Influence of the molding process and different surface regularization methods on the compressive strength of concrete specimens

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Abstract
Concrete is one of the most important material for civil construction, given its high applicability. C Compressive strength (fc) is one of the main parameters to evaluate the concrete quality. Concrete of the same mixing volume may vary even with the same materials preparation. Concrete specimens molding, and its surface regularization contribute to these variations that are often hard to measure. Therefore, this paper aims to determine the variations in compressive strength of concrete, simulating different processes for casting, initial curing and surface treatment. In stage 1, the specimens were subjected to five surface treatment types, resulting in variations of 30% for concrete fc, whereas grinding specimens reached the highest 28-day compressive strength, so they were carried over to the next stage. In stage 2, specimens were produced as per ABNT NBR 5738 (2015) and with induced errors in casting and initial curing. The specimen produced according to the standard achieved the second-best result, whose 28-day fc was3% lower than that of the similar method, despite leaving the specimen uncovered for the first 24 hours after casting. Specimens produced in metal cylinder form works shows higher results than those produced in polyvinyl chloride molds (PVC).

Keywords: Concrete, Casting, Surface treatment, Compressive strength.

Introduction

Evaluation of concrete through laboratory tests is a standardized procedure that measures the quality of the cementitious matrix, relating its properties to the requirements of design (Neto, Vasconcelos, & Albuquerque, 2017). The compressive strength test is applied to evaluate the concrete elements load capacity and it is one of the most important proprieties for the structural performance of a building (Helene, 2011; Neville & Brooks, 2013; Thandavamoorthy, 2015). If the results show that the concrete in use did not reach the design characteristics, then it can compromise the stability of the structure and its users (Couto, Carvalho, Cintra, & Helene, 2015). It is important to assure the quality of building materials, so the facility to run the compressive strength test and its low cost make it the most usedformaterial quality control (Moreno, Solís-Carcaño, Varela-Rivera, & López, 2016). According to Tunç (2018) and Pacheco et al. (2018), compressive strength is the most important and applied analysis, considering concrete specimens. Gupta (2018) considers the advantage of the destructive test commonly applied is its cost of execution. As a disadvantage, the author mentions the internal faults in the structure cannot be identified.

ABNT NBR 5738 (2015) states how fresh-state cylindrical concrete specimens should be molded. The choice of specimen size depends on the dimension of the aggregates, considering a diameter at least three times larger than the nominal maximum dimension of the coarse aggregate. The use of cylindrical specimens may be justified by the absence of edges, favoring consolidation, but Bezerra, Alves, Barbosa, & Torres (2016) evaluated an hourglass-shaped specimen, in which the distribution of stress at the edges is irrelevant, with the greatest stress occurring in the middle of the specimen. Tam, Daneti & Li (2017) mentioned that the cylinder shape is favorable, considering the material consumption to specimencast. Also, it should be noted that cubic specimens, such as those used in Europe, follow the NP EN 12390 (2009) standard, present disadvantages regarding their slenderness, since the area of the cubes is higher than that of the cylinders.Consequently, the load concentrates on the edges, so the same concrete attainshigher cubic strength than cylinder strength. Moreover, the method with the cylindrical specimen is more conservative, because it is closer tothe ones measuredon-site, as per conclusions of Nalon, Lima, Martins & Alvarenga (2016), Araújo, Guimarães & Geyer (2016) and Mazepa & Rodrigues (2011).

In the process of casting, both mechanical and manual consolidation methods depend on the consistency of the mixture, which is evaluated by the slump test and classified by ABNT NBR 8953 (2015). For concretes that fit class S10 ($10 \leq S < 50$ mm), the consolidation must be performed mechanically, while for concretes of classes S50 ($50 \leq S < 100$ mm) and S100 ($100 \leq S < 160$ mm) it can be either manual or mechanical. Above class S160, manual consolidation becomes mandatory.

During the manual consolidation of the 100x200 mm (diameter x height) specimens, the responsible professional must be careful when adding the concrete to the cylinder formwork, adding the concrete mass in two layers for concretes below S160, while monitoring the intensity and the number of blows per layers, in accordance with ABNT NBR 5738 (2015). The purpose of consolidation is to eliminate the entrapped air that was incorporated in the process of mixing and casting the matrix, reducing voids in concrete. However, excessive consolidation can segregate components, especially coarse aggregates. Then, the mixture has its homogeneity compromised, which influences the compressive strength test results (Sousa, 2006). These flaws can be identified by the ultrasonic wave propagation velocity. Chies, Rohdenand & Filho (2014) and Fernandeset al.(2018) explain that this technique can detect flaws within the concrete, hence providing complete and efficient scans.

Even when casting on a flatplane, the processes of leveling and finishing the surfaces of the specimens might not provide the flat and smooth surface that the compressive strength test requires (Indelicato & Paggi, 2008). A rough surface causes = uneven loadings on the specimen, resulting in higher strength variation and lower representativity (Boesing, Philippsen, & da Luz, 2010; Pan, Shi, Shi, Ling, & Li, 2017a).

Errors in the specimen casting process comprise most of the coefficients of variation for compressive strength results and come from induced errors made when preparing, consolidating and curing concrete, just like in the number of blows and layers (Oliveira Júnior, Pedroti, & Fernandes, 2018 and Gil et al., 2017).

