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Investigation of the influence of different surface regularization methods for cylindrical concrete specimens in axial compression tests

Investigação da influência de diferentes métodos de regularização das superfícies de corpos de prova cilíndricos de concreto nos ensaios de compressão axial




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Abstract

This study was conducted with the aim of evaluating the influence of different methods for end surface preparation of compressive strength test specimens. Four different methods were compared: a mechanical wear method through grinding using a diamond wheel established by NBR 5738; a mechanical wear method using a diamond saw which is established by NM 77; an unbonded system using neoprene pads in metal retainer rings established by C1231 and a bonded capping method with sulfur mortar established by NBR 5738 and by NM 77. To develop this research, 4 concrete mixes were determined with different strength levels, 2 of group 1 and 2 of group 2 strength levels established by NBR 8953. Group 1 consists of classes C20 to C50, 5 in 5MPa, also known as normal strength concrete. Group 2 is comprised of class C55, C60 to C100, 10 in 10 MPa, also known as high strength concrete. Compression tests were carried out at 7 and 28 days for the 4 surface preparation methods. The results of this study indicate that the method established by NBR 5738 is the most effective among the 4 strengths considered, once it presents lower dispersion of values obtained from the tests, measured by the coefficient of variation and, in almost all cases, it demonstrates the highest mean of rupture test. The method described by NBR 5738 achieved the expected strength level in all tests.

Keywords: axial compression tests, surface preparation methods of cylindrical specimens.

Resumo

Este estudo foi realizado com o objetivo de avaliar a influência de diferentes métodos de regularização dos topos de corpos de prova cilíndricos de concreto nos ensaios de compressão axial. Foram comparados os métodos de desgaste pela retificação com disco de desbaste estabelecido pela NBR 5738 e equipamento tipo policorte estabelecido pela NM 77, o método da almofada de neoprene confinada C 1231 e o método de capeamento colado com argamassa de enxofre estabelecido pela NBR 5738 e NM 77. Para desenvolvimento desta pesquisa foram determinados 4 traços com níveis de resistências diferentes, sendo 2 do grupo 1 e 2 do grupo 2 de resistência da NBR 8953. O grupo 1 é composto pelas classes C20 até C50, de 5 em 5MPa, também conhecidos como concretos de resistência normal. O grupo 2 é formado pelas classes C55, C60 até C100 de 10 em 10MPa, também conhecidos como concretos de resistência elevada. Os ensaios de compressão foram realizados com 7 e 28 dias para os 4 métodos de regularização. Os resultados deste estudo apontam que o método estabelecido pela NBR 5738 é o mais eficaz entre os 4 níveis de resistência estudados por possuir menor dispersão nos valores obtidos nos ensaios, mensurado por meio do coeficiente de variação e, em quase todos os casos, apresentar maior média das tensões de ruptura. O método da NBR 5738 atingiu o nível de resistência desejado em todos os testes.

Palavras-chave: ensaios de compressão axial, métodos de regularização de corpos de prova cílidricos.

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1. Introduction

One of the most effective and used methods for evaluating concrete characteristics is to determine the axial compressive strength through the rupture of the concrete sample, molded for this purpose only. This type of test is commonly used to evaluate the mechanical performance of the concrete due to its ease of execution, its relatively low cost and its sensitivity to other material properties, which enables the establishment of correlations. Helene and Terzian (1992) [1] certify that, for a same concrete sample, the axial compression test results may depend on variables relative to the geometry, dimensions and degree of consolidation of the specimen, as well as planeness, parallelism and perpendicularity relative to the longitudinal axis and the loading surfaces of the specimens. Bezerra (2007) [2] mentions that other influencing factors are the load application rate and the stiffness of the test equipment. Neville (2016) [3] points out that, for the execution of the axial compression testing of concrete specimens, it is necessary that the surfaces where the loads are applied should be plane, parallel and smooth, so that uniform loading is achieved, in addition to guaranteeing the orthogonality to the longitudinal axis of the specimen. Mehta and Monteiro (2014) [4] assert that small irregularities on the surface are sufficient to cause eccentricity due to uneven loading and consequently, a reduction in the ultimate strength. It's possible to minimize the effect of the irregularity at the ends of the specimens through mechanical grinding using diamond wheel, leveling with cement paste or capping with sulfur mortar; these are prescribed in Brazil by NBR 5738 (ABNT, 2008) [5]. C617/617M standard (ASTM, 2012) [6] and C39 standard (ASTM, 2014) [7] prescribe that the planeness irregularities should not exceed 0.05 mm, and that the deviation between the end faces and the longitudinal axis of the specimen should be less than 0.5 °. However, Brazilian NBR 5738 standard (ABNT, 2008) [5] establishes requirements only for the mold, which must be plane to within 0.05mm. Therefore, when removed from the mold, cylindrical specimens end surfaces do not meet the standards' requirements to perform the compression test without suffering interference of irregularities in the results. Thus, it is necessary to achieve this planeness on the end surfaces through one of the methods mentioned before. Helene and Terzian (1992) [1] point out that inadequate finishing of the surface of the specimens will result in a reduction of 30% in strength for concave surfaces and 50% in strength for convex surfaces, these data where reasserted by Andrade and Tutikian (2011) [8]. Methods for end surface preparation of cylindrical concrete specimen are divided into three groups: bonded capping systems, unbonded capping systems and mechanical wear systems, which will presented subsequently.

