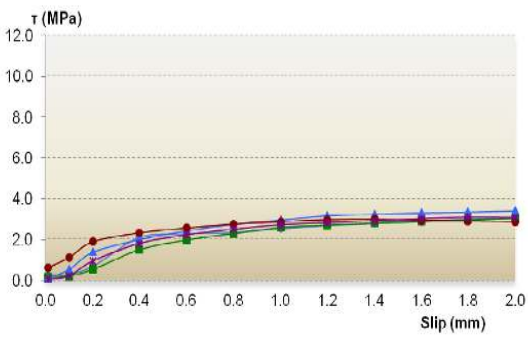

Figure 22: Bond stress-slip (Φ9.5 mmCA-60).

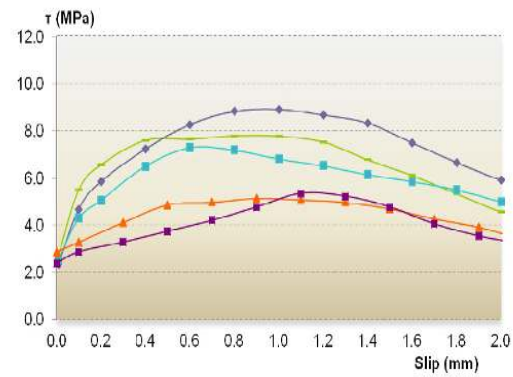

Figure 23: Bond stress-slip (Φ6.3 mm CA-50).

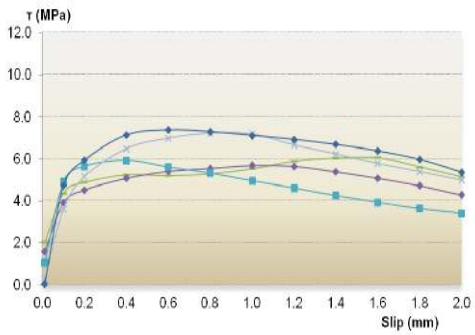

Figure 24: Bond stress-slip (Φ8.0 mmCA-50).

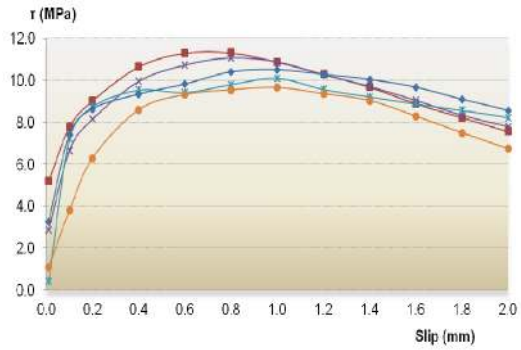

Figure 25: Bond stress-slip (Φ10.0mm CA50).

The Load-slip curves show that the behavior of the specimens of a same sample was more homogeneous for 9.5 and 10.0 mm diameters rebars. Highlight that these specimens also exhibited higher anchorage lengths.

The graph in Figure 26 shows a comparison between the behaviors of the notched (CA-60) and ribbed (CA-50) bars. This graph shows that the bond strength of 10.0-mm and 8.0-mm ribbed bars is greater than that of 9.5 mm and 8.0-mm notched bars, respectively. In the case of 5.0-mm ribbed bars and 6.3-mm notched bars, the results indicate that there may be no significant difference. Therefore, thin ribbed bars may have better bond performance than that of the notched bars. It ís noted that ABNT-NBR 7480 (2007) does not consider that thin reinforcing bars exhibit a performance gain based on bars with different conformations (plain, notched, or ribbed) as shown in Table 1.

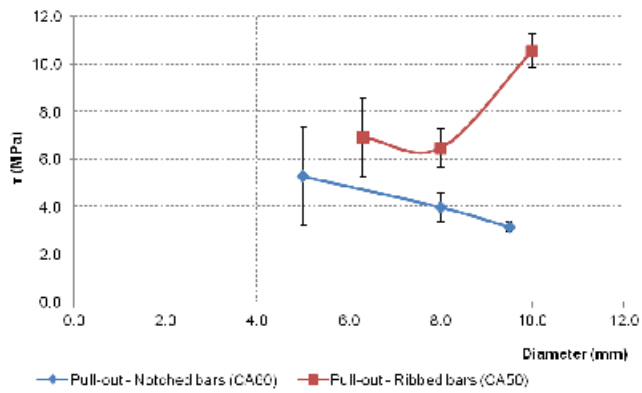

Figure 26: Bond performance - Notched and Ribbed rebars- pull-out.

3.3 Beam Tests

Table 5 presents the bond strength (τu), which are the average of the results of the specimens of each sample, i.e., each diameter of the steel rebar. Also are present the sample Standard Deviation and the Relative Standard Deviation.