Regarding the compressive strength test, Souza & Bastos (2017) state that smalldimensional variations, along with casting and operational errors have severe impact on the results. In order to ensure reliable compressive strength data, it is necessary to make sure that the loads are uniformly distributed on the top surface area of the specimen (Chies, Rohden, & Filho, 2014). For that, the standard (ABNT NBR 5138:2015) leaves two options of processes to prepare the bases of the specimen: grinding and capping with sulfur mortar. Grindingmeans towear the surface of to make its edged free of ripples and bulges, whereas capping consists of applying a layer of coating with maximum thickness of 3 mm. Both methods prioritize the flatness and uniformity of the load-exposed faces, as expressed by Boesing, Philippsen & da Luz (2010).

ASTM C1231/C1231M (2010) specifies capping with neoprenesheet, which is commonly used in Brazil. This practice regards the use of metal discs filled with neoprenesheet that deform with the initial loading to adapt to the contour of the specimen’s ends, while metal plates prevent them from spreading laterally. The hardness of the neoprene element must be between 50 and 60 Shore. This standard also allows the neoprenesheet to be reused, but it is necessary to perform qualification tests on the sheet.

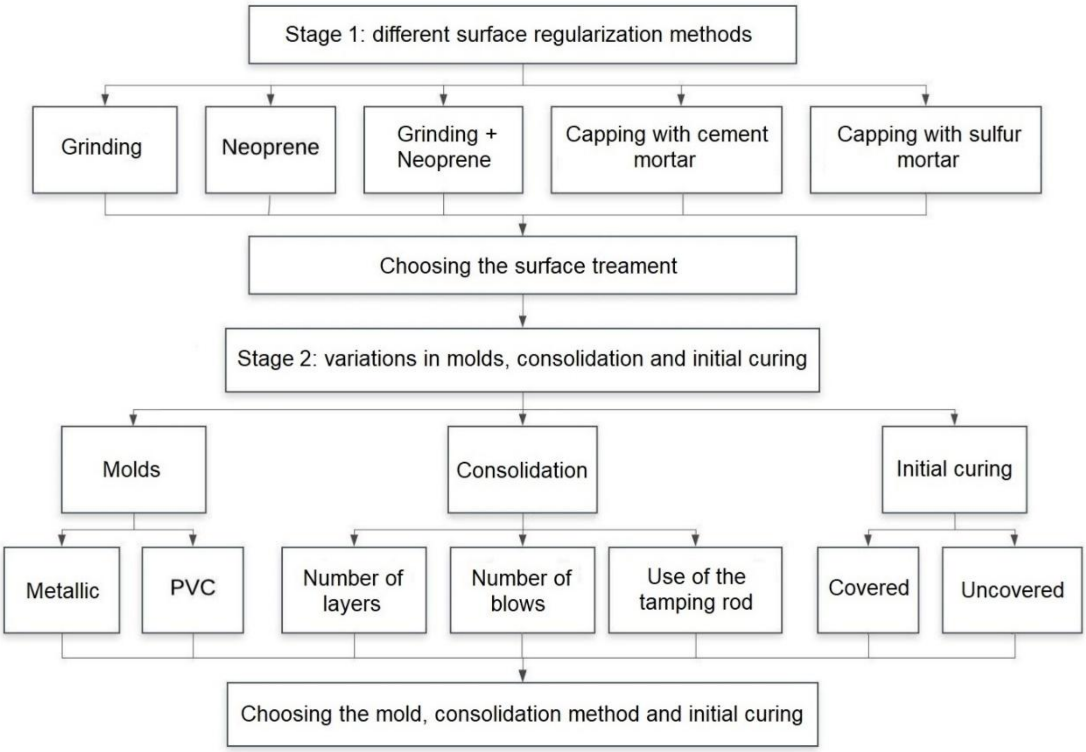
Chies, Rohden & Filho (2014) and Ehrenbring et al. (2019) reported that, for conventional concretes (CC), the technique of regularizingthe surface by mechanical grinding was more efficient, whereas high-strength concretes (HSC) showed no significant variation between treatments by capping with neoprenesheet and surface grinding. On the other hand, Souza & Bastos (2017) found out that concrete specimensattained lower standard deviation for both CC and HSC. Silva et al.(2011) and Silva et al. (2017) used cylindrical specimens of 100x200 mm andidentified that leveling the top surface in a specimen grinding machine increases reliability as it produces smaller coefficients of variation between the results. Bezerra, Aguilar & Cetlin (2008) verified thatcapping with neoprenesheet makes it possible to achieve strength values that are equivalent or even greater than those of sulfur capping. Still, Silva & Filho (2011) pointed out that, by capping the surface with neoprenesheet, the compressive strength was higher, because regularizationsheet are made of flexible material, so they suit better the imperfections of the specimen; whereas the results for regularization by sulfur and grinding are similar.Pan, Shi, Shi, Ling, & Li (2017b) presents comprehensive details of four types of concrete treatments, including surface coating, hydrophobic impregnation, pore blocking surface treatment and multifunctional surface treatment.

Considering the facts presented, this study aims to measure the influence of the casting process and different surface regularization methods on the compressive strength of concrete specimens.