1.1 Bonded capping systems

Bonded capping systems are comprised of materials forming a regular layer which adheres physically or chemically to the end surface of the specimen (ANDRADE; Tutikian 2011 [8]). In bonded systems there are two main techniques: the use of a mixture of sulfur and the use of cement paste or cement mortar (NEVILLE, 2016 [3]). Both NM 77 Standard (AMN, 1996) [9] and the NBR 5738 Standard (ABNT, 2008) [5] establish that the use of cement paste for capping must be done in cylindrical concrete specimens generally a few hours after curing. Whereas for hardened concrete cylinders, sulfur mortar or mechanical wear should be used. Souza (2006) [10] points out that sulfur offers advantages when used as capping material such as fast hardening which provides high productivity compared to the cement paste; its good adhesion to the surface of the specimen; as well as a high axial compressive strength at a very early age. However, Souza (2006) [10] and Bezerra (2007) [2] report that its major disadvantage is the release of hydrogen sulfide gas during the melting of sulfur powder: without using the appropriate Personal Protection Equipment (PPE) the operator is exposed to elevated health risks. In Concrete and Construction Magazine (2011) [11] papers were presented comparing the results between capping using a sulfur mixture and using cement paste. Comparing these results it is observed that when using a sulfur mixture as capping material, it is possible to obtain greater strengths and minor variations for the strength levels studied in these researches. Moreover, it is interesting to note that C617/C617M (ASTM, 2012) Standard [6] states that the strength of the capping material should be greater than the cylinder compressive strength to be tested, but not less than 35 MPa for concrete with strength up to 50 MPa fck^{-1}. To test concrete with a strength greater than 50 MPa, the compressive strength of the capping material should not be less than test concrete strength. In contrast, the Brazilian standards specify only that the strength of capping with sulfur should be greater than 35 MPa, therefore it is necessary to carefully evaluate the effects of this capping method on concrete cylinders with high compressive strength. Another interesting fact is that C617 / C617M (ASTM, 2012) Standard [6] determines the maximum average thickness of the caps in 6 mm for concrete cylinders with strength up to 50 MPa, and for those with strength greater than 50 MPa, up to 3 mm. Whereas NBR 5738 (ABNT, 2008) [5] only specifies that the thickness of the sulfur mortar cap should not exceed 3 mm at any point, regardless of the concrete strength to be tested.

1.2 Unbonded capping systems

Andrade and Tutikian (2011) [8] highlight that the unbonded or non-adherent capping systems are characterized by the use of a material as a pad for the ends of the specimens, which may be confined in a metal retainer or not. Among the most widely used materials are the elastomers, such as neoprene, but sand confined within a retaining ring may also be used for this purpose. According to Bezerra (2007) [2], capping using elastomeric pads which is regulated by C1231 Standard (ASTM, 2014) [12] is being widely used in Brazil and worldwide, but there are few scientific studies published regarding its use. The main elastomer used for this purpose is polychloroprene, known commercially as neoprene, which may be confined or not in a metal retainer. However, the use of neoprene pads without the metal retainer has been presenting inconsistency and divergence compared to the results obtained with sulfur capping in the few articles published on this matter. This is due to the fact that the neoprene pad deforms radially to a greater extent than the test specimens, which generates tensile stress at the bottom ends of the specimens. Souza (2006) [10] points out that for the unbonded system using neoprene pads, a metal retainer is used in order to restrain excessive lateral spreading of the elastomeric pads. Therefore, restraining the material from spreading laterally, cause a reduction of the different stress states responsible for the increase in the variation of strength results. However, it is not recommended to use this system for testing concrete with compressive strength below 10 MPa or above 85 MPa. According to Vieira (1991) [13], when using this method, some precautions must be taken with the elastomer, since the rubber may be reused 1,000 times, and yet, it should not be reversed into the metal retainer. In case there is excessive wear on the edges, it should be replaced immediately, even if its maximum number of reuses hasn't been reached yet. In contrast to the above, C1231/C1231M Standard (ASTM 2014) [12] specifies that neoprene hardness varies according to the test concrete strength, so does the number of reuses, which must not exceed 100 tests.

1.2 Mechanical wear systems

This method makes use of a diamond wheel, an abrasive media, so that the irregularities in the specimen ends are corrected by grinding, in order to ensure the structural integrity of the layers adjacent to the one removed. Neville (2016) [3] mentions that this system, by mechanical means, removes a thin layer of the top end of the specimen being prepared. Moreover, Andrade and Tutikian (2011) [8] highlight that the specimen after being subjected to this type of surface preparation, it presents a smooth surface, free of irregularities, it is important to always check if the working surface do not depart from a plane by more than 0.05mm. 77 NM Standard (AMN, 1996) [9] permits this type of surface preparation to be applied to cores extracted from concrete pavements, as they present irregular surfaces. In this system two different machines are used, such as a diamond saw and a surface grinder, however, these machines facilitate and speed up the procedure in a laboratory with a high demand for compression testing on cylindrical concrete specimen (MEHTA; MONTEIRO, 2014 [4]; NEVILLE, 2016 [3]).

§ Diamond saw: This method involves cutting a piece of the top end of the concrete specimen, obtaining a flat, smooth surface. The device is equipped with a special diamond wheel for cutting concrete (NEVILLE, 2016 [3]).

§Grinding machine: the mechanical surface preparation using a grinding machine allows the surface of the specimen to be grinded with a diamond abrasive grinding wheel which has its speed and wear limit calibrated in the equipment (ANDRADE; Tutikian 2011 [8]).