Bar type	Ø (mm)	τ_u (Sample average values) (MPa)	Sample Standard Deviation (S) (MPa)	Relative Standard Deviation (RSD) %
Notched CA-60	5.0	12.07	1.42	12
	8.0	6.52	0.91	14
	9.5	4.11	0.09	2
Ribbed CA-50	6.3	12.93	2.19	17
	8.0	11.36	1.9	17
	10.0	10.99	1.15	11

Table 5: Bond strength values (τ_u) – Beam test.

Table 5 presents the results of the specimens with anchorage lengths equal to 10 times the bar diameter. The bond strength values of specimens of the same sample exhibited high Relative Standard Deviation in some cases (6.3 and 8.0 mm diameters bars). In general, comparing the data obtained with a repeated measurement using the beam test method can be complicated.

The graph in Figure 27 shows a comparison between the behaviors of the notched (CA-60) and ribbed (CA-50) bars in beam tests. This graph also shows the bond strength of 10.0-mm and 8.0-mm ribbed bars is greater than that of 9.5 mm and 8.0-mm notched bars, respectively. In the case of 5.0-mm ribbed bars and 6.3-mm notched bars, the results indicate that there may be no significant difference. Therefore, thin ribbed bars may have better bond performance than that of the notched bars.

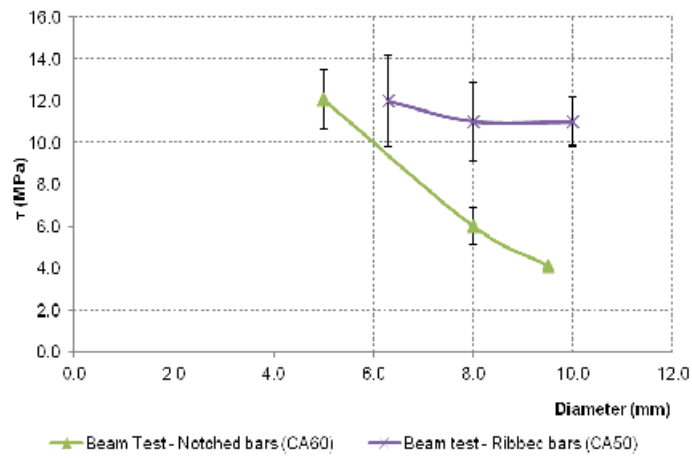

Figure 27: Bond performance - Notched and Ribbed rebars- Beam test.

The graphs in Figure 28 show a comparison between pull-out and beam tests results:

Beam tests results showed good approximation to the pull-out tests results for 10 mm diameter bars, as expected. In the case of thin rebars, beam tests results were greater than pull-out results but, as cited previously, the small anchorage length may have contributed to the increase in the differences showed in Figure 28. Beam test more accurately represent the steel concrete bond in bent concrete elements than the pull-out test, but it is much more laborious to perform. Pull-out

test has been widely adopted as a method of testing the steel concrete bond-strength in Brazil and other countries. In addition, the results presented previously also to highlight that the pull-out test produced better results than confined bars test. Then it is believed that the pull-out is the best methodology to evaluate the steel-concrete bond for thin reinforcing bars (Φ<10 mm) and it is possible to calculate the surface conformations coefficients (η), prescribed by ABNT-NBR 7480 (2007) (Table 1), adopting the results from pull-out.

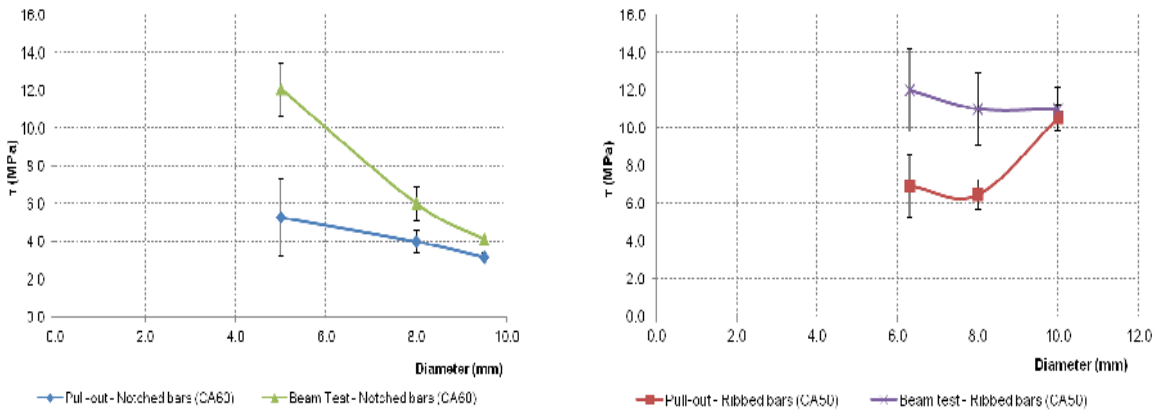

Figure 28: Bond performance - Notched and Ribbed rebars- Pull-out x Beam test.