Methodology

The experimental procedure of this research was divided into two stages. Stage 1 covered the analyses that measured the impact of different types of surface regularization on the compressive strength of the specimens andstage 2 counted with specimens that underwentinduced errors in the process of casting and initial curing, along with variations in cylinder formwork types. Therefore, cylindrical specimens with dimension of 100x200 mm (diameter x height) were produced using C35 (fc equal to 35 MPa) and S100 concrete, casted in a concrete batcher. For stage 1, all specimens were produced undertemperature of11.3°C and relative humidity (RH) of 52.6%, whereas stage 2 had temperature of 10.8°C and RH of 67.3%.

Figure 1. Research workflow. Source: elaborated by the authors.



Research Stages

Stage 1

For stage 1, 25 cylindrical specimens were casted, which received the following types of surface treatment after being produced: grinding, capping with neoprenesheet, grinding accompanied by capping with neoprenesheet, capping with cement mortar and capping with sulfur mortar. Hence, 5 specimens were produced for each type of surface treatment, considering 2 to assess compressive strength at 7 days and 3 at 28 days. The specimens were casted 24 hours after being casted and were left to cure under the conditions determined by ABNT NBR 5738 (2015). Table 1 shows each type of surface treatment, whose specimens were produced after recommendations of ABNT NBR 5738 (2015). Concrete was cast in two layers into the cylinder formworksthat were greased with release oil and each layer was struck 12 times with a tamping rod, and then the surface was leveled.

Table 1. Summarization of surface treatments. Source: elaborated by the authors.** Surface treatments performed as per orientations of ABNT NBR 5738 (2015).*

Specimen	Type of surface treatment	Description	Image
RET*	Grinding	Process that wears the specimen with a sheet until the surface is smooth and leveled	
CAAE	Capping with neoprenesheetwith 60 Shore	Neoprenesheet with thickness of 10mm and greater diameter than that of the specimen that is attached to the metal dish to prevent excessive deformation of neoprenesheet. These are placed on both surfaces of the specimen during the test.	
RET+CAAE	Grinding accompanied by capping with neoprenesheet	This process combines the two mentioned above, grinding the specimen and then capping it with neoprenesheet and dishes during the test.	
CAPAC*	Capping with cement mortar	It consists of applying a layer of up to 3mm of cement mortar, whose strength is higher than that of concrete, to each face of the specimen, so that these faces remain smooth and orthogonal to the specimen.	
CAPAE*	Capping with sulfur mortar	It consists of applying a layer of sulfur mortar to each face of the specimen, so that these faces remain smooth and orthogonal to the specimen.	

Stage 2

For stage 2, 60 cylindrical specimens were casted, produced in 10 distinct forms, all of which are presented in Table 2, with 8 undergoing intentional non-standard procedures and 2 following the conditions prescribed by ABNT NBR 5738 (2015). The casting variations were performed as to represent induced errors that usually take place during the production of specimens for the evaluation of concrete. The specimens were deformed 24 hours after being produced and were left to cure throughout the investigation period under the conditions determined by ABNT NBR 5738 (2015). Hence, 6 specimens were produced for each variation, considering 3 for the verification of compressive strength at 7 days and 3 at 28 days. All specimens were checked for ultrasonic wave propagation velocity prior to the compressive strength test. After casting and curing, the specimens received the surface treatment that had achieved the best results and the lowest standard deviation in stage 1.

Bearing in mind that:

REF-A. Set A was produced as per ABNT NBR 5738 (2015), adopted as reference, in two layers, and received 12 blows with a standard tamping rod;
B. Set B was produced with a single layer filling the entire cylinder formwork and consolidated by mechanical vibration;
C. Set C was produced with a single layer filling the entire cylinder formwork, but no consolidation whatsoever;

D. The fourth set was produced the same way as the reference, but it was not covered during its initial curing, hence remaining in the open;
E. For this set, the rod touched the bottom of the cylinder formwork during consolidation, thus not abiding by the standard;
F. Set F was consolidated with a 16 mm of diameter steel bar instead of the standard rod;
G. This set was produced in accordance with the standard, but in 100x200 mm PVC cylinder formworks;
H. Produced in 100x200 mm PVC cylinder formworks with a single layer of concrete and no consolidation;
I. Set I was produced in a PVC tube (100 mm of diameter and 120 mm of height), with no consolidation, and was stored vertically. Later, the tube was sawed, yielding 6 specimens with height of 200 mm. This condition represents the incomplete casting of the specimen with only one layer, which can happen at the construction site;
J. Produced the same way as set I, but stored horizontally, followed by the same sawing to yield 6 specimens with height of 200 mm.

Table 2. Casting types. Source: elaborated by the authors.

Specimen	Number of layers	Number of blowsper layer	Material of the cylinder formwork(100x200 mm)
A – REF*	2	12	Metal
D		12	Metal
E		12 (touching the bottom of the cylinder formwork)	Metal
F		12 (steel bar 16 mm Ø)	Metal
G*		12	PVC
B	1	12	Metal
C		0	Metal
H		0	PVC
I		0	PVC
J		0	PVC

Materials Used

Table 3 presents the mixing ratio of the concrete used in this study. It was mixed in a batcher with Portland cement type CP II-F-40, medium and fine silica sand, coarse basalt aggregates with maximum diameter between 12.5 and 19 mm, water-cement ratio of 0.6, and S100 slump-flow class. Also, the concrete provided had characteristic compressive strength of 35 MPa.

Table 3. Concrete mixing ratio. Source: elaborated by the authors.

