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Influence of the preparation of the cylindrical specimen surface and approach analysis on the test value of compressive strength

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Abstract: The worldwide use of the axial compressive strength test makes it fundamental to identify the concrete class. However, this test presents dispersion of results which, consequently, reduces the reliability of the test. The surface of the tops of the specimens influences the values of strength measured, since the lack of flatness impairs the uniform application of the load. Different types of procedures can be used to ensure the flatness of the surfaces. Besides, there are different approaches for data analysis, namely to detect outliers. Thus, this research aimed to study and evaluate, the influence of sulphur capping, capping with confined neoprene sheet and non-capping of the test specimens, and the influence of the approach to detect outliers in order to understand the interference in the results. The sulphur cap presented the lowest dispersion values and the cap with confined neoprene sheet obtained the highest strength. In addition, the results showed that the lack of regularization of the tops of the specimens increased dispersion as it causes an important decrease of the resistance in the concrete.

1. Introduction

Concrete is the most widely used construction material in the world and to do its quality control it is essential that there is a reliability in the testing measurements. The most performed test to evaluate the mechanical performance of concrete is the compressive strength test, where the values are obtained through applying the uniaxial compression load on moulded specimens in accordance with relevant standards [1]. Among the international technical specifications following are widely used for compressive strength test, the American Standard ASTM C39 [2], the European Standard EN 12390-3

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[3], the Brazilian Standard NBR ABNT 5739 [4], the Chinese Standard GB/T 50081 [5] and the Australian Standard AS 1012.14 [6].

The wide acceptance of this test is due to the ease of execution, relatively low operating cost and the fact that the strength provides a general perception of the concrete quality. However, the compressive strength test is subject to the dispersion of results due to intrinsic factors of the material, aspects of the test execution and the characteristics of the specimens [7].

The surfaces of specimens for axial compression tests with irregularities generate concentrations of stresses, which result in a decrease in the apparent strength of the concrete [8]. The tops of the specimens, therefore, must be smooth, flat and perpendicular to the central axis of the part to be tested, in order to guarantee the uniform application of the load over the entire surface of the tops.

In practice, different techniques and materials are used to remove the irregularities of the tops of specimens, such as smoothing or different types of capping [9]. The smoothing consists in the removal of a thin layer of material from the specimens bases with the use of machines adapted for this purpose. The capping is coating the tops of specimens with other materials.

The smoothing by mechanical system is recommended when the specimens show significant irregularities in their tops and that would probably not be corrected with the other methods used for capping. It is common to use this system when extracting specimens from existing structures or in high-strength concrete [9].

Bonded capping systems are those that used materials capable of forming a regular layer that adheres physically or chemically to the surface of the specimen base [9]. According to NBR NM 67 [10], the preparation of fresh concrete specimen capping must be done with Portland cement paste or mortar. As for specimens of hardened concrete in wet curing, the capping must be done with sulphur mortar.

The EN 12390-3 [3] standard indicates the preparation of the faces of the test pieces for when they exceed the tolerances of the EN 12390-1 standard [11]. This standard refers, in its Annex B, the method of evaluating the flatness of samples. The NBR 5738:2015 [12] does not mention possible methods to obtain the flatness and parallelism between the faces. The standard reports only the features required of the material used for capping including, adherence to the specimen; chemical compatibility with concrete; fluidity at the time of application; smooth and flat finish after hardening; and, mainly, compressive strength compatible with the values normally obtained in concrete [12]. Nowadays, capping with neoprene sheet is on the rise in Brazil, because it is a more practical method. ASTM C1231/C1231M:2010 [13] specifies capping with neoprene sheet and also allows it to be reused, but it is necessary to perform qualification tests on the sheet [14]. The use of capping with neoprene sheet has the disadvantage that they are well suited to standardized sizes and well-matched caps diameters. For

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drilled cores, diameters may fluctuate, resulting in gaps between the specimen wall and the sheet, and in turn leading to neoprene extrusion and creating uneven loading on the specimen plane.

Sulphur mortar is in disuse because of health and safety issues. Major disadvantage is the release of hydrogen sulfide gas during the melting of sulphur powder which without using the appropriate personal protection equipment the operator is exposed to elevated health risks [15]. Even so, it still makes up the European Standard (EN 12390-3:2011) [3] as one of the methods for capping, among others. Although nowadays the current standard allows other processes (mechanical smoothing and neoprene sheet) many laboratories, including research laboratories from the universities, did not shift to smooth by mechanical system, yet. The old version of Brazilian Standard NBR 5738:1994 [16] and the European Standard EN 12390-3 [3] state that only specimens that do not meet the tolerance conditions must be subjected to the preparation of the tops. Furthermore, this and the current standard accept grinding or capping procedures. The standard allows that other processes can be adopted, as long as they are submitted to prior evaluation by statistical comparison, and the results obtained from specimens are compatible. In case of doubt, the suitability of the capping material used must be tested by a statistical comparison, with results obtained from specimens whose tops were prepared by grinding. Therefore, capping concrete specimens with sulphur and applying neoprene sheet are presently largely used in Brazil.

