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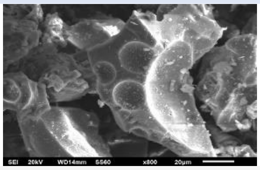

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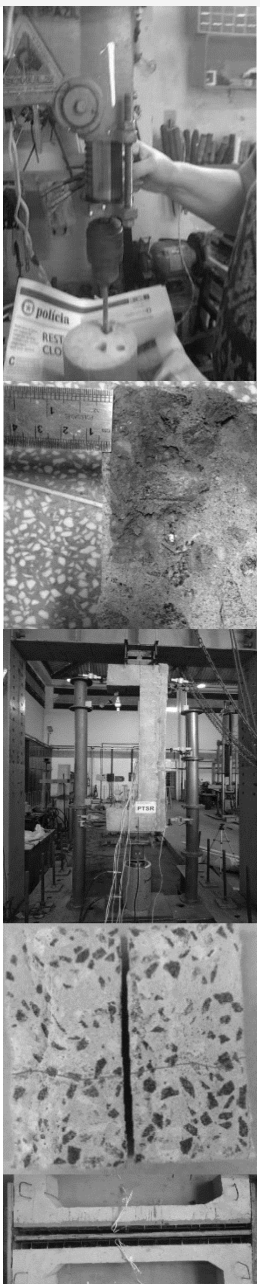