Material	Quantity/proportion (kg/m^3)	Material	Quantity/proportion (kg/m^3)
Mixing ratio	1: 2.83: 3.78	Gravel #0	229
Cement	302	Gravel #1	914
Fine silica sand	214	Water	181
Medium silica sand	642	Superplasticizer	3.26

Hardened State Characterization

Compressive Strength (f_c)

The compressive strength test was performed in accordance with ABNT NBR 5739 (2018). This test was performed with auniversal hydraulic press with capacity of 2000 kN and oscillating top plates, placed at itt Performance - Instituto Tecnológico em Desempenho e Construção Civil, within University of Vale do Rio dos Sinos (UNISINOS). The dimensions of the specimens were determined with a digital caliper before the destructive tests.

Dynamic Modulus of Elasticity (E_d)

Besides the determination of the specimens' fc, the ultrasonic wave propagation velocity was determined in step 2 by means of the instrumentation required by ABNT NBR 8802 (2019), to detect the difference in homogeneity between specimens, as some of them were produced with intentional errors. The direct transmission method was applied, in which the transducers are placed on the faces opposite to the specimen. As per ASTM C597 (2016), concrete is classified according to **¡Error! No se encuentra el origen de la referencia.**.

Table 4. Classification of concrete with regards to ultrasonic pulse. Source: elaborated by the authors.

Pulse velocity (m/s)	Concrete compactness
v ≥ 4.500	Very good
3.500 – 4.500	Good
3.000 – 3.500	Fair
2.000 – 3.000	Poor
v < 2000	Very poor

Results and Discussion

Compressive Strength (fc)of Specimens with Different Surface Treatments (Stage 1)

¡Error! No se encuentra el origen de la referencia. depicts the results for the potential compressive strength tests performed on the specimens of each of the five different surface treatments at 7 and 28 days, and Table 5 complements with the result of every specimen and the standard deviation.

Figure 2. Potential compressive strength at 7 and 28 days. Source: elaborated by the authors.

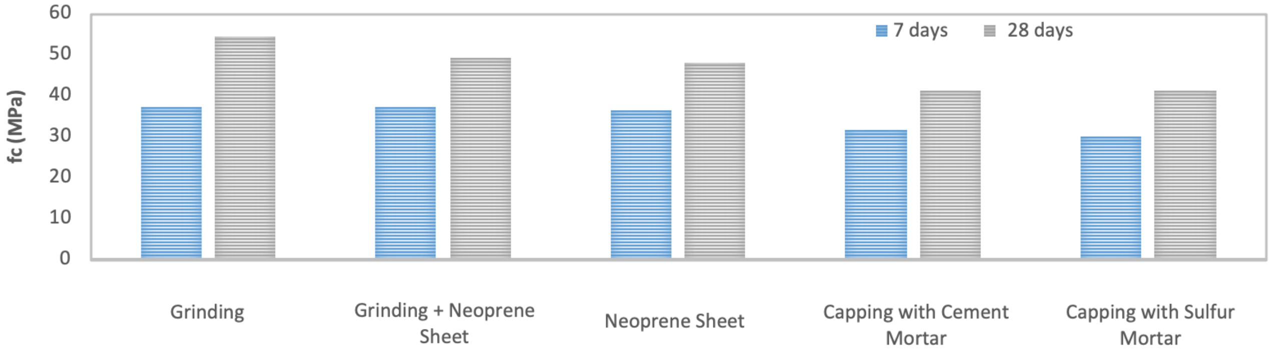


Table 5. Results for fc of specimens at 7 and 28 days. Source: elaborated by the authors.

Type of surface treatment	Age (days)	Average fc(MPa)	Potential fc (MPa)	Standard deviation (MPa)
RET	7	36.9	37.1	0.2
	28	52.1	54.4	1.7
RET+CAAE	7	37.0	37.4	0.4
	28	47.6	49.3	2.2
CAAE	7	36.3	36.4	0.1
	28	47.1	48.0	1
CAPAC	7	29.7	31.7	2.1
	28	41.2	41.4	0.2
CAPAE	7	29.9	30.0	0.1
	28	40.3	41.2	0.9

Hence, the 7-day specimens that underwent the process of grinding and were tested without and with capping with neoprenesheet attained potential compressive strength of 37.1 MPa and 37.4 MPa respectively. On the other hand, thetest specimens that were only capped with neoprenesheetachieved potential compressive strength of 36.4 MPa, which is slightly lower than the previous values. The standard deviation of these three types of treatment was low, meaning that the specimens and their surfaces were homogeneous with each other. Furthermore, at 28 days the grindingspecimens kept their tendency to yield higher compressive strength than the others' and low standard deviation, just like Souza & Bastos (2017) and Chies, Rohden & Filho (2014) had reported. This was due to this technique not relying on other materials and their strengths, what would increase the variables that influence the compressive strength of concrete specimens. By capping specimens with neoprenesheet, considering both grinding and not grinding, there was a decrease of about 7% in potential compressive strength for specimens that were only grinding. The specimens that were grindingand capped with neoprenesheet presented standard deviation of 2.2 MPa, i.e., the highest deviation in this study. One of the reasons for that may be the way concrete damaged, which underwent fractures on the edges, as **¡Error! No se encuentra el origen de la referencia.**c shows.