Previous studies have shown significant differences in the results of resistance of specimens that have undergone different methods of tops preparation [15],[14]. Furthermore, some methods have obtained a greater dispersion results than others, and some tests were even considered deficient because of this variation, according to performance evaluation test of NBR 5739: 2018 [17]; [18]; [9]; [1]; MARCO; REGINATO; JACOSKI, 2003 apud [9]; [19]; RUDUIT, 2006 apud [1];[14]; [15]; [20].

The demand for greater rigor in technological control in the materials used in major engineering works has been growing in line with the complexity of structural projects. In many situations, it is necessary that the tests are able to express the influence that the composition of different materials and additions have on the concrete.

Based on the above, to avoid the dispersion of the results and guarantee the reliability it is important to understand the interference of the types of the preparation process of the surfaces of specimens in the laboratory. Thus, in this study, the authors want to know how the preparation process of the surfaces of specimens (i) without capping, (ii) capping with confined neoprene sheet and (iii) capping with sulphur affect the measured value of the concrete compressive strength test. Besides, since that the work deals with dispersion, here, the authors want to know how distinct approaches identify outliers, how they affect the end result, and what approach looks is recommended. Therefore, in this work 60 concrete specimens from only one mix composition were moulded and tested for the compressive strength. The concrete specimens moulded were divided in three sets of 20 specimens: (i) without capping top and

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bottom, (ii) with capping top and bottom with confined neoprene sheet and (iii) with capping top and bottom with sulphur. The influence in the value obtained in the compressive strength test is evaluated through a statistical analysis of 20 specimens of each set specimens. The number of specimens was defined following the standard NBR 5739-Annex B [4] which is used to assess concrete ready-mixed quality control and conformity. In order to detect outliers, the concrete compressive strength values obtained were analysed (i) without any exclusion of outliers, (ii) by the Tukey's method, (iii) by the T stat suggested by the ASTM E178 [21], (iv) by the Dixon test suggested by the ASTM E178 [21], (v) according to the EN 206 [22], and (vi) according to the standard NBR 5739 [4].

2. Experimental Program and Test Results

2.1. Materials and preparation of specimens

The experimental program was developed at the Construction Technology Laboratory of Faculty of Santo Agostinho, at Montes Claros-MG-Brazil. In total, 60 concrete cylindrical specimens with diameter of 100 mm and height of 200 mm were prepared from four batches with 30 litres from a single concrete composition at rate of 1: 2.4: 3.1: 0.562 (Portland cement: natural sand: crushed stone: water) by mass. The type of cement used was the Brazilian CP V [23] from Lafarge. The physical properties of the aggregates are shown in Table 1.

Table 1 – Physical properties of the aggregates test results of physical properties

Property	Sand	Gravel
Type	Fine (silica)	#1 (limestone)
Bulk density (kg/m³)	1314	1325
Specific mass (kg/m³)	2646	2632
Fineness Modulus	2.083	7.090
Maximum aggregate size (mm)	1.2	19.0

Cylindrical steel moulds with diameter 100 mm and height 200 mm were used, lubricated with demoulding oil before filling with concrete. The moulding and curing concrete specimens processes were carried out by following the standard NBR 5738:2015 [12]. The moulding took place on a flat and level surface and the flatness of the samples took place in accordance with EN 12390-1 [24].

Pouring concrete inside the mould followed the number of layers and number of strokes defined in the NBR 5738:2015 [12], which vary according to its dimensions and the type of density to be applied. In this experimental program manual compacting with 12 strokes (using a steel rod with 16 ± 2 mm diameter) was used in two layers. The tops of the specimens were scraped with a trowel, ensuring their flat as much as possible. Figure 1 shows the specimens after being moulded and demoulded.

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After this process, the moulds were placed on a horizontal, rigid surface, free from vibrations and any other disturbance and, during the first 24 hours, were stored in laboratory conditions. After this initial curing period, the specimens were demoulded, labelled and stored for 28 days in a saturated solution of calcium hydroxide until the time of the test. This recommendation is in accordance with stated in the Brazilian standards NBR 12655 [25] and NBR 5738 [12] for the specimens to be tested in order to verify the quality and uniformity of the concrete used in the construction or to decide on its acceptance.

Two hours before performing the compressive strength tests, the capping with liquid sulphur was conducted with the application of the sulphur in its liquid form in the specimen tops (see Figure 2a,b). The tops of the specimens were dried to prevent the appearance of bubbles. The entire capping process was carried out with the aid of a plumb instrument (Figure 2c), in order to guarantee the flatness of the faces and the orthogonality of the specimens. In addition, through calliper measurements, it was ensured that the thickness of the cap did not exceed 2 mm, considering that greater thicknesses can lead to lower strength results [26]. Figure 2d presents the top of the specimen after capped with sulphur.

Figure 1 – a) Specimens just after moulding and b) Specimens just after demoulding.