2. Materials and experimental program

This research aimed to compare four methods for end surface preparation of cylindrical concrete specimen prior to axial compression testing, including one bonded system – using sulfur mortar; one unbonded system - using neoprene pads; and two mechanical systems – using a diamond saw and a grinding machine. The comparison parameter used was the standard system applied for hardened concrete specimens described by NBR 5738 (ABNT, 2008) [5] as the grinding system and by NM 77 as the sulfur mortar system (AMN, 1996) [9]. It was considered of great importance to study the two strength groups established by NBR 8953 (ABNT, 2011) [14]. Belonging to group 1, the strength levels 20 and 40 MPa were studied, and belonging to group 2, the strength levels 60 and 80 MPa were studied, denominated mix 1, 2, 3 and 4, respectively. Those different strength levels were determined in order to widely analyze the possible influence of the type of surface preparation technique used on the compressive strength of concrete specimens. All specimens were molded with dimensions of 100 mm by 200 mm. After molding and curing the specimens until test age - defined in this study as 7 and 28 days, the different methods for surface preparation mentioned before in this item of this article were applied and consequently the axial compression tests were performed. All procedures mentioned were executed following the respective current standards of the Brazilian Association of Technical Standards - ABNT, Asociación Mercosur de Normalización - AMN and the American Society for Testing and Materials - ASTM. The compressive strength test results were compiled and the data were statistically analyzed. To perform the statistical analysis it was used an Excel® add-in program called *action*. The practices of this research were carried out at the Civil Engineering Laboratory – ECF which belongs to the Civil Engineering Department of the University of Southern Santa Catarina – UNISUL, campus Tubarao - Santa Catarina. In order to achieve more complete results, it was found necessary to classify the aggregates used for mixing the

Table 1
Test results of physical properties

		Crushed sand	Fine sand	Gravel	Crushed stone 1”
Fineness modulus		3,020	1,422	5,712	6,782
Maximum aggregate size	(mm)	4,8	0,6	9,5	19,0
Loose unit weight	(kg/m³)	1731	1480	1335	1530
Pulverulent materials content	(%)	12,78	1,43	1,48	1,80
Organic impurities	Ppm	-	< 300	-	-
Clay Lumps and Friable Particles	(%)	-	0,37	-	-
Bulk density	(g/cm³)	2,662	2,684	2,660	2,632
Water absorption	(%)	0,098	0,229	0,573	0,300

Table 2
Concrete mix design

Mix	fck (MPa)	Cement	Fine sand	Crushed sand	Gravel	Crushed stone 1"	Water	Admixtures
1	20	1	1	2,5	0,75	3	0,71	0,0057
2	40	1	0,66	1,33	0,5	2	0,48	0,0058
3	60	1	0,33	0,77	0,33	1,33	0,32	0,0066
4	80	1	0,077	0,23	0,23	0,92	0,23	0,01

batches of concrete, related to the molded specimen to conduct the research.

2.1 Characterization of aggregates

For the calculation of the concrete mixes; the physical properties of the aggregates must be known before mixing concrete. The results are shown in (Table [1]). The tests were sieve analysis, determination of unit weight, determination of pulverulent materials content, determination of organic impurities, determination of clay content, determination of bulk density and water absorption of the materials - aggregates: crushed sand, fine sand, gravel and crushed stone 1''. The test followed what is established by ABNT, specifically by NBR NM 52 (ABNT, 2002) [15] NBR NM 46 (ABNT, 2003) [16] NBR NM 44 (ABNT, 1996) [17] NBR NM 53 (ABNT, 2002) [18], and NBR NM 30 (ABNT, 2001) [19]. The crushed stone 1", gravel and crushed sand were supplied by Pedreira Falchetti, from Tubarao - SC; and fine sand was supplied by Terfal Mining, from Laguna - SC.

2.2 Dosage e mixing procedures

The concrete mixes prepared for this research are presented in (Table [2]). The cement used was Cimpor CP V – 32, as it has a lower level of additions and its commercialization is more common in the southern region of the State. All mixes were molded for each type of surface preparation technique. Six specimens were cast for each mix, three of them to be broken at 7 days and the other three at 28 days. All specimens were molded according to the criteria of NBR 5738 (ABNT, 2008) [5].

Concrete was mixed in a horizontal concrete mixer, according to NBR NM 79 (ABNT, 1996) [21], following the mixing order highlighted by Medeiros et al. (2013) [22]: the coarse aggregate was added first; then 70% of water was poured and both well mixed, then the fine aggregate was added; and subsequently, the cement, the remaining water and the admixture were also added into the mixer. The mixture was well homogenized and the slump test was performed according to NBR NM 67 (ABNT, 1997) [23]. After collecting the slump test values of the mixes, the concrete was mixed in the horizontal mixer once again and homogenized to then proceed to molding concrete, as stated by NBR 5738 (ABNT, 2008) [5] which establishes the molding and curing methods for cylindrical specimens in Brazil. After the molds were properly cleaned and prepared, the concrete was poured to half the capacity of the mold and twelve taps were applied on the outside of the mold, to then fill the remainder of the molds with concrete, apply taps again to achieve proper consolidation of the concrete. Finally, after consolidation, the proper finishing of the top surfaces was applied. The specimens cured in a moist chamber at 23 ± 2 ° C and relative humidity higher than 95%, according to NBR 5738 (ABNT, 2008) [5]. In order to evaluate the compressive strength according to the surface treatment, after 7 and 28 days curing ages, the samples were corrected according to each method disclosed above. Then, the test for determining the compressive strength of cylindrical

Figure 1
Alignment device used and application of sulfur mortar caps

Figure 2
a) Retaining rings and neoprene pads; b) Specimen with neoprene caps

concrete specimens was performed following the procedure prescribed by NBR 5739 (ABNT, 2007) [24].