Regarding specimens with capping, the 7-day potential compressive strength results were much lower, 31.7 for cement mortar and 40.0 MPa for sulfur mortar specifically. Therefore, a decrease of about 20% can be noted for the specimens' compressive strength in comparison with the ones that were grindingand capped with neoprenesheet. At 28 days, the specimens retained the worst results, with average compressive strength 22% lower than grindingspecimens. In both cases, the standard deviation was small, hinting that for higher loads both types of capping underwent a standard but ineffective performance.

The 7-day analysis showed that the use of cement mortar yielded results that were more heterogeneous than the other types of treatment, as the standard deviation for such specimens was 2.1 MPa. This can be explained by the slow strength growth of mortars. It should be noted, though, that the mortar capping remained undamaged after the test. At 28 days, capped specimens were broken in their extension, and capping was not the cause of this test result, as depicted in Figures 3d and 3e.

Figure 3. Test specimens with different surface treatments. Source: elaborated by the authors.

(a) Grinding

(b) Grinding + Capping with Neoprenesheet

(c) Capping with Neoprenesheet

(d)Capping with Cement Mortar

(e) Capping with Sulfur Mortar

Compressive Strength of Specimens with Casting Errors and Dynamic Modulus (Stage 2)

¡Error! No se encuentra el origen de la referencia.shows the results for average compressive strength of specimens tested at 7 and 28 days, while Table 6 presents the average and potential strength results and their standard deviation. The potential compressive strength represents the highest strength value among the specimens tested for each cast.

Figure 4. Compressive strength at 7 and 28 days. Source: elaborated by the authors.

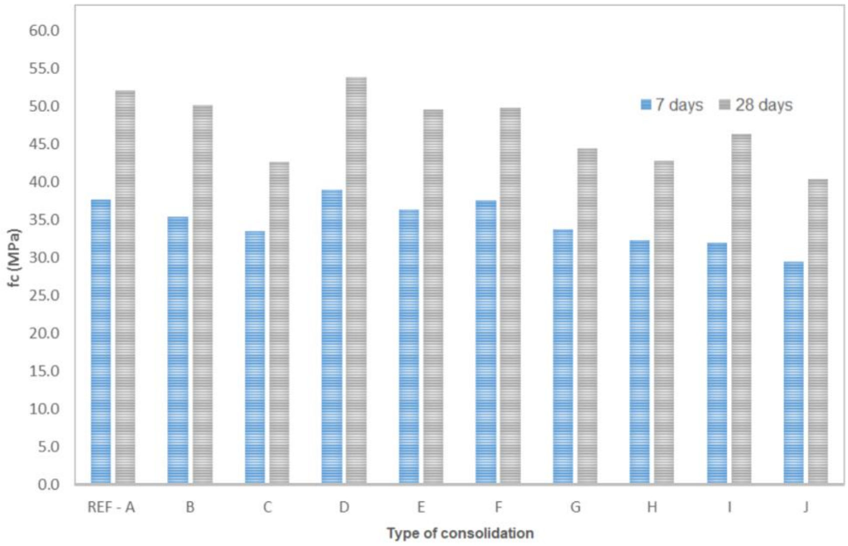


Table 6. Compressive strength at 7 and 28 days. Source: elaborated by the authors.

ID	Age (days)	Average fc (MPa)	Potential fc (MPa)	Standard deviation (MPa)
A –Reference	7	37.6	39.1	1.1
	28	52.1	54.4	1.7
B	7	35.5	36.2	0.7
	28	50.1	50.9	0.8
C	7	33.6	35.0	1.1
	28	42.7	43.9	0.8
D	7	39.0	40.7	1.3
	28	53.9	55.2	0.9
E	7	36.4	37.5	1.1
	28	49.6	51.1	1.1
F	7	37.5	37.6	0.0
	28	49.8	50.5	0.5
G	7	33.8	36.0	2.4
	28	44.5	45.2	0.5
H	7	32.3	34.1	1.8
	28	42.8	43.9	1.3
I	7	32.0	32.3	0.3
	28	46.4	49.3	2.5
J	7	29.5	31.0	1.2
	28	40.5	43.3	3.4

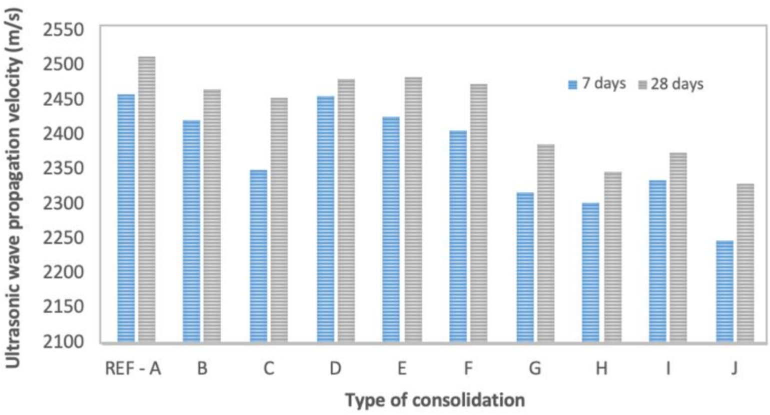
Analyzing the 7-day results, the specimens named REF-A reached average compressive strength of 37.6 MPa. Then again, specimens that were produced in the same way but remaineduncovered in the initial curing (D) attained higher average strength than the reference, with average compressive strength of 39.0 MPa. Moreover, the specimens produced in conformity with the current standard, but consolidated with a metal bar (F), presented results like the reference. Nevertheless, the casting with the intentional error of touching the bottom of the cylinder formwork during consolidation (E) was able to affect the average compressive strength as it presented results slightly lower than the previous ones. This result agrees with item 7.4.2.2 of ABNT NBR 5738 (2015), according to which one must avoid hitting the bottom of the cylinder molds during consolidation. The 28-day analysis reveals that the specimens produced under standardized procedures in metal cylinder formworks (REF-A) maintained the best results, since the specimens that remained uncovered during the initial curing (D) presented the best result of 53.9 MPa. The specimens that were consolidated with 2 layers of 12 blows tend to yield smaller standard deviation, showing that this type of castingbrings more homogeneity to the specimen. The consolidation performed with the 16mm diameter steel bar (F) yielded the smallest standard deviation for both 7 and 28 days, indicating that this type of casting performed similarly to the standard rod.