Figure 2 – a) Sulphur at the beginning of heating, b) sulphur during melting, c) aid of a plumb instrument for orthogonality, and d) detail of the specimen surface after capping.

The capping system with confined neoprene sheet was composed with steel discs and circular neoprene sheet pads, whose thickness is equal to 15 mm – according to ASTM C1231/C1231M [13], which suggests the use of neoprene sheet pads with thicknesses exceeding of 13 mm. Figure 3 shows the steel discs and neoprene sheet pads used in this work.

The compressive strength test was carried out for cylindrical specimens according to NBR 5739 [4]. The specimen was positioned in a hydraulic press automatic machine, 100 tons of capacity, and applied the load continuously at speed 0,45 ± 0,15 MPa/s, as recommended by the same standard, NBR 5739 [4]. Figure 4 shows the test with different tops conditions and already positioned on the press.

Figure 3 – Neoprene sheet pads and metal discs used for capping.

Figure 4 – Test specimens with different tops preparations: (a) with sulphur capping; (b) with confined neoprene sheet and (c) non-capping.

2.2. Operational issues and testing results

During the execution of capping with sulphur, it was observed the need to adopt safety measures to avoid laboratory accidents. The major disadvantage of this capping method is the release of hydrogen sulfide during the fusion of powdered sulphur, and this gas is highly toxic and irritates the mucous

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membranes of the respiratory tract [9]. Thus, it was necessary to use a respirator mask, gloves to avoid the contact of the sulphur with the skin and to perform the heating in an open place.

In addition, during capping with sulphur, some specimens did not present a satisfactory visual aspect, being necessary to remove the already hardened sulphur layer and repeat the capping process, until a uniform, flat and thick material layer was obtained. A positive aspect of using sulphur in capping is it can be removed from the tops without damaging the specimens and be reheated for reuse in new capping.

As for capping with confined neoprene sheet, after testing ten specimens, excessive wear was noticed at the edges of the pads, as shown in Figure 5.

Figure 5 – Neoprene sheet pads after use in the axial compression tests of 10 specimens

ASTM C1231/C1231 M [13] recommends the maximum number of reuses of neoprene sheet pads based on the strength specimen and the neoprene sheet specifications. For specimens with strength between 28 MPa and 50 MPa, the maximum number of reuses of 100 times is allowed [13]. However, in this study it was found the neoprene sheet pads with a number of uses is only 10 times. Thus, new neoprene sheet pads were replaced with the same characteristics as those used previously to test the remaining ten specimens.

It can be said that the capping with confined neoprene sheet pads has more simplified execution and more practical than that the capping with sulphur, given that it is not necessary to separate additional time to perform capping with a confined neoprene sheet, in addition to not be necessary to adopt additional safety measures.

When performing the axial compressive strength test, it was noticed that the specimens without capping broke quickly and uniformly for all specimens. Sulphur capping also showed similar ruptures for all specimens, however, it broke in a longer period of time when compared to the specimens without capping. On the other hand, the specimens capped with a confined neoprene sheet suffered later ruptures, with the deformation of the neoprene sheet pads being noticeable in Figure 6.

Figure 6 – Confined neoprene sheet pads: (a) before the press is applied and (b) after the press is applied and the specimen breaks

This exhaust of the neoprene sheet while running the test probably was because the cushions had dimension greater than the diameter of the specimens. Thus, the transfer of the entire load that was being applied by the press to the specimens may not have occurred, which explain the higher values found for capping with a confined neoprene sheet when compared to capping with sulphur.

It was also identified that the failure occurred in different ways for specimens with different top preparation conditions, as shown in Figure 7. For specimens capped with sulphur, there is a Type E

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(shear) rupture, in specimens with capping in confined neoprene sheet there were Type A (conical) ruptures, while in specimens without capping, the rupture was Type C (columnar with cone formation).

According to NBR 5739:2018 [4], these are types of failure mode that, in general, do not fit in trials with significant dispersion results, which tends to occur by moulding defects and trimming the tops of the specimens. This demonstrates that, in this work, the moulding and finishing procedures did not negatively influence the values found, in addition to substantiating the low results found for standard deviation and coefficient of variation within the group.

Figure 7 – Failure modes of the specimens with different types of preparation of the tops: (a) capping with sulphur; (b) capping with confined neoprene sheet and (c) non-capping.

The 60 tests values obtained of the compressive strength are presented in the Table 2. In addition, it is presented some notable values, i.e. the corresponding values of the average, minimum, maximum, standard deviation and coefficient of variation.

Table 2 – Values obtained for the compressive strength tests [MPa].