2.3 Methods for surface treatment of the specimens

According to NM 77 (AMN, 1996, p. 3) [9] "[...] before the compression test of the specimens or cylindrical cores, it is essential to treat their ends in order to ensure that they are flat surfaces, parallel to each other and perpendicular to the longitudinal axis of the specimen [...] ".

a) Capping with sulfur: sulfur mortar was prepared and capping of the specimens performed according to the procedures described by NM 77 (AMN 1996) [9]. The apparatus shown in (Figure [1]) was used to maintain the specimen perpendicular to the surface and to ensure plane surfaces. After the mixture was prepared, it was poured onto the surface of the capping plate so that the specimen end adhered to the melted material, while the cylinder was properly aligned. This system is described by NM 77 (ANM 1996) [9] as the standard practice for hardened concrete specimens, as are the samples of this research.

b) Neoprene pads: this method for end preparation of specimens for compression test was performed according to C1231 standard (ASTM, 2014) [12], which permits the use of unbonded neoprene caps for a number of reuses below the maximum defined by the standard, depending on its Shore A hardness. Two metal retainers were used (Figure [2]), specific for this test, having internal diameter of 100 mm, and two neoprene pads. The metal retainers equipped with the neoprene pads were placed on the specimens to perform the axial compression test.

c) Diamond saw: this surface preparation technique consists of removing a thin layer of the specimen by cutting it with a saw to obtain a flat and smooth surface. This system is established by NM 77 (AMN, 1996) [9] to prepare the surface of cores extracted from portland cement concrete pavements. The standard does not mention the need to perform another type of treatment to prepare the surface after cutting it; so it is possible to conclude that this is characterized as a surface treatment system for specimens in the hardened state. The apparatus used is shown in (Figure [3]).

d) Grinding machine: the method of grinding the specimen in order to correct the surface of the test sample is performed

Figure 3
Diamond saw

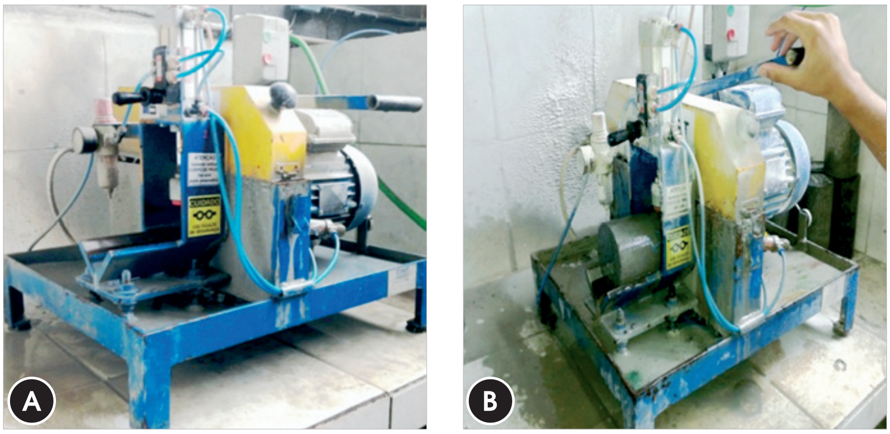

Figure 4
Grinding machine

by mechanical wear using a diamond wheel. This operation is performed in a piece of equipment specially adapted for this purpose (Figure [4]) (AÏTCIN 2000 [25]). Andrade and Tutikian (2011, p. 633) [8] highlight that "[...] the surface correction shall be performed in order to ensure the structural integrity of the layers adjacent to the layer removed and provide a surface [...]" that meets the 0.05mm irregularity limit. This system is suggested by NBR 5738 (ABNT, 2008) [5] to prepare the end surfaces of cylindrical specimens, which is the surface treatment system established as reference to verify the suitability of other systems.

2.4 Axial compression test

The axial compression test was performed according to NBR 5739 (ABNT, 2007) [24] in an EMIC PCE 150 tf compression-testing machine installed at LEC. (Figure [5]) illustrates the mentioned equipment.
After capping, the sample was thoroughly cleaned to prevent any deviations, and placed on the lower bearing block, carefully aligned with the center of the testing machine. An addendum must be done on the eccentricity of the load, because, according to Neville (2016) [3] eccentricities greater than 6 mm lead to a decrease in the compressive strength up to 10%. The compressive axial load was applied continuously, with an increase in the loading rate of about 0.5 MPa /s, until failure occurred. The calculation of the compressive strength of the specimen was carried out according to NBR 5739 (ABNT, 2007) [24] following (Equation [1]).

$$f_{ci} = \frac{4Q}{\pi d^2} \tag{1}$$

f_{ci} is the individual compressive strength for each of the specimens, at j days of age, in megapascal (MPa); Q is the maximum load in Newtons (N), and d is the diameter of the specimen in millimeters (mm). From the results, a statistical analysis was performed to compare the results obtained.

2.5 Data analysis

The individual compressive strength test results for the four

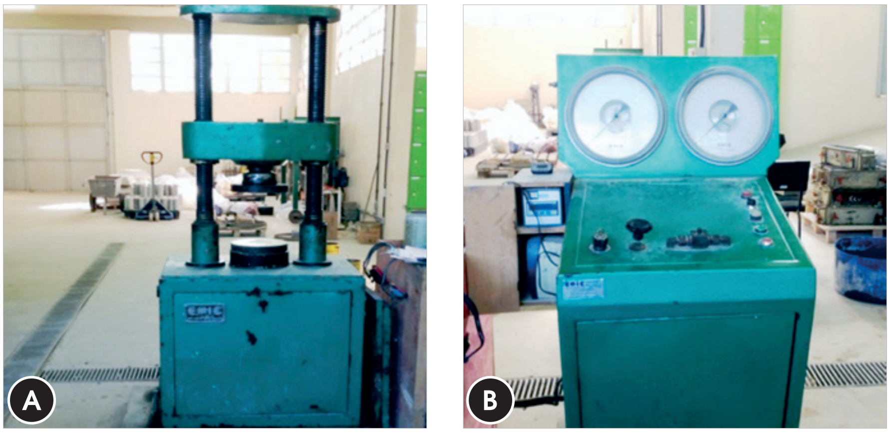

Figure 5
Compression-testing machine EMIC PCE 150 tf

Table 3
ANOVA results for the 4 surface preparation systems evaluated for the four mixes of concrete