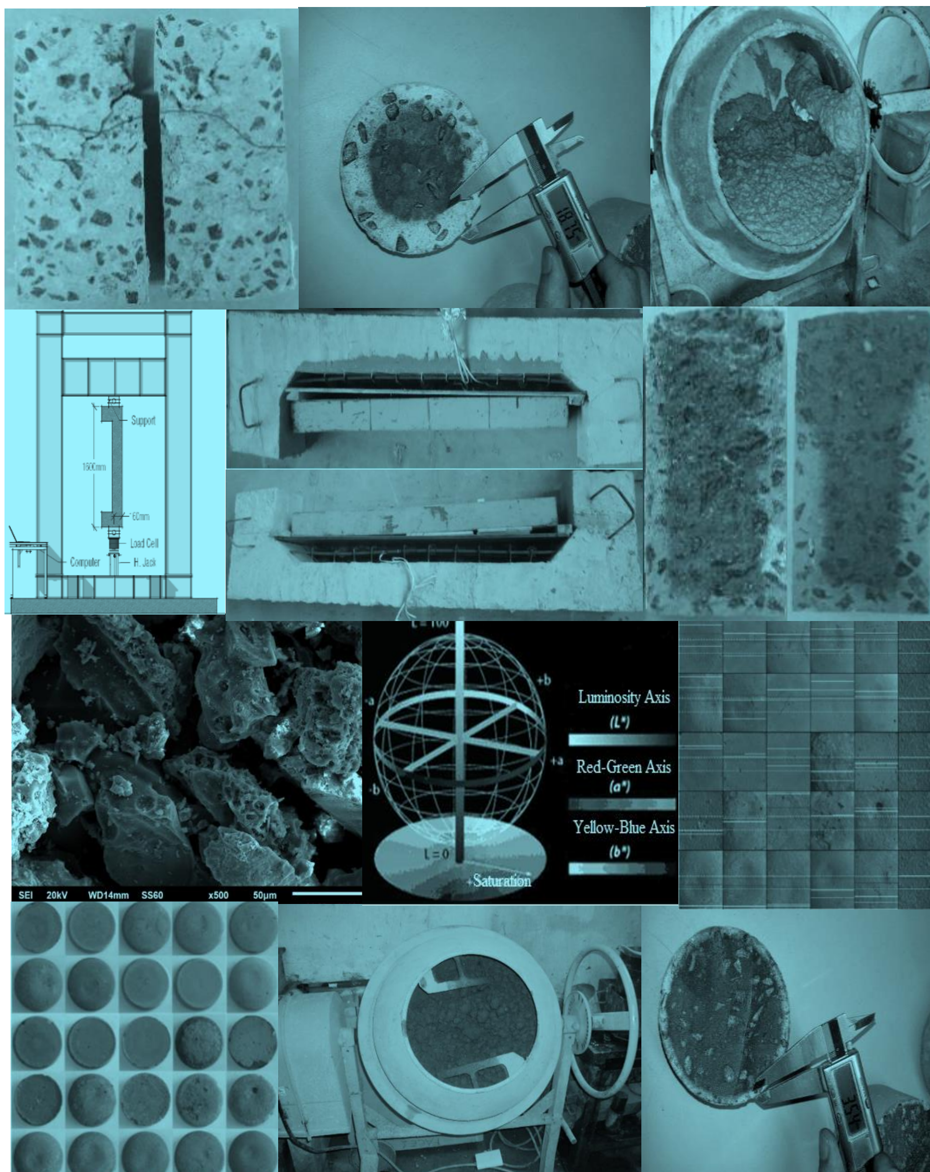

Latin American Journal of Quality Control, Pathology and Construction Recovery

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RAV8N2, May - August 2018

Message from the Editor in Chief

JOURNAL OF THE LATIN-AMERICAN ASSOCIATION OF QUALITY CONTROL, PATHOLOGY AND RECOVERY OF CONSTRUCTION

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With great satisfaction, we present the second issue of the 8th year of the ALCONPAT journal.

The aim of the journal is to publish case studies, quotable production (basic and applied research, reviews) and documentary research, related to the themes of our association, namely quality control, pathology and recovery of constructions.

The V8 N2 issue begins with a research from **Brazil**, in which Romildo Berenguer et al purpose to analyze, through chemical tests, the quantity of chloride ions in concretes made from different traces (proportions of materials) in their depths. Laboratory tests were performed, and test samples were made partially immersed in seawater, according to standards and the Mohr method. The results confirmed that the penetration percentage of chloride ions is less for the rich trace, when compared with the other test samples studied. Accordingly, it is concluded that the stronger the concrete, the greater the resistance to chloride ion penetration. These results were expected, since the concrete with greatest strength and made from the same materials tends to hinder the entry of these ions.

The second paper comes from **Brazil,** where Carina Ferreira et al verify the compatibility of an existing predictive model of life with the penetration of chlorides in exposed concrete elements in the city of Pelotas / RS. To this end, the samples were exposed at different locations in the city for a period of 16 months and silver nitrate solution was applied to determine the depth of the chlorides. The Bob model (1996) was used for comparison and analysis of the results. Significant values of chloride were found in the elements together with a great potential of the model applied when describing the behavior of the depth of chlorides over time, despite the differences found.

In the third paper from **Brazil,** Rosana Schmalz et al studied the influence of nanosilica dispersed on superplasticizer, and its combined effect with silica fume, on different concrete properties. Compressive strength, tensile strength by diametrical compression and water absorption by capillarity tests, as well as accelerated durability tests against chloride ions were carried out. Results indicated that isolated nanosilica addition (0.1 to 0.5%) did not improve concretes in any tests performed. However, for 0.5 and 0.7% content of nanosilica combined with 10% of silica fume, there was an increase in compressive strength, reduction of capillary absorption and reduction of chlorides penetration.

In the fourth paper, Denio R. C. de Oliveira et al, from **Brazil,** investigated **t**he behavior of six uniaxial compression columns. Specimen featured an initial section of (120 x 200) mm^2, a final section of (200 x 200) mm^2 and height of 1.600 mm, strengthened on the tensile and compression sides with plaster or not. Adherence between new and old concrete, and cracking pattern was satisfactory. Although coated columns showed the same behavior to their respective non-coated ones even when concrete area was reduced by approximately 20%, problems consisted in the crushing of the reinforced concrete layer immediately prior to the rupture of the columns. This strengthening proved to be more adequate when undertaken at the columns´ compressed zone and may be executed through conventional procedures with or without mortar coating layer.