Specimen	Non-capping	Confined neoprene sheet	Sulphur capping
1	29.65	37.38	39.74
2	27.87	37.39	34.29
3	25.97	41.94	38.43
4	21.17	42.16	34.92
5	20.84	38.66	39.57
6	31.87	40.54	32.17
7	31.87	38.83	34.76
8	28.28	38.52	36.80
9	26.97	35.75	38.38
10	26.17	32.33	37.42
11	28.76	39.83	37.99
12	27.65	38.22	32.75
13	30.77	30.93	32.68
14	29.36	31.96	39.36
15	26.56	41.24	37.36
16	23.13	33.23	37.96
17	26.65	38.15	31.08
18	26.60	37.34	37.66
19	29.37	41.25	33.88
20	20.42	40.17	34.89
Min	20.42	30.93	31.08
Max	31.87	42.16	39.74
Average	27.00	37.79	36.10
Standard deviation	3.39	3.38	2.68
Coef. Variation %	12.55%	8.93%	7.42%

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3. Analysis and Discussion of Results

The notable values of a set of data are the values that one uses to summarise the results. Provably, the most used one is the average value of the data. However, other notable values are frequently necessary, among others, the minimum, maximum, standard deviation and coefficient of variation. However, all theses notable values face the same problem, they can be excessively influenced by outliers [27] (i.e., values that are in the data but should not belong to the set). Therefore, the analysis of results starts with the identification of outliers according to several methodologies. Then, it is followed by the analyses of variance. Besides, the results are compared not only between the different approaches, but also with the ones presented in the literature.

3.1. Identification outliers and the notable values

3.1.1. Tukey's method

Tukey's method or better known as boxplot defines lower (Eq. 1) and upper (Eq. 2) limits from the interquartile range (IQR) and the first and third quartiles. Data outside these limits will be considered outliers [28].

$$L_{\text{low}}=Q1-(1.5*IQR) \quad (1)$$

$$L_{\text{upp}}=Q3+(1.5*IQR) \quad (2)$$

where: $Q1$ is the first quartile, $Q3$ the third quartile, $IQR = Q3–Q1$, L_{low} the lower limit and L_{upp} the upper limit.From the data presented in Table 2, it was possible to make the box-plot graph of Figure 8a, constructed to represent the quartiles in the three different groups of the condition of preparation. Two outliers (specimens 5 and 20) were identified in the non-capping group (NC) by the Tukey's method (Figure 8a). In Figure 8b, the box-plots are presented after the exclusion of the two specimens of the NC group considered outliers. It is also observed the presence of an outlier (specimen 4) in this group. Figure 8c shows the plox-plot after excluding specimen number 4, in which no outliers were identified. The values of $Q1$, $Q3$, IQR, L_{low} and L_{upp} are reported in Table 3.

(a)
(b)
(c)

Figure 8 – Behaviour of the specimens according to the preparation condition

Table 3 – Values of $Q1$, $Q3$, IQR, L_{low} and L_{upp} in the three different groups of the condition of preparation.

	Q1	***Q3***	***IQR***	L_{low}	L_{upp}
Non-capping (n=20)	26.02	29.37	3.35	21.00	31.05

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Non-capping (n=18)*	26.46	29.44	2.98	21.99	33.91
Non-capping (n=17)**	26.58	29.51	2.93	22.19	33.91
Confined neoprene sheet (n=20)	36.15	40.45	4.30	29.70	46.90
Sulphur capping (n=20)	33.98	38.28	4.30	27.53	44.73

* after deleting specimens 5 and 20; ** after deleting specimens 5, 20 and 4.

After excluding outliers with the Tukey's method the new notable values for the 17 values accepted for non-capping are, average = 28.09 MPa, minimum = 23.13 MPa, maximum = 31.87 MPa, standard deviation = 2.28 MPa and coefficient of variation = 8.10 %. These values compare with the ones determined before excluding outliers (see untreated data in Table 2), i.e. average = 27.00 MPa, minimum = 20.42 MPa, maximum = 31.87 MPa, standard deviation = 3.39 MPa and coefficient of variation = 12.55 %. Analysing these changes, one concludes that the Tukey's method changed the markedly the end results as the average result improved 4% and the minimum result considered improved more than 13%. It also concluded that, although excluding outliers with the Tukey's method had markedly changed the notable values of the non-capping tests, it noted that such change was not enough to cover the difference for the results from tests with a confined neoprene sheet or with sulphur capping.

3.1.2. ASTM E178 [21]

The standard ASTM E178: 'Standard Practice for Dealing With Outlying Observations' is frequently used to detect outliers [29]–[31]. This standard presents several distinct methods to detect the outliers. Here, the authors check the outliers according to two distinct methods presented in the ASTM E178.

T stat

One of the criteria to check if the extreme values of a data set is an outlier, is to transform the highest or lowest value into a *T* stat given by the Eq. 3:

$$T_n = \frac{X_n - \bar{X}}{SD} \quad \text{and} \quad T_1 = \frac{\bar{X} - X_1}{SD} \tag{3}$$

where X_n is the largest value, X_1 the smallest value; $\bar{X}$ the mean value and SD is the standard deviation of the data set.

If the *T* statistic is higher than the critical value of the reference table (Table 1 of the ASTM E178 [32]), at an adopted significance level, the observation will be considered an outlier. To apply this method, it is necessary that the data set has an approximately normal distribution.

