Volume 1, Number 1 (September 2005) p. 29-46
Revista IBRACON de Estruturas
IBRACON Structural Journal

Analysis of bond steel-concrete with tire rubber incorporation

Análise da Aderência Aço-Concreto com Incorporação de Resíduos de Pneus


V. H. FRANÇA [a]
valerio@dec.feis.unesp.br
M. P. BARBOSA [a]
barros@civil.uminho.pt

Abstract

In the present work the adherence behavior of steel-concrete incorporated by rubber derived from tire rethreading residues has been evaluated. The analysis employed the 7477 NBR lifter as well as the CB RC6 and C234 ASTM conforming pullout tests. Conventional and rubber-incorporated concrete, both reinforced with 10.0, 12.5 and 16.0 mm diameter CA 50 steel ribs, have been submitted to test, using periods of 28 and 90 days. From the adherence results, it has been found out that rubber-incorporated concrete can only be suggested for structures under light or negligible efforts. In fact, in the case of structures requiring significant efforts, a necessary concrete matrix improvement must be obtained in order to enhance the rubber-incorporated steel-concrete mechanical resistance and, as a consequence, a much better adherence behavior.

Keywords: bond steel-concrete; residues of tires; alternative material; concrete with rubber.

Resumo

Neste trabalho avaliou-se o comportamento da aderência aço-concreto com incorporação de resíduos de borracha oriundos da recauchutagem de pneus. Para esta avaliação utilizou-se o ensaio de tirantes normalizado pela NBR 7477 e o ensaio de arrancamento, "pull-out-test" normalizado pela CB RC6 e também na ASTM C234. Realizaram-se os ensaios para o concreto convencional e com incorporação de resíduos de borracha, utilizando-se barras de aço CA 50 nervuradas nos diâmetros de 10,0, 12,5 e 16,0mm. Os ensaios foram realizados nas idades de 28 e 90 dias. Com a obtenção dos resultados das tensões de aderência obtidos foi possível avaliar a utilização do concreto com incorporação de resíduos de borracha em estruturas sem grandes esforços atuantes. Para situações com esforços solicitantes significativos, é necessário melhorar a matriz do concreto de forma a obter um acréscimo nos índices de resistência mecânica e conseqüentemente na aderência aço-concreto.

Palavras-chave: aderência aço-concreto; resíduos de pneus; material alternativo; concreto com borracha.

[a] Universidade Estadual Paulista, Depto. de Eng. Civil, Faculdade de Eng. Ilha Solteira, Alameda Bahia, 550, Ilha Solteira- SP, Brasil

1 Introduction

Unusable tires have become a growing a problem. There is no correct environmental destination, since it takes 240 years to decompose after they are dumped in waste lands, in addition to providing breeding nests to disease transmitting mosquitoes. The option to burn results in greater damage to the environment due to the enormous black and smoke and oil contaminating the soil and aquifers. A form of reducing this impact would the reuse of tires by recapping.

Recapping generates a large quantity of residues without definite destination. Some researchers study the use of these residues in concrete, mortar, paving (Raghavan[3], Fazio[4], Lima[5]) etc. Thus, in addition to finding a destination to tire residues, the consumption of natural aggregates such as sand would be reduced.

Fiber concrete, as against conventional concrete, has a higher plastic capacity. With the addition of rubber fibers, considered as elastic material, concrete becomes ductile and presents behavior similar to that of an elastic structure under loading action. The addition of rubber fivers incorporates a plastic share to the behavior of concrete, which, according to Topçu[6], would Grant it greater shock resistance. According to the author, these concretes can be used in constructions subjected to shock such as contention walls, bridges and roads.

To make the use of rubber residues possible as a substitute of part of minute concrete aggregates, trials involving the mechanical properties of concrete with rubber were conducted, comparing results from conventional concrete tests. However, to allow its use in reinforced concrete structures would require evaluation of its structural behavior. This present study therefore began with the analysis of steel-concrete bond with rubber residues through symmetrical traction trial specified by RILEM and the NB-1 standard pull-out test with CA50-A steel ribs in three different diameters: 10, 12.5 and 16 mm. The tests took place within 28 and 90 days, methodology and results are described below.

2 Concrete with addition of rubber residues

In Brazil, civil construction is responsible for about 30% of natural resource consumption, equivalent to 220 million tones of natural aggregates per annum extracted for use in mortars and concrete production.

With the need for new materials to replace said aggregates, some researchers (Lima [5], Ribeiro [7]) came up with the idea of using rubber residues from tire recapping as part of the minute aggregate. Thus, seeking better utilization of rubber, several studies (Akasaki [8], Fioriti [9]) have been developed toward adding this residue to concrete.