The 7-day result forcasting with only one layer (B) was lower than the reference. This behavior was also identified by Namoulniara, Mahieux, Lux, Aït-Mokhtar, & Turcry (2019). The specimens that were consolidated with 12 blows presented average compressive strength greater than the specimens that were not consolidated (C), with respective values of 35.5 MPa and 33.6 MPa. At 28 days, the specimens that were produced with a single layer with consolidation showed results like those of the specimens that were produced in two layers but with no consolidation, with a decrease of 18% of strength compared to the reference.This study thereby showed that the use of PVC cylinder formworks does not supply favorable results for average compressive strength. Considering specimens produced with 2 layers of 12 blows, the 28-day results for PVC cylinder formworks were 17% lower than those of PVC metal cylinder formworks, owing to the fact that the metal cylinder formwork does not lose as much temperature as the PVC cylinder formwork, meaning that it conserves the internal temperature of concrete, accelerating cement hydration processes.

As expected, due to the lack of consolidation and the high susceptibility to problems, the results for specimens that were produced in 100x120 mm tubes were not satisfactory, since they comprised a long layer of 120 mm that remained unconsolidated, whose potential compressive strength underwent up to 20% of variation. At 28 days, the specimens produced in 100x200 mm PVC cylinder formworks (H) maintained the worst results as their average compressive strength was between 10% and 22% lower than that of specimens produced in metal cylinder formworks. The specimens that were produced in 100x120 mm PVC cylinder formworks and cured horizontally presented standard deviation of 9-0=3.4 MPa, namely, the highest standard deviation in this study. One of the possible causes regards the stress that the specimens bear when being sawed and by the direction that curing takes place, which is different from that of casting.

To better understand the results, the dynamic modulus test was performed. Figure 5 shows the results for ultrasonic wave propagation velocity at 7 and 28 days.

Figure 5. Ultrasonic wave propagation velocity at 7 and 28 days. Source: elaborated by the authors.



The ultrasonic wave propagation velocity followed along the compressive strength values, displaying high values for specimens whose consolidation was performed in 2 layers with 12 blows in metal cylinder formwork. These test results remained between 2250 and 2500 m/s approximately, meaning that the specimens have poor compactness as per ASTM C597 (2016). Comparing the different types of consolidation, the propagation velocity decreases for specimens that were not consolidated according to ABNT NBR 5738 (2015), thereby showing consistence with regards to the procedures described by this standard.

Conclusions

In Stage 1, the specimens that were only grindingstood out because this type of treatment yielded the highest strength at both 7 and 28 days. Specimens that were grindingand capped with neoprenesheet also had a noteworthy performance at the shorter age, considering that their strength was practically the same as that of specimens that were only grinding. Once the specimens have been grinding, though, they render the use of capping with neoprenesheet unnecessary as it would only generate more costs to the laboratory that is going to perform the tests. However, when no specimen grinding machine is available, capping with neoprenesheet becomes a viable solution, despite yielding lower compressive strength values than surface grinding. Sulfur and mortar capping are not recommended, since the compressive strength results are about 80% of the average value yielded by grindingspecimens. Besides, the use of sulfur is hazardous to the users and the environment. Capping with mortar has a disadvantage with regards to its curing time, as it may take around 48 hours to cap both top and bottom surfaces. The results of this study were similar with those of Chies, Rohden & Filho (2014) and Souza and Bastos (2017), according to which grinding the edges of the specimen is the most adequate type of surface treatment as it attains higher strength than the others and low standard deviation. The test results for capping with neoprenesheet presented higher standard deviation, demonstrating that this surface regularization method is less reliable, as noticed by Silva et al. (2017).

Stage 2 revolved around the analysis of compressive strength and ultrasonic wave propagation velocity and demonstrated noteworthy results for the specimenthat wasproduced in metal cylinder formworks under ABNT NBR 5738 (2015) with 2 layers of 12 blows each,which was covered during the initial curing, because this configuration attained the highest potential and average strengths at both 7 and 28 days. Even though specimens that remained uncovered during the initial curing displayed higher strength than the reference, this procedure is not recommended because it can cause loss of water during curing and hinder cement hydration and strength evolution. Casting with a single layer, with and without consolidation, should be avoided too as it may incur a strength loss of approximately 20%. It is not recommended to use PVC cylinder formworks either, as the compressive strength results turned out to be around 80% of the average value of the reference specimens.