This criterion has been applied to the results of compressive strength test results of the specimens in the three different groups. Table 4 presents the smallest value (X_1), largest value (X_n) and Xi values, with

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their respective *T* values. At a significance level of 5% and for a sample size n = 20, the critical value of the reference table (Table 1 of the ASTM E178 [32]) is equal to 2.557. Therefore, according to this criterion, none of the evaluated observations were considered outliers.

Table 4 – Extreme values of compressive strength test results with their respective *T* values.

Non-capping		Confined neoprene sheet		Sulphur capping	
X_i	T_i	X_i	T_i	X_i	T_i
20.42	1.94	30.93	2.03	31.08	1.87
31.87	1.44	42.16	1.29	39.74	1.36

<u>Dixon test</u>

The Dixon test is another criterion used to assess whether the extreme value in a sample is an outlier in the ASTM E178 [21]. The Dixon test is not based on mean and standard deviation, but on the proportion of differences between observations. The Dixon test statistic is represented by r_{ij}, where i indicates the number of extreme values on the same side (upper or lower) of the data as the suspected outlier (i = 1 or 2); and j indicates the number of extreme values on the opposite side of the data (j = 0, 1 or 2). The Dixon test statistic depends on the sample size and it is recommended: r_{10} for $3 \leq n \leq 7$; r_{11} for $8 \leq n \leq 10$; r_{21} for $11 \leq n \leq 13$ and r_{22} for $n \geq 14$. Table 2 in the ASTM E178 [32] provides the appropriate expressions for calculating the statistics of this test according to the sample size and critical values for the 1%, 5% significance levels and 10%.

Table 5 shows the results of the Dixon test applied of compressive strength test results of the specimens with three different conditions of preparation. At a significance level of 5% and for a sample size n = 20, the critical value of the reference table (Table 2 of the ASTM E178 [32]) is equal to 0.45. Therefore, according to this criterion, none of the evaluated observations were considered outliers.

Table 5 – Extreme values of compressive strength test results with their respective r_{ij} values.

Non-capping		Confined neoprene sheet		Sulphur capping	
X_i	r_{22}	X_i	r_{22}	X_i	r_{22}
20.42	0.072	30.93	0.136	31.08	0.193
31.87	0.093	42.16	0.093	39.74	0.054

3.1.3. <u>Analysis of results according to the EN 206</u> [22]

The European standard EN 206 [22] guides that when two or more specimens are produced from a sample and the range of variation of the individual test results is greater than 15% of the average, these results should be disregarded, unless an investigation shows that there is an acceptable reason that justifies the elimination of a value individual test. Based on this criterion, analysing the results presented in Table 2 and Table 6 is obtained. Note that, firstly the values marked with * were excluded because they were out of the range f_{cm}±15%. Secondly, the new f_{cm}±15% were determined and the values marked

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with ** were excluded. Finally, the new (and final) f_{cm}, standard deviation and coefficient of variation were determined because all the values were within the range f_{cm}±15% specified in the standard EN 206 [22].

The results according to the EN 206 [22] are compressive strength of non-capping 27.90±5.37%, compressive strength of confined neoprene sheet 38.86±5.98%, and compressive strength of sulphur capping 36.10±7.41%. When compared the results found following the standard EN 206 [22] with the full untreated data presented in Table 2 (i.e. compressive strength of non-capping 27.00±11.60%; compressive strength of confined neoprene sheet 37.79±9.37%; compressive strength of sulphur capping 36.10±7.28%.), it is concluded that there was no changes on the sulphur capping results as no values were excludes. For non-capping six values (more than 25%) were excluded because they were considered as being outliers, the average of the compressive strength increased ~1 MPa and the coefficient of variation decreased markedly. For the confined neoprene sheet three values (15%) were excluded because they were considered as being outliers, the average of the compressive strength increased almost 1 MPa and the coefficient of variation decreased markedly.

Table 6 – Outliers analysis according to the EN 206 [22]

	Specimen	Non-capping	Confined neoprene	Sulphur capping
	1	29.65	37.38	39.74
	2	27.87	37.39	34.29
	3	25.97	41.94	38.43
	4	21.17*	42.16	34.92
	5	20.84*	38.66	39.57
	6	31.87*	40.54	32.17
	7	31.87*	38.83	34.76
	8	28.28	38.52	36.80
	9	26.97	35.75	38.38
	10	26.17	32.33**	37.42
	11	28.76	39.83	37.99
	12	27.65	38.22	32.75
	13	30.77	30.93*	32.68
	14	29.36	31.96*	39.36
	15	26.56	41.24	37.36
	16	23.13**	33.23	37.96
	17	26.65	38.15	31.08
	18	26.60	37.34	37.66
	19	29.37	41.25	33.88
	20	20.42*	40.17	34.89
1st iteration * to be excluded	Average	27.00	37.79	36.10
	Average - 15%	22.95	32.12	30.69
	Average + 15%	31.05	43.46	41.52