Some properties of concrete can be improved with the use of rubber, for instance, propagation of cracks. According to (Accetti and Pinheiro [10]), the rubber fiber obstructs the development of cracks. The author state that by intercepting micro cracks that emerge during the hardening of the paste, the fibers prevent their progression and the appearance of premature micro cracks. In the hardened mixture, they also limit length and opening of cracks.

Currently, in Brazil, rubber fiber is being used incorporated to asphalt. The rubber is used in the asphalt strain and improves many of its properties. In some countries, it is already used in speed-breakers. Eldin and Senouci [11] in one of their researches use rubber from the scarping of tires with large furrow areas. A test track was made with the material, mixing strips with material from the region such as soil and rocks.

3 Steel-concrete bond

The bond ensures equality in specific deformities of the reinforcement and of the concrete around it when subject to load. Its behavior has a decisive importance in relation to the load capacity of reinforced concrete structures.

Several tests determine the bond tension values between steel reinforcement and concrete. It can be pointed out amongst them the pull-out-test, ring pull-out-test, beam test, push-out test, four-bar test, symmetrical pull test, etc. The pull-out test, considered as the most traditional bond tests, consists of extracting a steel bar positioned inside a concrete trial body placed over the support plates of a test machine. The two ends of the bar are projected outside the test body, measuring traction force applied to one end and slipping on the other.

The ring pull-out-test differs from the above due to the fact that the test body is cylindrical and is involved in a metallic ring that embraces the submersed length; the ring is connected to strain-gages that measure the traction on one of the ends of the bar and slipping, in addition to deformities suffered by the ring.

The Beam Test consists of a test body made of two stone rock blocks connected at the lower part by a steel bar destined to the bonding test and on the upper part by a metallic joint. The beam receives simple flexion over two supports by two concentrated forces of the same magnitude that acts at equal distances from the extremities. In the extremities of the bars are placed deflectometers so that relative dislocations of the bar in relation to concrete can be measured. Anchoring is limited to the specified length with the aid of plastic pipes that eliminate adherence in the desired stretches.

The main characteristics of the push-out-test is that the bar contained in the concrete test body suffers slid by a compression force rather than by traction, like in the conventional pull-out-test. The test results are superior to the traditional due to lateral dilation of the bar inside the concrete. In this work, we chose to conduct the symmetrical tests, according to Brazilian standard NBR 7477 and the pull-out-test that has been successfully used by other researchers (Barbosa [13], Barbosa [14]), which we describe below.

3.1 Symmetrical traction test

Also known as "rib test", the test, specified by NBR 7477 consists of exerting traction on the two extremities of an immersed bar in the center of the prismatic concrete trial body (figure 1) with the objective of evaluating the concrete-steel bond. In general, these tests are used in the study of cracks and reproduce quite well the real conditions suffered by the bars in region of flexed beams under traction (Barbosa [13]). NB-1 suggested this test for reinforced concrete cracking study.

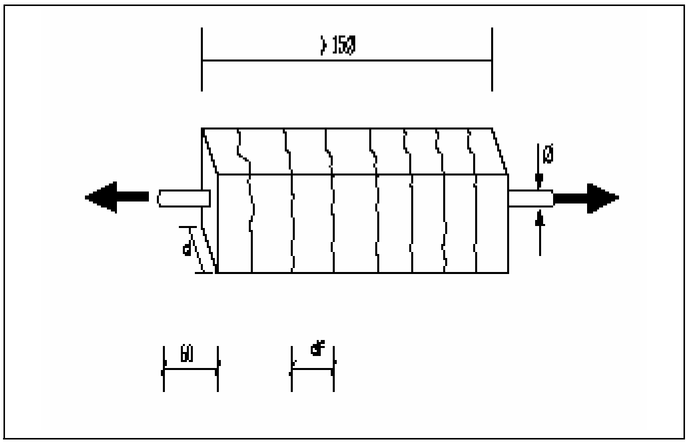


Figure 1 - Symmetrical Traction Test.

Where:

df= distance b/w cracks; φ = bar diameter

Through evaluation from the opening and distance of cracks, the symmetrical traction test allows determining surface conformation coefficient of bars and steel strings destined for reinforced concrete frames.

3.2 Pull-out-test

This type of test has been used mainly to study the behavior of different bar profiles, to evaluate bonding of bars to different qualities of concrete, to determine the effect of concreting direction, to determine the effect of the duration and type of loading, to evaluate influence of frame position and research the influence of immersed length to the study of influence on cover, spacing, transversal frame and transversal forces bonding.