Therefore, it can be stated that process of casting and curing specimens mustcomply with the Brazilian current standard, whereas grinding is the most adequate surface treatment method to maximize compressive strength.

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References

ABNT NBR 5738. (2015). *Concreto - Procedimento para moldagem e cura de corpos de prova*. Associação Brasileira de Normas Técnicas (ABNT).

ABNT NBR 5739. (2018). *Concreto - Ensaios de compressão de corpos de prova cilíndricos.*. Associação Brasileira de Normas Técnicas (ABNT).

ABNT NBR 8802. (2019). *Concreto endurecido – Determinação da velocidade de propagação de onda ultrassônica*. Associação Brasileira de Normas Técnicas (ABNT).

ABNT NBR 8953. *Concreto para fins estruturais – Classificação pela massa específica, por grupos de resistência e consistência*. Associação Brasileira de Normas Técnicas (ABNT).

Araújo, S. da S., Guimarães, G. N., &Geyer, A. L. B. (2016). Influência do tipo de concreto, da dimensão do corpo de prova e do tipo de laboratório na determinação da resistência à compressão do concreto. *Revista Engenharia Civil Universidade do Minho*, *52*, 5-22. Retrieved from: <http://www.civil.uminho.pt/revista/artigos/n52/pag.05-22.pdf>. 2016.

ASTM C1231/C1231M (2010). *Standard practice for use of unbonded caps in determination of compressive strength of hardened concrete cylinders*. American Society for Testing and Materials (ASTM).

ASTM C597. (2016). *Standard test method for pulse velocity through concrete*. American Society for Testing and Materials (ASTM).

Bezerra, A. C. da S.,Aguilar, M. T. P., & Cetlin, P. R. (2008). Influência do capeamento nos resultados do ensaio de resistênc ia à compressão em concretos. In: *50ºCongresso Brasileiro do Concreto*. Salvador, Bahia/Brazil: IBRACON.

Bezerra, U. T., Alves, S. M. S., Barbosa, N. P., & Torres, S. M. (2016). Hourglass-shaped specimen: compressive strength of concrete and mortar (numerical and experimental analyses). *Revista IBRACON de Estruturas e* Materiais, *9*(4), 510-524. doi: doi.org/10.1590/S1983-41952016000400003

Boesing, R., Philippsen, R. A., & da Luz, C. A. (2010). Influência do material de capeamento na resistência à compressão dos corpos de prova de concreto e argamassas: comparação entre enxofre, pasta de cimento e pasta de gesso.In: *13º Encontro Nacional de Tecnologia do Ambiente Construído.* Canela, Rio Grande do Sul/Brazil: ANTAC.

Chies, J. A., Rohden, A. B.,&Filho, L. C. P. S. (2014). Tratamentos superficiais em corpos de prova de concreto submetidos à compressão. *Revista IBRACON de Estruturas e Materiais*, *7*(5), 775-800. doi: https://doi.org/10.1590/S1983-41952014000500004.

Couto, D., Carvalho, M., Cintra, A., & Helene, P. (2015). Concrete structures: Contribution of the safety assessment of existing structures. *Revista IBRACON de Estruturas e Materiais*, *8*(3), 365-389. doi: https://doi.org/10.1590/S1983-41952015000300007

Ehrenbring, H. Z., Quinino, U., Oliveira, L.S.,& Tutikian, B. F. (2019). Experimental method for investigating the impact of the addition of polymer fibers on drying shrinkage and cracking of concrete. *Struct. Concr., 20*, 1064–1075. doi:10.1002/suco.201800228.

Fernandes, B., Gil, A.M., Bolina, F.L.,& Tutikian, B.F. (2018). Thermal damage evaluation of full scale concrete columns exposed to high temperatures using scanning electron microscopy and X-ray diffraction. *DYNA (Medellín), 85*, 123–128.

Gil, A., Pacheco, F. Christ, R. Bolina, F.L. Khayat, K. H., & Tutikian, B.F. (2017). Comparative study of concrete panels' fire resistance. *Aci. Mater. J., 114*, 755–762.

Gupta, S.L. (2018). Comparison of Non-Destructive and Destructive Testing on Concrete : A Review. *Trends in Civil Engineering and its Architecture, 3*(1), 351–357. doi: http://dx.doi.org/10.32474/TCEIA.2018.03.000154

Helene, P. (2011). Análise da resistência à compressão do concreto em estruturas acabadas com vistas à revisão da segurança estrutural. *Revista ALCONPAT*, *1*(1), 64-89. doi: https://doi.org/10.21041/ra.v1i1.7

Indelicato, F., & Paggi, M. (2008). Specimen shape and the problem of contact in the assessment of concrete compressive strength. *Materials and Structures, 41*(2), 431-441. doi: 10.1617/s11527-007-9256-7

Mazepa, R. C., & Rodrigues, T. de C. (2011). *Estudo comparativo entre corpos de prova cilíndrico e cúbico para o ensaio de resistência a compressão axial.* (Master's Dissertation, Universidade Tecnológica Federal do Paraná, Curitiba). Retrieved from http://repositorio.roca.utfpr.edu.br/jspui/handle/1/1401