2nd iteration ** to be excluded	Average	27.59	38.50	-
	Average - 15%	23.45	32.72	-
	Average + 15%	31.72	44.27	-
3rd iteration (final - none to be excluded)	Average	27.90	38.86	-
	Average - 15%	23.72	33.03	-
	Average + 15%	32.09	44.69	-
	Min	25.97	33.23	31.08
	Max	30.77	42.16	39.74
	Standard Deviation	1.50	2.32	2.68
	Coef. Varition	5.37%	5.98%	7.41%

3.1.4. Analysis of results according to the NBR 5739 [4] Standard

The Brazilian Standard does not provide analysis for the exclusion of results by outliers, however, it specifies specimen test values to dismiss. Besides, it provides analyses for the coefficient variation. The NBR 5739 [4] specifies that, at least, ten sets of two specimens are tested to assess quality control and conformity of concrete from a ready-mixed plant. In this paper, each set of specimens is composed of 2 specimens in sequence. Examples: Set A is composed by the specimens Number 1 and Number 2, set B is composed by the specimen Number 3 and 4, and so on. According to the standard NBR 5739 [4] for each set of specimens only the higher value of the compressive strength test is considered. The lower value is dismissed (although, it is not considered an outlier). Table 7 presents the values of the compressive strength f_{ci} to be considered for each set of specimens. As referred above, after this selection of values, no outlier's analysis is applied.

Table 7 – Values obtained for the compressive strength tests [MPa].

Set	**Non-capping**		**Confined neoprene sheet**		**Sulphur capping**	
	A_i	**f_{ci}**	**A_i**	**f_{ci}**	**A_i**	**f_{ci}**
A:1&2	1.78	29.65	0.01	37.39	5.45	39.74
B:3&4	4.80	25.97	0.22	42.16	3.50	38.43
C:5&6	11.03	31.87	1.88	40.54	7.40	39.57
D:7&8	3.59	31.87	0.32	38.83	2.04	36.80
E:9&10	0.80	26.97	3.43	35.75	0.95	38.38
F:11&12	1.11	28.76	1.60	39.83	5.25	37.99
G:13&14	1.41	30.77	1.03	31.96	6.67	39.36
H:15&16	3.43	26.56	8.01	41.24	0.60	37.96
I:17&18	0.05	26.65	0.80	38.15	6.58	37.66
J:19&20	8.95	29.37	1.08	41.25	1.01	34.89
Min		25.97		31.96		34.89
Max		31.87		42.16		39.74
Average		28.85		38.71		38.08
Standard deviation		2.23		3.09		1.45
Sum A_i	36.95		18.39		39.44	
S_e	3.28		1.63		3.50	
Coef. Variation (cv_e)	11.36%		4.21%		9.18%	

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Different than the other methodologies, the NBR 5739 [4] specifies its own approach to control spreading of results. In the NBR 5739 [4] the standard deviation (called 'S_e') and the coefficient of variation (called 'cv_e') are determined as followed.

$S_e = \frac{\sum_{i=1}^{n} A_i}{\mathrm{d}_2 \times n}$	(1)
$cv_e = \frac{S_e}{\mathrm{f}_{\mathrm{cm}}} \times 100$	(2)

where:

S_e → Standard deviation determined according to the NBR 5739 [4] – see values in Table 7;
A_i → Spread of strength values of the set, i.e. the difference between the highest and lowest value of the set (MPa) – see values in Table 7;
n → Number of sets; here n=10;
d_2 → Coefficient obtained from the Table B.1 from the NBR 5739 [4]; here, d_2=1.128.
cv_e → Coefficient of variation (%) according to the NBR 5739 [4] – see values in Table 7;
f_{cm} → Average compressive strength of the sets – see average value in Table 7 (MPa).

The coefficient of variation determined according to the NBR 5739 [4], then, is evaluated according to Table 8 (Table B.2 in Annex B of NBR 5739 [4]). As it can be noted when one compares the cv_e values presented in Table 7 and the limits of the Table 8, according to the standard NBR 5739 [4], the coefficient of variation with confined neoprene sheet is classified as being 'Good' whereas the others are classified as 'Deficient'.

Table 8 – Evaluation of the test using the coefficient of variation (cv_e) (%)

Level 1 (Excellent)	Level 2 (Very Good)	Level 3 (Good)	Level 4 (Reasonable)	Level 5 (Deficient)
$c_{ve} \leq 3.0$	$3.0 < c_{ve} \leq 4.0$	$4.0 < c_{ve} \leq 5.0$	$5.0 < c_{ve} \leq 6.0$	$c_{ve} > 6.0$

From the observed results, the average compressive strength increased for all sets when compared with the full untreated data presented in Table 2. The average compressive strength for the non-capping increased at 6.9% (1.85 MPa), for the confined neoprene sheet increased at 2.4% (0.92 MPa) and for the sulphur capping increased at 5.5% (1.96 MPa). It is noted that the biggest average compressive strength nominal increase is for the sulphur capping, which it was the only methodology that did not present any outlier in the previous methodology. Also, the average compressive strength of the confined neoprene sheet method is higher when applied the EN 206 [22] than by the NBR 5739 [4].