The advantages of this test are those, which, besides low cost and simplicity, provides a clear idea of the anchoring concept.

This direct pull-out test is approved by RILEM, doc. 7.II.128 (1973) and is referred in ASTM C234 (1991).

4 Experimental program

The procedure used in the evaluation and comparison of steel-concrete bond between two types of concrete is introduced below: conventional and with the incorporation of rubber fibers from tires, tested with three different rib bar diameters.

The bars used in this work were rib type with circular nominal section diameter equal to 10.0, 12.5 and 16.0 mm, CA-50, manufactured by Belgo-Mineira steel mill in Piracicaba-SP. On The characteristics of the reinforcements are presented on Table 1.

The materials used for the concrete were from the region of Ilha Solteira- SP-Brazil, namely:

Minute Aggregate: medium sand from Paraná river bed, Nossa Senhora Aparecida sand port in the city of Castilho-SP with fineness module equal to 2.25, specific dry mass equal to 2.58 g/cm^3 and unit mass apparently dry of 1.533 g/cm^3;

Table 1 - Results of the steel bar characterization.

Diameter mm	Inclination ribs (°)	Drainage limit (Kgf/mm^2)	Resistance (Kgf/mm^2)	Length (%)
10.0	51	619.0	778.3	14.00
12.5	46	609.7	776.3	14.67
16.0	47	630.7	795.0	16.07

Minute Aggregate: type 1 broken stone, calcarium origin, deriving from the city of Monções - SP, with maximum diameter of 19.0 mm, finesses module equal to 6.95 and specific dry weight equal to 2.92 g/cm^3;

Cement: high initial resistance Portland cement (CPV-ARI) with Blaine specific surface of 4499 cm^2/g and absolute density of 3.15 g/cm^3;

Rubber Residues: from tires recapping process, from Recuperadora de Pneus Araçá-Ltda, maximum diameter of 1.19 mm, finesses module equal to 2.2, specific absolute mass equal to 1.09 g/cm^3;

Two types of concrete were produced: the conventional and the concrete with the addition of 10% rubber residues, which composition is described below:

Table 2 - Traces of concrete used.

Materials	Conventional Concrete Kg/m3	Concrete with added residues kg/m³
Cement	295.57	325.80
water	195.03	215.03
sand	931.53	768.35
broken stone	1,000.57	1,000.57
rubber residues	-----	36.06

The values of the mechanical properties of the concretes (fc, ft and Ec) were obtained by Means of tests conducted in accordance with Brazilian standards [15], [16] and [17]. Table 3 presents the results obtained for resistance to compression, resistance to traction and deformation module at the ages of 7, 28, and 90 days.

Table 3 - Values obtained in tests of mechanical properties of concrete.

	Age (days)	Conventional Concrete	Concrete w/ residues
Resistance to compression (MPa)	7	24.18	17.24
	28	27.97	19.29
	90	30.35	19.72
Resistance to traction (MPa)	7	2.84	1.88
	28	3.57	2.34
	90	3.88	2.41
Module of deformation (GPa)	7	35.05	32.50
	28	41.27	34.45
	90	42.48	34.96

5 Results and analysis

5.1 Symmetrical traction test

In the symmetrical traction test the steel bar was subjected to a force equal to 0.8 times its drainage limit and during the loading in stages of 5 equal addition of loads the cracks that emerged on the tie-beam were verified and marked (figure 2).

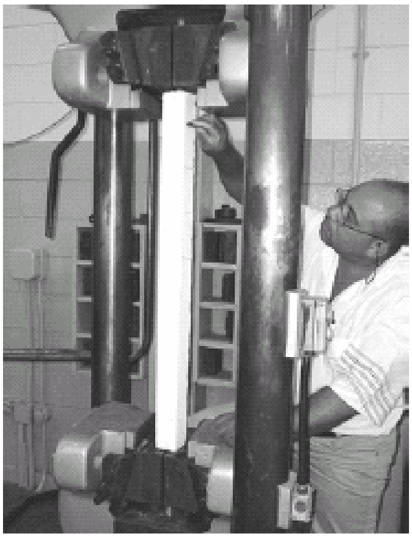


Figure 2 - Loading system and marking of cracks.

At the end of application of the maximum load, the distances between cracks were measured in the longitudinal axle, on the four surfaces of the tie-beam, which allowed calculating the surface conformation coefficient. Figure 3 shows the tested tie-beams.