3.4 Calculation of the Surface Conformation Coefficients (η) from the Pull-Out and Cylinder Splitting Tests Results

As already shown, the results of the confined bars tests were unsatisfactory in calculating the surface conformation coefficients (η) of thin reinforcing bars. In view of this, it is proposed that the surface conformation coefficients are calculated using the results from the pull-out and cylinder splitting tests using equation 6, which is based on the equation prescribed by the French standard, B.A.E.L. 91 (1994).

$$\tau_s = \psi_s^2 \times f_{tj} \tag{6}$$

The ψs variable is related to the steel rebar surface conformation, τ_s refers to the bond strength, and f_{tj} is the tensile strength of the concrete.

Therefore, it is suggested that both the ultimate bond resistance (τ_s=τ_u), obtained in the pull-out tests, and the tensile strength, obtained by cylinder splitting tests (f_{tj}), which is obtained in the concrete characterization (ABNT-NBR 7222 (1994)), be used to calculate the bar surface conformation coefficient (η), where η= ψ_s and using equation 7.

$$\eta = \psi_s = \sqrt{\frac{\tau_s}{f_{tj}}} \tag{7}$$

The calculated η values are shown in Tables 6 and 7.

Notched bars			
ϕ (mm)	τ_s (MPa)	f_{tj} (MPa)	$\psi_s=\eta$
5.0	5.29	2.43	1.47
8.0	3.99	2.32	1.31
9.5	3.16	2.53	1.12

Table 6: Calculation of notched (CA-60) bars' surface conformation coefficient (experimental average values).

Ribbed bars			
ϕ (mm)	τ_s (MPa)	f_{tj} (MPa)	$\psi_s=\eta$
6.3	6.93	2.33	1.72
8.0	6.47	2.71	1.54
10.0	10.55	2.36	2.11

Table 7: Calculation of ribbed (CA-50) bars' surface conformation coefficient (experimental average values).

Tables 6 and 7 show the surface conformation coefficients (η) of the notched (CA-60) and ribbed (CA-50) thin bars. Note that the values were greater than the minimum values defined in ABNT-NBR 7480 (2007) (Table 1). Additionally, by evaluating the results from Tables 6 and 7, a performance gain of the surface conformation coefficients can be observed of the notched bars compared with that of the ribbed bars.

With regard the structural design of concrete elements, the anchorage length (l_b) of reinforcing thin bars can be calculated by equation 1, according to Brazilian standard ABNT-NBR 6118 (2014). It can be safety if the reinforcement bond strength (f_{bd}) be obtained by equation 2, adopting $\eta 1$ equal 1.

In these terms, one can consider that the results from pull out tests are better than those obtained by confined bars test. These considerations indicate that, besides being an adequate test to evaluate the bond performance of thin reinforcing bars, the pull-out test could be used to determine the surface conformation coefficient of these bars. The importance of the cylinder splitting tests is highlighted as a complementary test to determine the surface conformation coefficient and indirectly, the bar-concrete bonding capacity.

4 CONCLUSIONS

The results of the confined bars tests show that this test may be inadequate to determine the surface conformation coefficient (η) of reinforcing bars thinner than 10 mm, especially for notched (CA-60) steel bars. One hundred percent of the specimens with notched rebars (CA-60) for 5.0 and 8.0 diameters did not show the minimum of six cracks in their cross-section, which is required by ABNT-NBR 7477 (1982), to calculate the surface conformation coefficient (η). The only case where η met the requirement of standard ABNT-NBR 7477 (1982) was for the one specimen notched bar with the 9.5-mm diameter. The others eight 9.5-mm diameter bar specimens did not show the minimum of six cracks in their cross-section. The notched rebars did not present surface conformation coefficient (η) greater than 1.0, which is established by standard ABNT-NBR 7480 (2007).

The good results of the pull-out tests and the cylinder splitting tests reinforce the idea of adopting them to evaluate the bond capacity of thin reinforcing bars to calculate their surface conformation coefficient.

Regarding the specimens for the pull-out tests, a modified model with an anchorage length equal to 10 times the bar diameter is suggested (Figure 29).

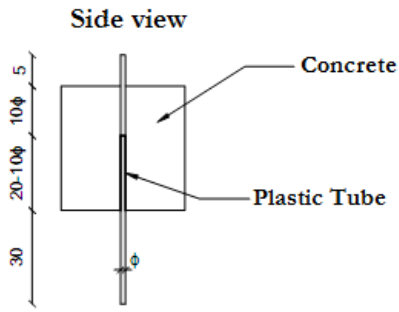

Figure 29: Pull-out Specimen: modified model.

Noteworthy that these modified model is suggested once the high dispersion of the results in this research was attributed to the small bonding length (5 times the nominal diameter), especially when compared to the heterogeneities of the concrete, such as the coarse aggregate size. The anchorage length equal to 10 times the bars' diameter is greater than the length recommended by RILEM-CEB RC6 (1983), but this length has been already recommended by Montoya et al (1994). The main objective to increase the anchorage length is to verify if will be a decrease in the dispersion of the pull-out tests results.

It is also believed that smaller specimens can facilitate the test performance because of they are lighter and easier to manipulate. The issues surrounding the best specimen model for the pull-out tests are important and should be investigated.

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