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Regarding the coefficient of variation of the NBR 5739 [4] (cv_e), one notes a reduction on the three sets when compared with the conventional coefficient of variation from the full untreated data presented in Table 2. The confined neoprene sheet presenting the higher reduction when applied the NBR 5739 [4] (more than a 50% reduction).

3.2. Analysis of variance

3.2.1. Full data

The ANOVA analysis of variance was performed to compare the average compressive strength between the three groups, at the level of 0.05. In order, to identify in which group the observed difference is located, multiple comparisons were made using the Bonferroni test, at the level of 0.05. Shapiro Wilk Test was performed, at the significance level of 0.05, to verify the normality of the distribution of the variable of strength compressive for the three groups. The results of Shapiro-Wilk Test, suggest that the distributions are normally distributed (p-value = 0.109; 0.065 and 0.158. The Levene Test was also performed to assess the homogeneity of the variances, which result indicates that the variances of the three groups are homogeneous (p-value = 0.904. The ANOVA Test,, indicates that the three averages are not the same, at least one of the groups has a different average F (2.57) = 67.31; p-value = 0.000.The results of Multiple Comparisons (Benferroni, level 0.05), indicates that the average of the "non-capping" group showed a significant difference from the means of the "neoprene confined" group (p-value = 0.000) and "sulphur" group (p-value = 0.000). No significant difference was observed between the means of the "neoprene confined" and "sulphur" (p-value = 0.292).

3.2.2. Comparison of the ANOVA for after excluding data by distinct methodologies

The Table 9 summarizes the descriptive statistics (average and standard deviation) and analysis of variance (ANOVA) applied to the compressive strength test found in the different types of analysis. In the 4 types of analysis, a statistically significant difference was identified between the average of the groups (p-value <0.05). The average compressive strength of the non-capping group was significantly different from the other groups in all types of analyses. The average compressive strength of the confined neoprene sheet and sulphur capping groups were similar when considering all data (without excluding outliers), by the Tuckey method and NBR 5739, but were different in the analysis by the EN method. The results presented at the Table 9 showed that the NBR 5739 presented higher average compressive strength of non-capping and for sulphur capping and that the EN 206 presented higher one for confined neoprene sheet.

Table 9 – Comparison of set of results according to the condition of preparation.

Type of Analyse	**Non-capping**	**Confined neoprene sheet**	**Sulphur capping**	**Test ANOVA p-value**

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	Average (SD)	Average (SD)	Average (SD)	
Full data / T stat / Dixon test	27.00 (3.39)[a]	37.79 (3.38)[b]	36.10 (2.68)[b]	0.000
Tuckey method (box-plot)	28.09 (2.28)[a]	37.79 (3.38)[b]	36.10 (2.68)[b]	0.000
EN 206	27.90 (1.50)[a]	38.86 (2.32)[b]	36.10 (2.68)[c]	0.000
NBR 5739	28.84 (2.23)[a]	38.71 (3.09)[b]	38.08 (1.45)[b]	0.000

a,b,c: different letters indicate a significant difference between the average means and equal letters indicate that the average are similar between the groups; SD: standard deviation.

3.3.Comparison of methodologies

Previously we applied six different approaches to detect the outliers and to determine the notable values of the results. Base on the findings presented and on the authors' learnings, the authors summarised their opinion about the different approaches in Table 10. Note that, the authors opinion regards to analysis of data similar to the ones of the present paper, *i.e.* it is for the analysis of values of the compressive strength tests of concrete. Thus, when no special analysis is required, the authors recommend to apply the EN 206 [22] for the analysis of concrete compressive strength data.

Table 10 – Strengths and weaknesses according to the condition of preparation.

Type of Analyse	**Strengths**	**Weaknesses**
Full untreated data	- Well-known - Conventional - Easy to apply - Basic math approaches	- No exclusion of outliers - 'Untreated' data
Tuckey method (box-plot)	- Well established worldwide - Well supported scientifically	- Requires expertise of the users due to advanced math approaches - Not friend for the typical civil/concrete engineer
ASTM E178 [21] T stat	- It is from a standard	- Requires expertise of the users due to advanced math approaches - Not friend for the typical civil/concrete engineer
ASTM E178 [21] Dixon test	- It is from a standard	- Requires expertise of the users due to advanced math approaches - Not friend for the typical civil/concrete engineer
EN 206 [22]	- It is from a standard - Very easy to understand - Very easy to apply - It makes sense for the user	- Not based in scientific criterium
NBR 5739 [4]	- It is a standard - Very easy to understand - Provides a different analysis to control spreading	- It does not make sense for the user - Requires much more specimens - Excludes results without a statistical criterium - It is not clear what to do with the different analysis to control spreading

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3.4.Comparison of results to other studies in the literature

When comparing the results found in this work with previous studies in Table 11, it is possible to notice that some studies did not fit satisfactory the test levels, as they obtained high coefficients of variation. However, in general, sulphur capping resulted in the smallest standard deviation in this study and in other studies. This suggests that the variation in the results obtained is less when using sulphur in capping, when compared with the other top preparation conditions analysed.