According to NBR 7477 [1], the surface conformation coefficient should be calculated by the following expression (equation 1):

$$\eta = \frac{2,25}{\Delta\ell mean} \quad (1)$$

Where:

η = surface conformation coefficient;
d = side of the tie-beam's section;
$\Delta\ell$ = mean distance between cracks, considering the four sides.

On table 4 are presented the mean spacing values between cracks for each type of concrete and bar test, as well as variation coefficient (CV) of each sample.

This analysis is made to compare variability of several samples with their mean value. It is pointed out, according to (Barbosa [13]), that if the value is smaller than 25%, the sample is accepted. It can be seen that the results have a variation coefficient below 25%, which makes them acceptable. After overall analysis of the results were calculated the coefficients of surface conformation. Table 5 presents the results at ages 28 and 90 days, respectively.

NBR 7480 [18] determines that the minimum value for the surface conformation coefficient is equal to 1.5 for steel bars in nominal diameter equal or superior to 10.0 mm.

Table 4 - Mean value of spacing between fissures (cm) and their respective variation coefficients (%).

TESTS CONDUCTED BY 28 DAYS					**TESTS CONDUCTED BY 90 DAYS**				
Ø of bar	**Conventional Concrete**		**Concrete w/residues**		**Ø of bar**	**Conventional Concrete**		**Concrete w/residues**	
(mm)	**XM**	C.V.	**XM**	C.V.	(mm)	**XM**	C.V.	**XM**	C.V.
10.0	**7.94**	12.1	**7.43**	17.53	10.0	**7.84**	5.41	**7.01**	8.25
12.5	**7.73**	9.37	**8.34**	4.53	12.5	**7.60**	3.62	**8.25**	3.92
16.0	**7.96**	7.52	**8.59**	9.48	16.0	**7.72**	2.36	**8.38**	3.62

Where: XM = Mean value of spacing between fissures and C.V. = sample variation coefficients

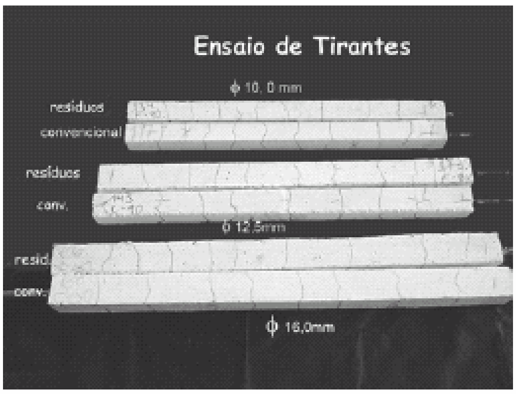


Figure 3 - Symmetrical traction test.

Table 5 - Surface conformation coefficient.

Ø of bar (mm)	**Conventional Concrete (days)**		**Concrete with residues (days)**	
(mm)	28	90	28	90
10.0	1.36	1.38	1.45	1.54
12.5	1.57	1.60	1.46	1.53
16.0	1.72	1.78	1.60	1.64

For conventional concrete, only the bars of 10.0 mm diameter did not meet the specification of the standard at ages 28 and 90 days while those of 12.5 and 16.0 mm attained the value for both ages.

In concrete with the addition of rubber residues it was seen that the 10.0 and 12.5 mm bars did not attain the value required by the Standard at age 28 days but in the tests conducted by 90 days, all bars met the standards.

Through this crack spacing and opening evaluation it is determined the so called surface conformation coefficient (ηb) of steel bars and strings used in reinforced concrete structures, according to ABNT/NBR 7477 [1], where smooth bars show large and more spaced cracks in-between while in the ribbed ones the cracks are closer and smaller.

According to (Castro [18]), from the calculation of mean spacing between cracks it can be determined the mean bond tension of steel bars in concrete of different resistance classes by applying the following equation (2):

$$\tau_m = 0,375 \frac{f_{ct}}{X_m} \cdot \frac{\phi}{\rho} \qquad (2)$$

Where:

τ_m – mean bond tension;
f_{ct} – concrete's resistance to simple traction;
X_m – mean distance between fissures;
Ø – bar diameter;
$\rho = A_s / A_c$ (amount between steel area and concrete area)

With this equation it is possible to calculate the bonding between two types of concrete whose results can be seen on table 6.

Table 6 - Bond tension (Mpa) according to Castro [18].

Ø (mm)	Conventional Concrete		Concrete with residues	
	28 days	90 days	28 days	90 days
10.0	4.78	5.26	3.34	3.65
12.5	4.93	5.44	2.99	3.12
16.0	4.71	5.28	2.86	3.02

Pull-out-test

To better evaluate the steel-concrete bond, we also decided to conduct the pull-out-test according to a second test procedure under standard RILEM (1973) [2].