	Diamond saw	Grinding machine	Neoprene	Sulfur mortar
SQ	2399,16	7531,44	8198,30	3856,13
GI	3,00	3,00	3,00	3,00
MQ	799,72	2510,48	2732,77	1285,38
F	17,09	106,29	76,18	94,29
P	9,65E-06	1,85E-12	4,06E-11	5,66E-12
$F\alpha = 0{,}05$	3,10	3,10	3,10	3,10

surface preparation methods mentioned above, at the ages of 7 and 28 days, were analyzed to determine $f_{ck,est}$ - estimated characteristic strength of the concrete from test samples – for each surface preparation method, according to the concrete mix. Therefore, the highest value of this lot was considered as $f_{ck,est}$. Moreover, from the f_{ci} results, the average strength (f_{cm}) was calculated by the compressive strength of the concrete determined at j days of age in MPa, as well as the standard deviation (sd) in MPa and the coefficient of variation expressed as a percentage. The average strength was calculated using the arithmetic mean method. The standard deviation was calculated in accordance with NBR 12655 (ABNT, 2015), using the following equation:

$$s_d=\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(f_i-f_{cm})^2} \tag{2}$$

The coefficient of variation is defined as the ratio of the standard deviation to the mean, expressed as a percentage. Data were analyzed by the ANOVA method – Analysis of Variance - a statistical method which tests the hypothesis that the means of three or more populations are equal by examining the variances of samples that are taken. Therefore, it was used an Excel® add-in program called *action*. The analysis of the results was carried out following what was proposed by Triola (2005) [27], when P has a small value, which is less than or equal to 0.05, leads to rejection of the hypothesis of difference of means.

3. Results and discussion

Next, the compressive strength test results of samples at ages of 7 and 28 days are presented; detailing the various types of surface preparation techniques used. (Table [4]) shows the average strengths of the studied groups. Analyzing that table, it is observed that, for mix 1, only the grinding method achieved the expected compressive strength for 7 days, and achieve the highest value for 28 days. The same method also prevailed in mix 2, and it is the only method to achieve the expected strength for the two tested ages. In mix 3, none of the methods achieve the expected strength for 7 days, although for 28 days, the grinding method and the capping system using neoprene achieve the expected strength, the latter showed the best results. Finally, none of the methods used in the compression test achieved the expected results for any of the two ages.

Considering the estimated compressive strength data of mix 1 exposed in the graph shown in (Figure [6]), it is possible to point out that the surface leveling obtained by grinding was the only one to achieve the strength level of 20 MPa at 7 days, and the highest result achieved at 28 days of the four methods investigated. For this mix, the surface preparation technique using neoprene pads in a retaining ring achieved similar results to those obtained using the grinding machine, however, the expected strength level was only achieved at an age of 28 days.

For this mix, for none of the tested ages, the surface treatment provided by cutting with a diamond wheel achieved the expected

Table 4
Average strengths for each surface preparation system and each mix of concrete at the ages of 7 e 28 days

Concrete age	Surface preparation system	Mix 1	Mix 2	Mix 3	Mix 4
7	Diamond saw water cooling	12,75	23,58	33,46	37,07
	Grinding machine	22,33	40,57	52,16	65,78
	Neoprene	19,11	31,45	51,92	60,28
	Sulfur	17,06	33,88	43,01	48,84
28	Diamond saw water cooling	15,05	28,16	42,14	39,32
	Grinding machine	24,23	50,31	60,20	78,30
	Neoprene	22,02	38,96	64,76	75,01
	Sulfur	22,00	37,15	52,63	55,53

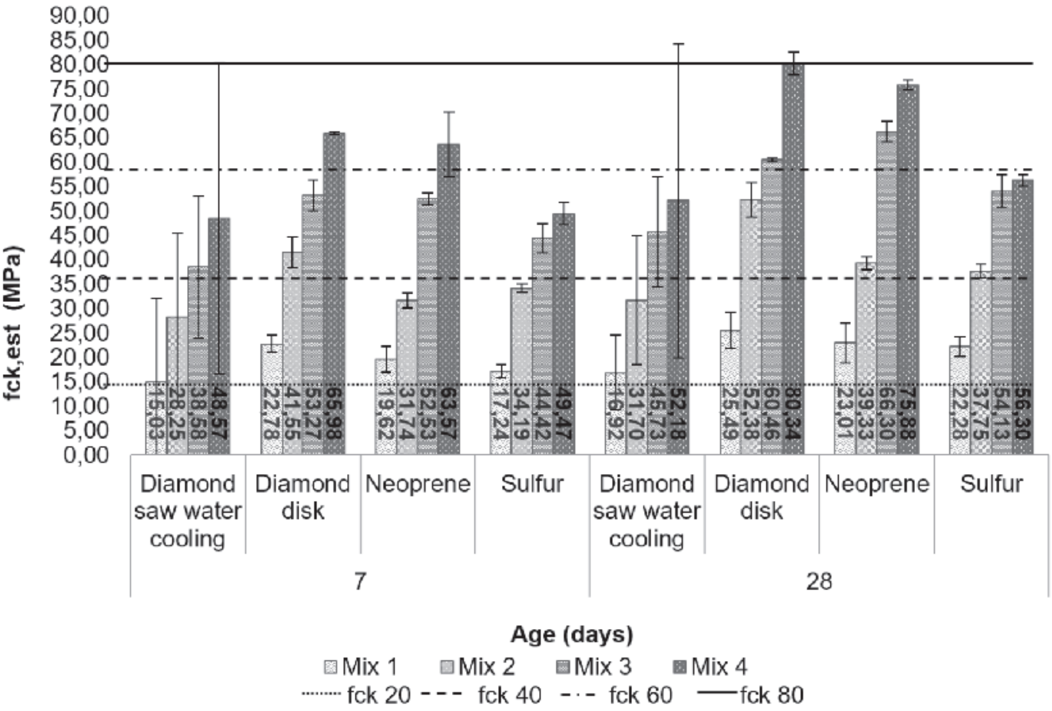

Figure 6

Correlation between estimated strength of mixes 1, 2, 3 e 4 and the different surface preparation systems and fck values