There was no agreement in all studies to the method that provides the highest strength values for concrete. In the capping with sulphur and neoprene sheet the variations might have occurred due to the thickness of sulphur capping and neoprene sheet cushion. In addition, the use of elastomeric pads and steel discs slightly larger than the diameter of the specimens may have resulted in a charge leak. However, when taking into account the standard deviation of the sets, it is understood that this difference was not considerable.

Table 11 – Compression strength [MPa], standard deviation [MPa] and coefficient of variation [%] in this study and others comparative studies of methods of preparing the tops of specimens.

Study	Grinding / Non-capping *	Confined neoprene sheet	Sulphur capping
Present study	27.00 / 3.39 / 11.36 *	37.79 / 3.38 / 4.21	36.10 / 2.68 / 9.18
Barbosa *et al.*, 2009 [9]	36.59 / 1.64 / 4.48	-	39.03 / 1.17 / 3.00
	24.31 / 0.82 / 3.38	24.90 / 1.60 / 6.44	26.47 / 0.35 / 1.33
Bezerra, 2007 [18]	-	33.71 / 1.02 / 3.03	31.50 / 1.13 / 3.58
Chies *et al.* , 2013 [1]	43.2 / 1.50 / 3.50	43.7 / 1.80 / 4.10	-
Marco; Reginato; Jacoski, 2003 *apud* Bezerra, 2007 [9]	-	24.08 / 1.13 / 4.7	25.36 / 0.90 / 3.55
Menezes, 2011 [19]	31.58 / 1.26 / 4.00	-	34.18 / 1.18 / 3.40
	22.23 / 1.18 / 5.30	-	24.20 / 1.08 / 4.50
Ruduit, 2006 *apud* CHIES, 2011 [1]	34.10 / 0.25 / -	-	35.30 / 1.41 / -
	23.00 / 1.41 / -	-	25.50 / 0.53 / -
Lerner et al, 2019 [14]	52.1 / 1.7 / -	47.1 / 1.0 / -	40.3 / 0.9 / -
Medeiros, 2017 [15]	24.23 / - / -	22.02 / - / -	22.00 / - / -
	50.31 / - / -	38.96 / - / -	37.15 / - / -
	60.20 / - / -	64.76 / - / -	52.63 / - / -
	78.3 / - / -	75.01 / - / -	55.53 / - / -
Sousa, 2006 [20]	26.8 / 1.0 / -		24.8 / 0.8 / -
	21.5 / 0.7 / -	18.9 / 0.8 / -	
	46.1 / 1.8 / -		34.0 / 8.8 / -
	30.3 / 0.7 / -	27.0 / 0.6 / -	

Contrary to the present study, the others listed in Table 11 compared two capping methods with the results found for specimens whose top and bottom were grinding. The other works used rectification and found results close to the other preparation conditions. This attests, once again, to the need to regularize the surfaces of the concrete specimens, by means of capping or grinding, in order to avoid the accumulation of stresses due to irregularities in the tops and, consequently, to reduce the resistances found. Dimitru et. al. [33] already said “No matter how carefully a cylinder end is finished, its end surface probably will exhibit some irregularities.”

Comparing surfaces with sulphur mixture and mortar as capping material, Medeiros at al. [15] conclude that the strength values is greater for the sulphur capping, and also the minor variations for the strength levels studied. Also emphasizes that 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 sulphur should be greater than 35 MPa.

4. Conclusions

The concrete compressive strength tests demonstrated that there are markedly differences between the average strengths of the concrete, as well as in the dispersion of these results, when comparing methods of preparing the surfaces of different specimens. Confined neoprene sheet capping obtained the best results regarding the variation coefficient (cv_e), proving to be the most reliable method among the three evaluated ones. The smallest deviation standard deviation for the sample results was found for the sulphur capping, however it is pointed that this type of capping is difficulty to carry out.

The capping with confined neoprene sheet resulted in highest values for the concrete. In addition, due to the ease of execution, the reason for its wide use in Brazilian laboratories is understood. However, there was excessive wear of the elastomeric pads with few uses, this being a factor that must be observed during the execution of the tests.

For all methods of preparation top's specimens tested was performed a statistical analysis to ensure the reliability of the results and rank tests at levels statistically acceptable. However, the average compressive strength of specimens without capping were considerably reduced, while there was an increase in the dispersion of results. This demonstrates the needs to grind the surfaces, even when apparently they look regular. The possible irregularities in the surface that receives the tension applied by the hydraulic press unevenly interfere in getting reliable laboratory results.

The results were analysed applying different approaches in order to identify outliers and the corresponding influence on the notable values. From the different analyses resulted that the approach provided by the European Standard EN 206 is the one that the authors recommend applying to compressive strength data when no special analysis is required. This approach based in excluding the values higher and lower than the average value plus and minus 15% is easy to understand, easy to apply even by non-expertise users and fits on the analysis of the concrete compressive strength.

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Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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