With the pull-out test we obtained mean bond tension using values corresponding to slides 0.01 mm (small), 0.1 mm (service) and 1.0 mm (rupture) at ages 28 and 90 days, as shown on table 7.

It is important to point out that τ_m corresponds to mean bond tension for slides of 0.01; 0.1 and 1.0 mm. The predominant form of rupture in conventional concrete was by spliting of the test body (figure 4) and steel bar rupture (figure 5), while in concrete with rubber residues, predominant rupture was of sliding steel bar (figure 6).

The same statistical test was conducted for tie-beam trials to evaluate the quality of the results obtained. Table 8 shows the results obtained.

Table 7 - Bond tension along the anchoring length.

Type of Concrete	Ø	τ (0,01) (Kgf/mm²)		τ (0.1) (Kgf/mm²)		τ (1.0) (Kgf/mm²)		τ mean (Kgf/mm²)	
	(mm)	28 days	90 days	28 days	90 days	28 days	90 days	28 days	90 days
Conventional Concrete	*10.0*	1.08	1.65	2.06	2.80	3.87	4.59	2.34	3.02
	12.5	1.46	1.66	2.56	3.01	6.39	6.48	3.47	3.71
	16.0	1.63	2.48	3.93	4.67	11.75	12.20	5.77	6.45
Concrete with residues	*10.0*	0.89	0.50	1.19	0.83	2.74	2.40	1.61	1.24
	12.5	0.71	1.05	0.94	3.01	2.76	3.11	1.47	2.39
	16.0	1.18	1.83	1.59	2.42	4.65	5.53	2.47	3.26

Table 8 - Variation coefficient for adherence tensions.

Type of concrete	Ø (mm)	CV for τ 0,01 (%)		CV for τ 0.1 (%)		CV for τ 1.0 (%)	
	(mm)	28 days	90 days	28 days	90 days	28 days	90 days
Conventional Concrete	*10.0*	11.4	16.5	18.9	18.6	11.3	9.6
	12.5	7.0	16.8	15.1	15.5	16.5	16.1
	16.0	13.8	19.8	12.0	15.9	15.2	11.3
Concrete with residues	*10.0*	5.0	21.6	11.4	21.2	7.4	13.1
	12.5	7.8	19.7	9.3	15.5	15.7	10.9
	16.0	15.5	16.8	13.9	11.5	13.9	14.0

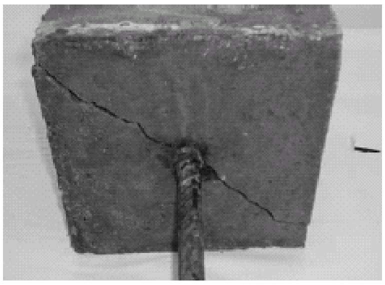


Figure 4 - Splitting of test body.

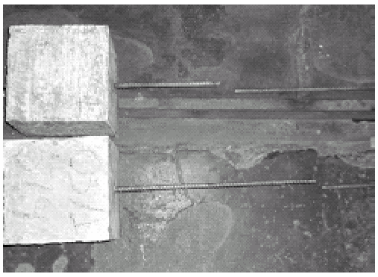


Figure 5 - Steel bar rupture.

Figure 6 - Steel bar slide.

It can be seen that the results obtained have a variation coefficient below 25%, which makes them acceptable, according to (Barbosa [13]).

It was also conducted a variance test for the two test types to statistically evaluate the effect of the influence of a given variable in the result. F value on the table below smaller than the F calculated is considered the significant effect for the obtained results under test. In all cases of the present work, significant level α = 0.05, equivalent to 95% safety level. Tables 9 and 10 show the results obtained for the tie-beam test and the Pull-out-test, respectively.

By analyzing tables 9 and 10 it is seen that the effects of the factors of resistance to compression and diameter of the bar are significant being that the F value calculated is greater that the table value for the significant level adopted.

Table 9 - Analysis of variance for tie-beam tests.

F (factor)	fc	φ
Calculated	19.31	19.27
on Table	1.32	1.28

With the forces applied and the respective sliding it was possible to obtain a sliding x bond tension curve for diameter bars 10.0, 12.5 and 16.0 mm presented in figures 7, 8 and 9, respectively.

Table 10 - Analysis of variance for Pull-out-test.

F (factor)	fc	φ
Calculated	148.36	297.31
on Table	1.32	1.22

It can be seen that for 10.0 mm diameter bars (figure 7) the concrete with incorporation of fibers presented a decrease in bond tension when compared with conventional concrete but the tension x sliding curve has quite a similar behavior as the conventional concrete. The two types of concrete had additions in bond tension from 28 to 90 days.