compressive strength level, proving its lower performance. Verifying the data related to mix 2, it is observed that for the results after 7 and 28 days, the only method to achieve compressive strength level of 40 MPa was the grinding method. For this same mix, the lowest values were achieved at both ages, using the diamond saw. Analyzing the values obtained with mix 3, it is possible to consider that none of the surface preparation methods achieved the compressive strength level of 60 MPa at an age of 7 days.

At an age of 28 days, this strength level was achieved by the grinding method and neoprene system; the latter achieved the highest values. Once again, the method in which a diamond saw is used affected negatively the strength of the sample. Observing mix 4 data, it is noted that none of the top end surface treatment systems of the specimens achieved the strength level of 80 MPa at 7 days. However, at 28 days, only the grinding system achieved that value. Among all the compressive strength levels evaluated, it was clear how the mechanical system using a diamond saw affected the results negatively, once it presented the lowest strength results among all surface preparation systems, as can be seen in (Figure [6]). The values obtained with the capping system using sulfur mortar also presented a performance lower than expected, confirming the need for further investigation of its use, probably resulting in the increase in the minimum strength of this capping system. It should be pointed out that neither of the two studied strength levels of group 2 strength levels described by NBR 8953 (ABNT, 2011) [14] were obtained at the age of 7 days, for none of the investigated surface preparation systems, even when using cement CP V – 32.

(Figure [7]) shows how the means and standard deviations varied for the other surface preparation systems compared with the grinding system which is established by NBR 5738 (ABNT, 2008) [5] as a comparison parameter, as it was mentioned above.

Observing the data shown in (Figure [7]), referring to mix 1, it is possible to point out that the values obtained using the diamond saw have the greatest divergence among the other systems, when its means are compared to the mean obtained using the grinding system. Likewise, its sample standard deviation is also the greatest. That occurs for the data obtained at 7 and 28 days. The surface preparation system that uses neoprene caps shows less divergence when its mean is compared to the mean obtained with the grinding system and also it presents the lowest standard deviation value. Observing the data presented in (Figure [7]) for mix 2, it is possible to point out that the values obtained using the diamond saw have the greatest divergence among the other systems, when its means are compared to the mean obtained using the grinding system. Likewise, its sample standard deviation is also the greatest for both ages evaluated. The lowest standard deviation value was obtained from the data of the capping system with sulfur at 28 days and with neoprene pads at 7 days. Observing the data presented in (Figure [7]) for mix 3, it is possible to point out that the values obtained using the diamond saw have the greatest divergence among the other systems, when its means are compared to the mean obtained using the grinding system. Also its sample standard deviation is the greatest. That occurs for the data obtained at 7 and 28 days. The surface preparation system that uses neoprene pads in a retaining ring shows less divergence when its mean is compared to the mean obtained with the grinding system. The lowest standard deviation value was obtained from the data of the capping system with sulfur at 7 days and with neoprene pads at 28 days. Observing the data shown in (Figure [7]) for mix 4, it is possible to point out that the values obtained using the diamond saw have the greatest divergence among the other systems, when its means are compared to the mean obtained using the grinding system. Its sample standard deviation is also the greatest, and that occurs for the data obtained at 7 and 28 days. The surface preparation system that uses neoprene pads shows less difference