Moreno, E. I., Solís-Carcaño, R. G., Varela-Rivera, J., & López, M. A. G.(2016). Resistencia a tensión del concreto elaborado com agregado calizo de alta absorción. *Concreto y cimento. Investigación y desarrollo*, *8*(1), 35-45. Retrieved from http://www.scielo.org.mx/scielo.php?script=sci_abstract&pid=S2007-30112016000200035&lng=es&nrm=iso&tlng=pt

Nalon, G.H., Lima, G. E. S., Martins, R. O. G., & Alvarenga, R. de C. S. S.(2016). Efeito da forma e do tamanho de corpos de prova na determinação da resistência à compressão e deformabilidade de argamassas mistas de cal e cimento.In: *22^o Congresso Brasileiro de Engenharia e Ciência dos Materiais.* (p. 1316-1324). Natal, Rio Grande do Norte/Brazil.

Namoulniara, K., Mahieux, P. Y., Lux, J., Aït-Mokhtar, A., & Turcry, P. (2019). Efficiency of water repellent surface treatment: Experiments on low performance concrete and numerical investigation with pore network model. *Construction and Building Materials, 227*(10). doi: https://doi.org/10.1016/j.conbuildmat.2019.08.019

Neto, I. R. V., Vasconcelos, N. R., & Albuquerque, G. L. A. (2017). Controle tecnológico de elementos estruturais: um estudo de caso de um edifício em sobral. In: *Congresso Técnico Científico da Engenharia e da Agronomia*. Belém, Pará/Brazil.

Neville, A. M., & Brooks, J. (2013). *Concrete Technology*. 3th. Canada: Building and Environment.

NP EN 12390. (2009). *Ensaios do betão endurecido - Parte 3: Resistência à compressão de provetes*. Norma Portuguesa (NP).

Oliveira Júnior, A. L., Pedroti, L.G., & Fernandes, W. E. H. (2018). Propagação de erros e incertezas em experimentos envolvendo propriedades mecânicas de um concreto ecológico reforçado com fibras de garrafa PET. In:*23^{o}Congresso Brasileiro de Engenharia e Ciência dos Materiais* (p. 2670-2685). Foz do Iguaçu, Paraná/Brazil.

Pacheco, F., Souza, R., Christ, R., Rocha, C., Silva, L., &Tutikian, B. (2018). Determination of volume and distribution of pores of concretes according to different exposure classes through 3D microtomography and mercury intrusion porosimetry. *Structural Concrete*, 1-9. doi: 10.1002/suco.201800075

Pan, X., Shi, Z., Shi, C., Ling, T., & Li, N. (2017a). A review on surface treatment for concrete – Part 1: Types and mechanisms. *Construction and Building Materials*, *132*(1), 578-590. doi: doi.org/10.1016/j.conbuildmat.2016.12.025

Pan, X., Shi, Z., Shi, C., Ling, T., & Li, N. (2017b). A review on surface treatment for concrete – Part 2: Performance. *Construction and Building Materials*, *133*(15), 81-90. doi: https://doi.org/10.1016/j.conbuildmat.2016.11.128

Silva, J. R. B., Mendonça, G., Modesto, M. A., & Agra, T. M. S 2017). Análise comparativa entre os métodos de correção de topo de corpos de prova: neoprene, enxofre e retifica. In *59º Congresso Brasileiro do Concreto.* Bento Gonçalves, Rio Grande do Sul/Brazil: IBRACON.

Silva, B. do V., & Filho, L.C.P.S. (2011). Análise da influência da regularização dos topos de corpos -de-prova cilíndricos sobre a resistência à compressão do concreto. In: *53^{o}Congresso Brasileiro do Concreto*. Florianópolis, Santa Catarina/Brazil: IBRACON.

Silva, M. J., Ricceli, R., Ponciano, B., Haltiery, D., Peixoto, R., & Bezerra, A. (2011). Influência de dois tipos de capeamento de corpos de prova de concreto. In:*53^{o}Congresso Brasileiro do Concreto.* Florianópolis, Santa Catarina/Brazil: IBRACON.

Sousa, G. G. (2006). *Influência dos procedimentos de ensaio à compressão de corpos-de-prova cilíndricos no controle de qualidade do concreto.* (Master's Thesis, Universidade Federal de Santa Catarina, Florianópolis). Retrieved from http://repositorio.ufsc.br/xmlui/handle/123456789/88935

Souza, P. T., & Bastos, P.S.S. (2017). Capeamento de corpos de prova cilíndricos de concreto com placas de HDF não aderentes. In: *59^o Congresso Brasileiro do Concreto*. Bento Gonçalves, Rio Grande do Sul/Brazil:IBRACON.

Tam, T., Daneti, S.B., & Li, W. (2017). EN 206 conformity testing for concrete strength in compression. *Procedia Engineering*, *171*, 227-237. doi: https://doi.org/10.1016/j.proeng.2017.01.330

Thandavamoorthy, T. S. (2015). Determination of concrete compressive strength : A novel approach. *Advances in Applied Science Research*, *6*(10), 88–96. Retrieved from https://go.aws/34vyBwP

Tunç, E. T. (2018). Strength Properties of Hardened Concrete Produced with Natural Aggregates for Different Water / Cement Ratios. *Avrupa Bilim ve Teknoloji Dergisi*, *14*, 280–287. doi: https://doi.org/10.31590/ejosat.486093