Observing the evolution of the bond tension for 12.5 mm steel bars, figure 8, we noted a decrease in the concrete with the use of fibers as against conventional concrete, similar behavior to 10.0 mm diameter bars. It is worth pointing out that there was slight increase in bond tension from 28 to 90 days. Fiber concrete presented constant addition from 28 to 90 days.

Steel bars of 16.0 mm diameter presented the same behavior seen in 10.0 and 12.5 mm diameter bars, Figure 9, with a decrease in bond tension upon incorporation of rubber into the concrete. It is also seen that there is increase in bond tension as bar diameter increases, this behavior having been observed by several researchers such as Barbosa [13], Ribeiro [20], Lorrain and Khélafi[21] among others.

6 Conclusions

From the evaluation of the results obtained, and comparison with others found in text, it is believed the use of concrete with rubber residues for the composition studied in structures that do not require high stress loads. Despite the low resistance to compression when compared to conventional concrete, concrete with rubber residues presents acceptable characteristics and performance for use in "popular" constructions.

It is also pointed out that in axial compression tests, samples with rubber residues suffered less abrupt rupture when compared to conventional concrete.

By analyzing the behavior of steel-concrete bond behavior for the two types of concrete, it is seen that the bond tension X dislocation curve has the same aspect. Thus, it can be concluded that the incorporation of rubber fiber leads to decrease in bond tension but the evolution behavior is quite similar to that of conventional concrete. For situations with significant demanding stress, it is necessary to improve the concrete matrix to obtain more elevated mechanical properties (fc, ft, Ec), which would lead to better bonding.

The decrease obtained in the surface index when compared to conventional concrete is due to lesser resistance in concrete with the rubber. However, it is emphasized with the incorporation of rubber fiber in concrete that there is a reduction in cracking.

The use of rubber in concrete is an attempt to attenuate the impact of tires to the environment and classify it as a new alternative material in civil construction, saving natural sand and aggregate resources. This justify the need toward advancements in the line of research.

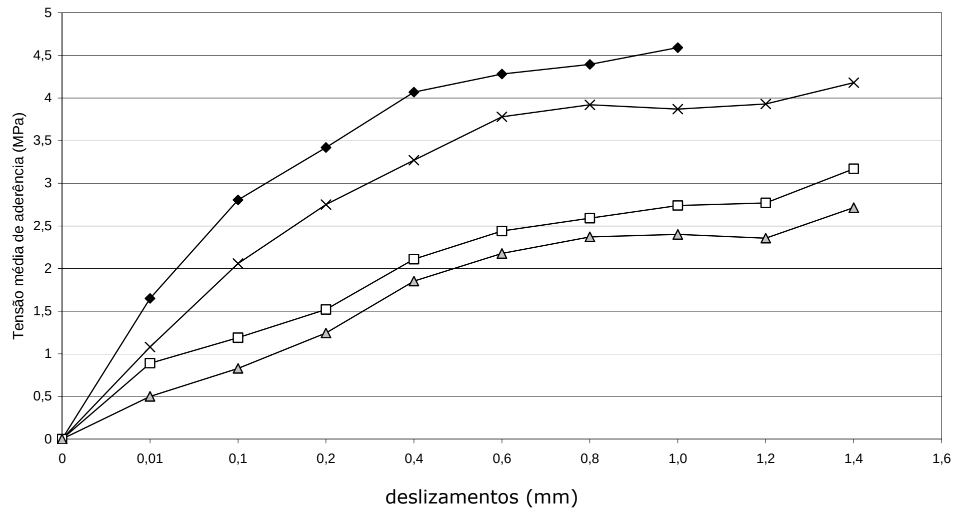
It was seen that with the increase in diameter of the bar (in the pullout-test) their increase in bond tension, i.e. for superior diameter bars there is greater bond tension. This fact was also verified by Barbosa [13] in his doctorate work.

Our thanks to:

Holcim do Brasil, Siderúrgica Belgo-Mineira and Araçá Recuperadora de Pneus Ltda for donating the materials used. Laboratório CESP de Engenharia Civil de Ilha Solteira – SP for the tests conducted.

Prof. Dr. Jorge L Akasaki for the orientation and determination of the compositions of concrete evaluated.