The fifth work of this number was written by Wilfrido Martínez et al from **México.** Their objective was to quantify the colorimetric values of clay with different types of additives. Aesthetic appreciation, based on the color of clay with different addition percentages (by clay mass), is explored using clay from the Santiago Undameo Bank, Mexico. The clay was kaolinite, and the additions were gypsum, lime, opuntia cactus mucilage, Portland cement, and sodium hydroxide. The addition percentages were 2%, 4%, 6%, 8% and 10%. The best colorimetric performances were obtained from Portland cement at 6%, sodium hydroxide at 4%, lime and gypsum at 8% and opuntia cactus mucilage at 4% and 8%. Some buildings where these clay materials were used are Casas grandes in Paquimé, Chihuahua, La Venta in Tabasco, and Yácatas in Tzintzuntzan, among others.

In the sixth work, from **Brazil,** Romildo Berenguer et al discuss the effect of air entrainment on the mechanical behavior and durability of molded concrete elements. The experiment was carried out using samples with 4 different masses (1500 kg/m^3, 1700 kg/m^3, 2000 kg/m^3, and 2300 kg/m^3) and 3 water/cement ratios (0.63-1:5, 0.50-1:4, 0.43-1:3) that were tested to determine compressive strength, water absorption, void index, and carbonation depth. The results showed significant decreases in performance and in the protection indicators of the reinforcement (water absorption and carbonation), confirming the need for additional mitigation for the structure (protective paints, stainless steel bars), under penalty of premature loss of durability over its lifetime.

In the seventh work, from **Mexico,** José Manuel Mendoza Rangel et al studied the influence of sugar cane bagasse ash (SCBA) as a partial substitution of Compound Portland Cement (PCC) to enhance the properties of a granular sand soil. AASHTO standard compaction test, unconfined compressive strength test, and CBR test were made. It has been compared the behavior of natural soil in study and mix with percentages of 3%, 5% and 7% of PCC as a control percentage, being carried out partial substitutions of PCC by SCBA in 0%, 25%, 50% and 100% percentages with respect to dry soil weight. The results showed enhances in the compacting, CBR and unconfined compressive strength features, reducing up to 25% the consumption of PCC.

The article that closes the edition is from Eduardo L. Machado et al from **Brazil.** Their study aimed to identify whether the use of a BIM platform software associated with the AHP decision-making method can assist in the decision-making process during the design phase of projects. Three construction systems were analyzed: Load-bearing masonry, Light Steel Framing and Light Wood Framing. BIM modeling enabled scenario simulations and facilitated the extraction of data, which, in turn, assisted experts in the selection of the most appropriate constructive system, considering the established criteria. The originality of this research lies on the consideration of several factors relevant to constructive system choice. The limitation lies in modeling only the walls of the analyzed constructive systems, and not of the complete building.

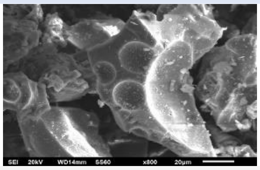
This second issue opens with the news that RA has met the quality requirements for its incorporation into Scopus and JCR. Therefore, at the beginning of the year, the corresponding application was made. We will be in evaluation for 1 - 4 years, after which I am sure we will be incorporated. Now, it is essential to meet and continue to meet the quality parameters, some of them being punctual in the publication, and in the three complete languages.

We are confident that the articles in this issue will be an important reference for those readers involved with issues of chloride, modeling applications and service life, as well as inspections with modern and / or improved methodologies. We thank the authors participating in this issue for their willingness and effort to present quality articles and meet the established times.