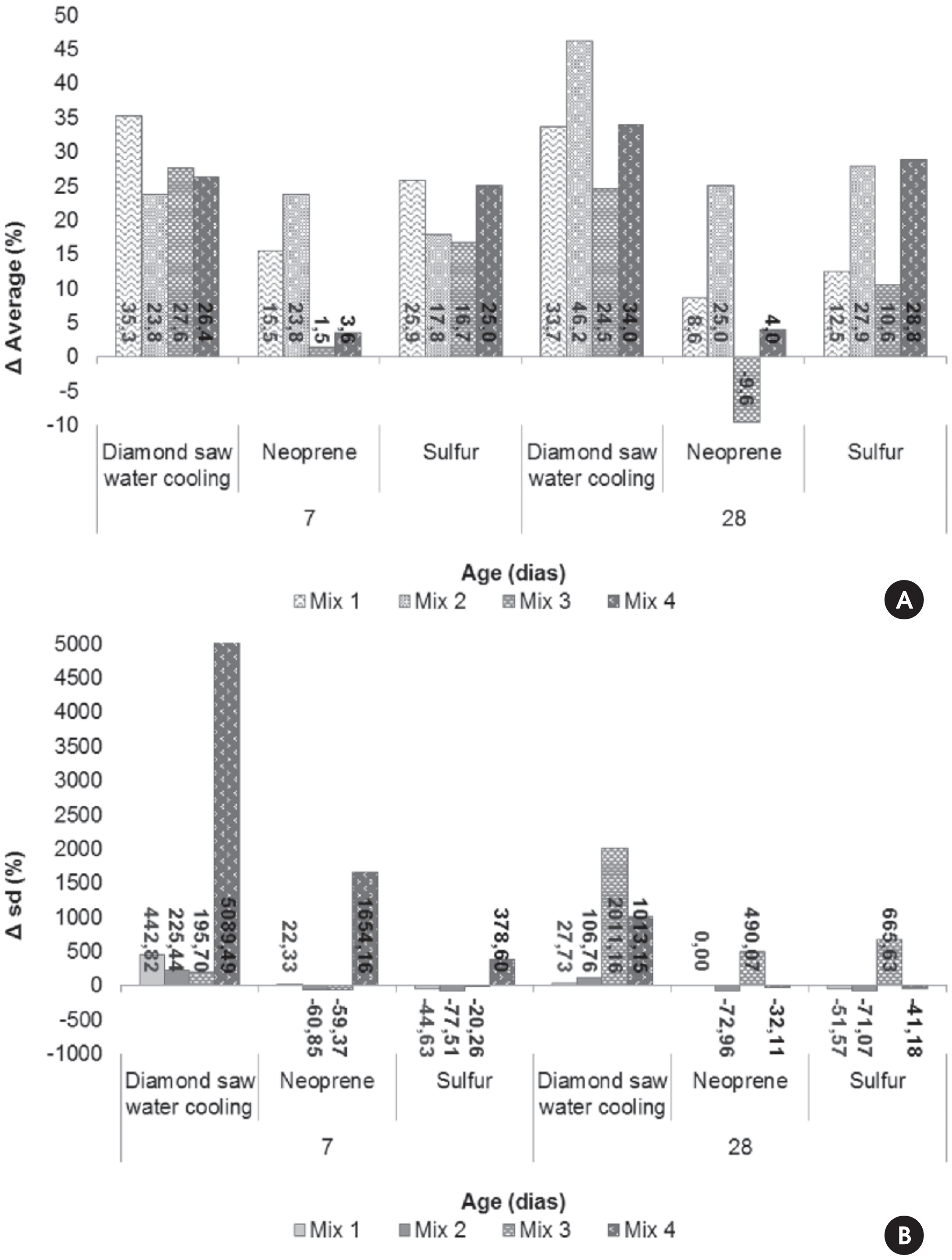

Figure 7
Comparison of surface preparation techniques and the standard established by NBR 5738.
a) Comparison of the mean values. b) Comparison of standard deviation values

when its mean is compared to the mean obtained with the grinding system. The lowest standard deviation value was obtained from the data of the capping system with sulfur at 7 days and with neoprene pads at 28 days.

(Figure [8]) shows how the other surface preparation systems varied compared to the capping system with sulfur mortar, which is established by NM 77 (AMN, 1996) [9] as the standard practice for capping hardened concrete specimens, as mentioned above.

Observing the data presented in (Figure [8]) for mix 1, it is possible to point out that the values obtained using the grinding system have

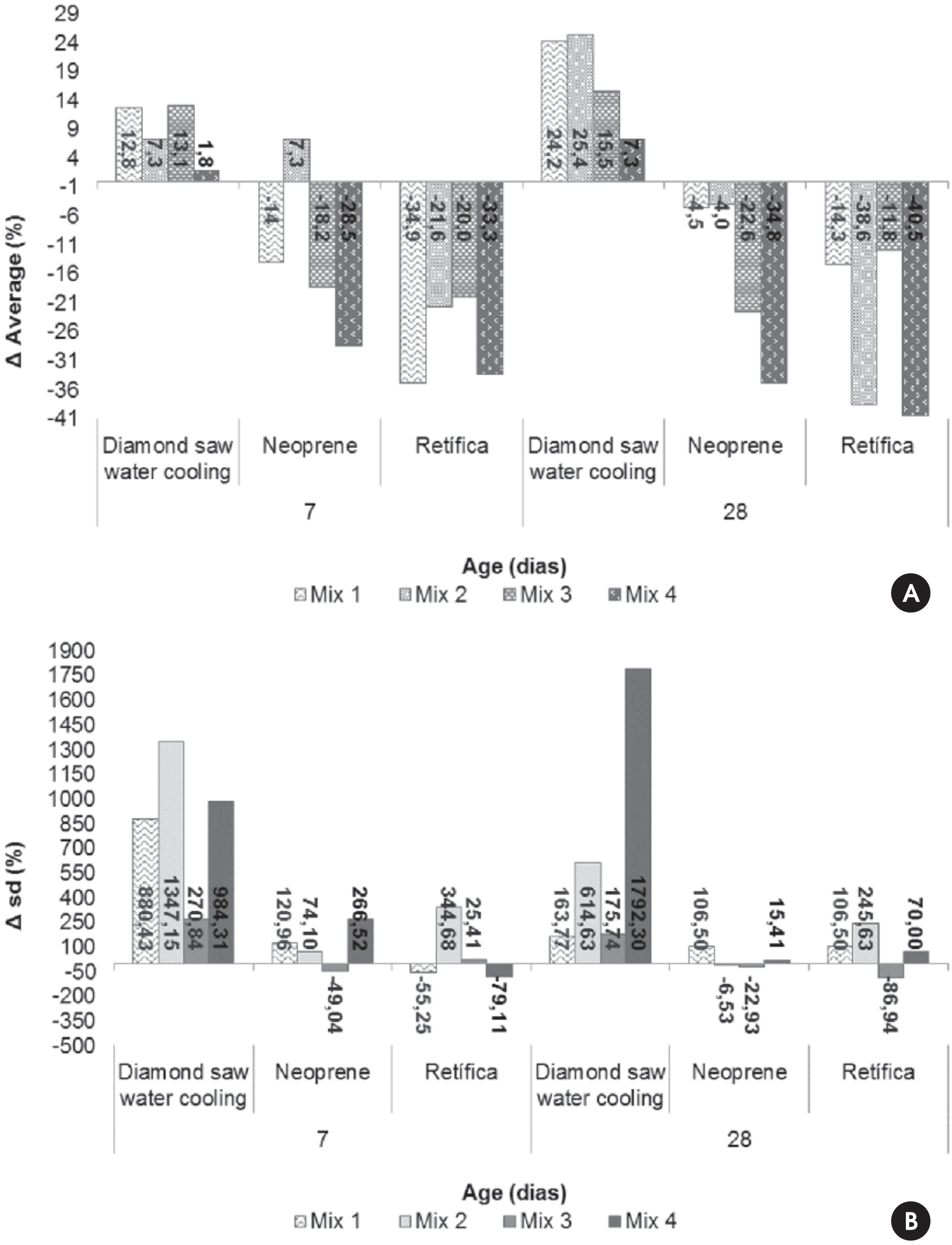

Figure 8
Comparison of surface preparation techniques and the standard established by NM 77.
a) Comparison of the mean values. b) Comparison of standard deviation values