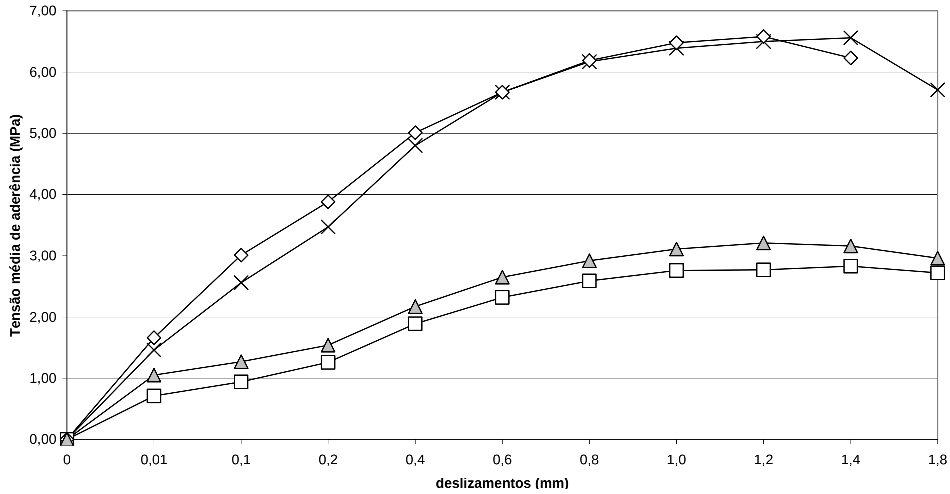
Pull-Out-Test Steel 10.0 mm - 28 and 90 days



conventional concrete, 28 days
conventional concrete, 90 days
concrete with residues, 28 days
concrete with residues, 90 days

Figure 7 - Pull-Out test Ø 10.0 mm.

Pull-Out-Test Steel 12.5mm - 28 and 90 days



conventional concrete, 28 days
conventional concrete, 90 days
concrete with residues, 28 days
concrete with residues, 90 days

Figure 8 - Pull-Out test Ø 12.5mm.

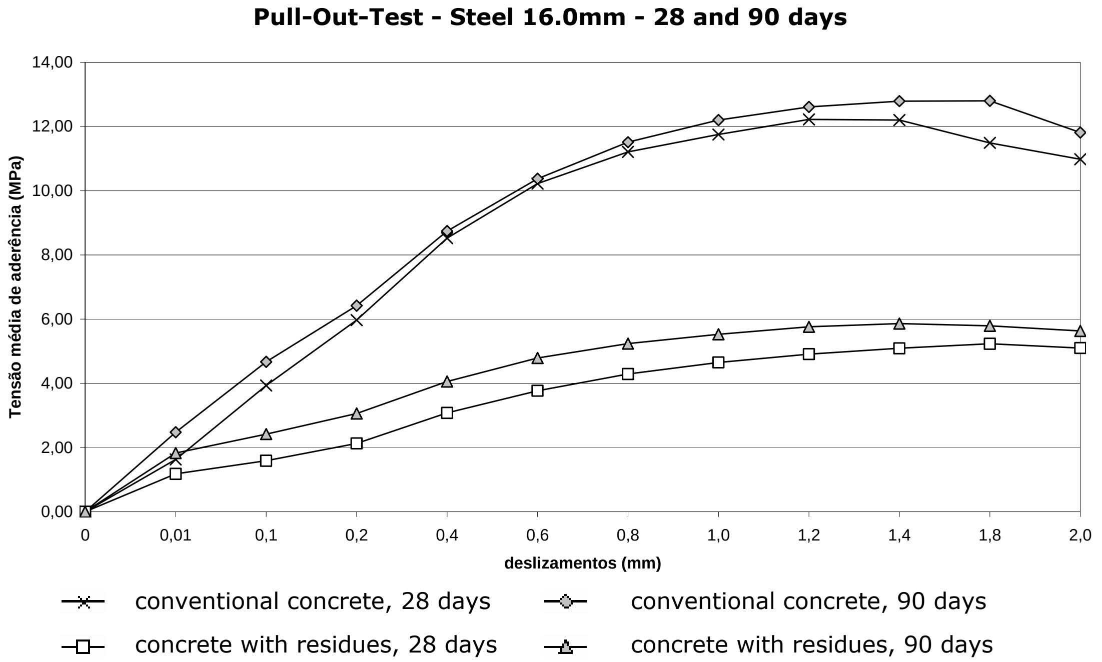


Figure 9 - Pull-Out test Ø 16.0mm.

References

[1] Associação Brasileira de Normas Técnicas. *NBR 7477:* Determinação do Coeficiente de Conformação Superficial de Barras e Fios de Aço Destinados a Armadura de Concreto Armado. São Paulo, 1982,

[2] RILEM, FIP, CEB, 1973, "Essai portant sur l'adhérence des armatures du béton. 1. Essai par flexion (7-II-28D). 2. Essai par tration (7-II-128), Recomamdations Provisoires. Matériaux et Constructions, (mars – avr), v. 6, n. 32, pp. 96–105.