For the Editorial Board

Pedro Castro Borges
Editor in Chief

Revista ALCONPAT



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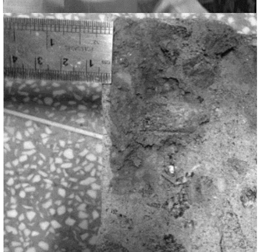

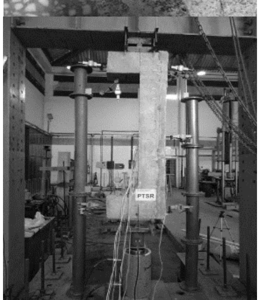

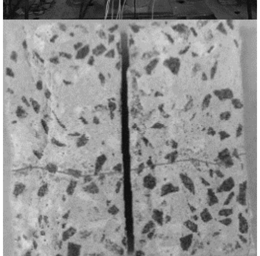

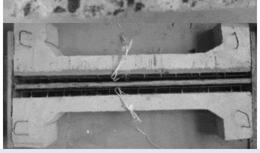

CONTENT

APPLIED RESEARCH

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Verifying chloride penetration in concrete test samples partially immersed in seawater in Recife, Pernambuco

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ABSTRACT
The objective of this research is to analyze, through chemical tests, the quantity of chloride ions in concretes made from different traces (proportions of materials) in their depths. Laboratory tests were performed and test samples were made partially immersed in seawater, according to standards and the Mohr method. The results confirmed that the penetration percentage of chloride ions is less for the rich trace, when comparted to the other test samples studied. Accordingly, it is concluded that the stronger the concrete, the greater the resistance to chloride ion penetration. These results are to be expected, because the concrete with greatest strength and made from the same materials tends to hinder the entry of these ions.
Keywords: chloride ions; Mohr method; seawater.

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Any dispute, including the replies of the authors, will be published in the first issue of 2019 provided that the information is received before the closing of the third issue of 2018.

Verificação de penetração de cloretos em corpos de prova parcialmente imersos em água do mar em Recife, Pernambuco

RESUMO

A pesquisa objetivou analisar através de ensaios químicos, o quantitativo de íons cloretos em concretos de diferentes traços (proporção de materiais), em suas profundidades. Para tanto, foram realizados ensaios em laboratórios, sendo confeccionados corpos de prova com a parcial imersão em água do mar de acordo com as normas e método de Mohr. Com os resultados verificou-se que o percentual de penetração de íons cloreto é menor para o traço rico, em relação aos demais. Sendo assim, conclui-se que quanto maior a resistência do concreto, maior será a resistência à penetração de íons cloretos, porém estes resultados são esperados, pois o concreto com maior resistência e mesmos materiais tende a dificultar a entrada desses íons.

Palavras-chave: iones de cloruro; método de Mohr; agua do mar.

Verificación de penetración de cloruros en cuerpos de prueba parcialmente sumergidos en agua de mar en Recife, Pernambuco

RESUMEN

El objetivo de esta investigación es analizar a través de ensayos químicos, la cantidad de iones cloruros en concretos de diferentes trazos (proporciones de materiales) en sus profundidades. Para ello, se realizaron ensayos en laboratorios, siendo fabricadas probetas con inmersión parcial en agua de mar según las normas y el método de Mohr. Con los resultados se verificó que el porcentaje de penetración de iones cloruro es menor para el trazo rico, en relación con las demás probetas estudiadas. Siendo así, se concluye que cuanto mayor sea la resistencia del concreto, mayor será la resistencia a la penetración de los iones cloruros, sin embargo, estos resultados son esperados, pues el concreto con mayor resistencia y mismos materiales tiende a dificultar la entrada de estos iones.

Palabras clave: iones de cloruro; método de Mohr; agua de mar.

1. INTRODUCTION

Since the beginning of the twentieth century, records show that reinforced concrete has been used in Brazil, but the use of concrete as a standard building material took off in the 1950s. This happened due the industrial revolution that brought modified techniques and new materials.