the greatest divergence among the other systems, when its means are compared to the mean obtained using the capping system with sulfur mortar at 7 days. For values obtained at 28 days, the greatest divergence among the means lies with the system using the diamond saw. The lowest standard deviation value at 7 days refers to the data from the grinding system and it is equal to the capping system with neoprene pads at the age of 28 days. Observing the data presented in (Figure [8]) for mix 2, it is possible to point out that the values obtained using the grinding system and the diamond saw system presented the same divergence among the other systems, when their means are compared to the mean obtained using the capping system with sulfur mortar. The highest sample standard deviation value belongs to the system using the diamond saw, and the lowest to the capping system with neoprene pads for both ages of 7 and 28 days. Observing the data from mix 3, it is possible to point out that the values obtained using the grinding system show the greatest divergence at 7 days and the capping system with neoprene at 28 days, among the other systems, when their means are compared to the mean obtained using the capping system with sulfur mortar. The highest sample standard deviation value belongs to the system using the diamond saw at the ages of 7 and 28 days. Still according to the data presented in (Figure [8]) for mix 4, it is noted that the grinding system has the greatest divergence among the other systems, while the system using the diamond saw has the lowest divergence, when their means are compared to the mean obtained using the capping system with sulfur mortar for both ages. The largest sample standard deviation belongs to the system using the diamond saw, for both ages of 7 and 28 days.

For assistance with the validation of the research results, it was considered essential to conduct a statistical analysis in order to verify the variance performing a single-factor ANOVA. Initially, it was verified the hypothesis of normal distribution, as suggested by Medeiros (2014) [26] to apply that method. ANOVA is based on the “within groups” variance, also known as error variance. To perform the statistical calculations, it was used an Excel® add-in program called *action*, as mentioned previously.

The data distributions of all samples were considered normal. As previously stated, Triola (2005) [27] describes that when P has a small value, which is less than or equal to 0.05, leads to rejection of the hypothesis of difference of means. Thus, it is possible to consider as valid all methods evaluated in this study, under the conditions described, as they presented P value, according to the ANOVA analysis, less than 0.05.

4. Conclusions

This research was proposed in order to evaluate the performance of four surface preparation techniques of cylindrical concrete specimens, which are the most used in Brazil and worldwide. Given the potential for application of the test method which determines the compressive strength of concrete specimens - a property sensitive to changes in other properties -; an updated evaluation of the most widely used surface preparation procedures becomes essential, relating their results to the procedures established by the current standard practices in Brazil.

It was taken into consideration the two compressive strength groups established by NBR 8953 ABNT, 2011) [14], because the standard practice from 2014, NBR 6118 (ABNT, 2014) [28] includes in its text some different procedures for the design of reinforced concrete structures with strengths belonging to the two compressive strength groups.

- The differences in the test results caused by failure to perform or inadequate application of a given surface preparation system may result in rejection of batches of concrete that should be accepted, or even worse, result in the acceptance of batches that should be rejected. This can interfere considerably in the durability and functionality of the structure.
- To carry out this research, it was determined the concrete mixes to be subjected to compression tests at ages of 7 and 28 days, with four top surface preparation techniques. It was considered essential to evaluate these techniques in concrete within both compressive strength groups established by NBR 8953 (ABNT, 2011) [14], since draftsmen have been largely using this second group, which was previously used only in special projects.
- Observing the analysis of the results, it is possible to conclude that the system established by NBR 5738 (ABNT, 2008) [5] proves to be very effective for the four strength levels analyzed in this research, considering their means and standard deviations presented for those strength levels. The capping system described by NM 77 (AMN 1996) [14] proves to be effective only for the strength level of 20 MPa; for the other 3 strength levels, its effective strength did not reach the expected value, and it turned out to be lower than the results obtained with the grinding process. This fact requires further studies regarding its application in concrete, especially those with high compressive strength. Possibly, the performance of this capping system may be improved with the use of sulfur mortars with strengths significantly greater than 35 MPa, established by the Brazilian regulation. As for its standard deviation, it is considerably small, showing that its distribution is also small; therefore, this system has a slight variation in its results. The system which makes use of neoprene caps didn’t reach any of the evaluated strength levels, its standard deviation was small, except for the strength level of 80 MPa. The system using a diamond saw proved to be ineffective regarding its average strength for all the assessed strength levels, and its standard deviations were the largest among the systems evaluated in this study.
- Therefore, it is possible to conclude that the system established by NBR 5738 (ABNT, 2008) is useful for axial compression tests of concrete belonging to the two compressive strength groups established by NBR 8953 (ABNT, 2011) [14]. The system established by NM 77 (AMN, 1996) [9] can be applied to evaluate concrete with strengths from group 1 of NBR 8953 (ABNT, 2011) [14], but for group 2 that system should not be applied. It is reasonable to consider that the objective of this research was achieved, since it was possible to analyze all systems in relation to the expected strengths.

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