[3] Raghavan, D. Study of rubber filled cementitious composites. Journal of applied Polymer Science, v. 77, p. 934-942, 2000

[4] Fazio, J. A., Oliveira, S. A. G. Utilização do pó de borracha de pneu reciclado em misturas betuminosas para pavimentação urbana e rodoviária. In: Encontro Nacional de Tecnologia do Ambiente Construído, 1995

[5] Lima I. S.; Rocha, F. S.; Ferreira, J. B. Um estudo de argamassa de cimento com adição de fibras de borracha vulcanizada para a construção civil. In: Congresso Brasileiro do Concreto, 42º, 2000, CD-ROM.

[6] TOPÇU, I. B. The properties of rubberized concretes. Cement and Concrete Research, v. 25, n. 2, p.304-310, 1995.

[7] Ribeiro F.C.V.; Bolorino H; Fernandes S.A. ; "Análise da Influência da adição de pneu na deformabilidade do concreto"; In:Congresso Brasileiro do Concreto 44º, 2002.

[8] Akasaki, J. L., Nirschl, G.C. Influência da granulometria das fibras de borracha vulcanizada em dosagens de Concreto. In: Congresso Brasileiro do Concreto, 44º, 2002, CD-ROM.

[9] Fioriti, C. F. Avaliação de Compósitos de Concreto com Resíduos de Borracha na Produção de Blocos para Alvenaria. Ilha Solteira 2002. 134 pps. Dissertação (Mestrado) – Faculdade de Engenharia de Ilha Solteira, Universidade Estadual Paulista.

[10] L.M. Acetti, K. M., Pinheiro, Tipos de fibras e propriedades do concreto cm fibras. In: Congresso Brasileiro do Concreto, 42, 2000, Fortaleza. Fortaleza: Arte Interativa, 2000. CD-ROM.

[11] Eldin N.N e Senouci A.B.. " Use of Scrap Tires in Road Construction ", Journal of Construction Engineering and Management, 118(3), pp561-576, 1992.

[12] Toutanji, H.A., 1996, The Use of Rubber Tire Particles in Concrete to Replace Mineral Aggregates – Departament Of Civil Engineering – University Of Puerto Rico, Mayagues, Puerto Rico. – Elsevier Science Limited -January/1996

[13] Barbosa, M.T.G. Avaliação do Comportamento da Aderência em Concretos de Diferentes Classes de Resistência. Rio de Janeiro 2002.203p. Tese (Doutorado) -Universidade Federal do Rio de Janeiro, Coppe.

[14] Barbosa, M.P. Uma Contribuição Experimental e Numérica sobre Estruturas de Concreto Armado de Elevado Desempenho: Estudo da Aderência-Ancoragem e o comportamento de Vigas Fletidas. Ilha Solteira,1998. 174pps. Tese (Livre Docência) – Faculdade de Engenharia de Ilha Solteira, Universidade Estadual Paulista.

[15] Associação Brasileira de Normas Técnicas. NBR 5739: Concreto – Ensaio de Compressão de Corpos-de-Prova Cilíndricos. Rio de Janeiro, 1994.

[16] Associação Brasileira de Normas Técnicas. *NBR 7222:* Argamassa e Concreto - Determinação da resistência à tração por compressão diametral de corpos-de-prova cilíndricos. São Paulo, 1994.

[17] Associação Brasileira de Normas Técnicas – ABNT,R.J. NBR 8522 :Concreto – Determinação do Módulo de Deformação Estatística e Diagrama Tensão-Deformação – Rio de Janeiro 1984.

[18] Associação brasileira de normas técnicas. *NBR 7480*: Barras e fios de aço destinados a armaduras para concreto armado. Rio de Janeiro, 1996.

[19] Castro, P. F., 2000, Notas sobre estudo da aderência aço-concreto, UFF, Niterói, Rio de Janeiro.

[20] Ribeiro, J. L. D., Análise Experimental dos fatores que influenciam a aderência em barras nervuradas. Porto Alegre 1985. 180pps.Tese (Mestrado). Universidade Federal do Rio Grande do Sul -RS.

[21] Lorrain, M.;Khélafi , H. Sur la resistence de la liaison armature-beton de haute resistence. Annales de I´Institut Technique du Batiment et dês Travaux Publics. Série: Béton 260, n. 470, p.117-28,dec.