According to Mehta and Monteiro (2014), concrete is only surpassed by water as the most consumed material on the planet. Due to its strength and versatility, concrete has played a major role in construction, and has been widely used by architects, due to the wide variety of possible formats, the aesthetic appreciation of structures and uses, and its ability be molded to the limit of creativity, especially when used uncoated.

With the passage of time, many constructions have been degraded by diverse pathological manifestations that may even lead to collapse. Therefore, there is a great need for research studies on the subject.

Among the principal pathological manifestations that attack reinforced concrete are the actions of heat and cold, climate and humidity, alkali/aggregate reactions, chemical aggression, corrosion by carbonatation and/or chlorides (Cascudo et al., 2014).

The penetration of chloride ions affects the constructions in coastal or seaside sites that have a high concentration of free chloride ions. They are considered to be the major cause of premature corrosion of structures (Verás Ribeiro et al, 2014 and Medeiros, 2014).
Brazil has a great amount of equipment and constructions that are in direct or semi-direct contact with the sea. Recife, the capital of Pernambuco, is one of the cities with the most urban facilities in contact with sea water. Buildings, bridges, anchorages, catwalks, in other words, projects where concrete structures are placed into a maritime environment: either submerged, partially submerged, or within the tidal zone, splash zone, or mist zone environments. Sea water contains high amounts of chloride ions and exposure to these makes these concrete structures more vulnerable (Pitan et al., 2015).
It is therefore necessary to research and build parameters and relationships that allow sustainable and economic decision making for projects that can increase the useful life of concrete structures.
This study aims to investigate with chemical tests the penetration of chlorides into specimens of different types of concrete (characterized as poor, medium, and rich) partially submerged in sea water. For this, the ISO TC 71/SC 1 will be used as a reference for the chloride penetration procedures and the Mohr method will be used as a reference for the laboratory chemical tests.

1.1 Marine environment
According to NBR 6118: 2014 the marine environment is recognized as aggressive to concrete structures, where it is considered to be in aggressiveness class IV. Its influence on the durability of concrete structures depends on the microclimate in which it is found (Cascudo et al., 2014). The aggressive agents present in the marine environment cause both the corrosion of the steel reinforcement and the corrosion of the concrete (cement matrix) (Lima and Morelli, 2004).
According to Andrade (2001) and Medeiros (2012), the penetration of chlorides into the concrete can happen in different ways, one of which is the incorporation of the chloride into the mass of the concrete, which has become less likely due to the limitations imposed by the current standards. Examples of other mechanisms that occur most frequently are capillary absorption and diffusion, which depend on external factors.
According to Verás Ribeiro (2014), capillary absorption is a mechanism where the chlorides present in a liquid medium penetrate into the concrete from the flow of the liquid, by the effect of surface tension acting on the capillary pores. According to Verás Ribeiro (2014) and Meira (2009), this mechanism depends on the pore diameter, the surface tension of the liquid, its density, and its viscosity.
Diffusion occurs because of chloride concentration gradients. Chlorides in higher concentration regions move to regions of lower concentration (Meira, 2009).
In the 2014 NBR 6118, attention can be drawn to a chapter on this subject, where classes of environmental aggressiveness for concrete constructions in urban and rural areas are identified as weak, moderate, strong, or very strong.
Such regulation also details the type of concrete to use as well as the specifications for the nominal covering to be adopted according to the component or element of reinforced or prestressed concrete. NBR 6118:2014 already recommends that the covering should be respected for construction projects including those with little or no control, since this is equal to the minimum covering necessary plus a tolerance factor.
Most of the constructions in direct contact with the marine environment begin to show pathological manifestations within a short time after construction, with significant decomposition of the concrete and intense corrosion of reinforcement (Verás Ribeiro, 2014). Sea water has high amounts of chloride ions. The classification between aggressive and non-aggressive environments is relative and refers mainly to the amount of H_2S, SO_2, NOx, SO_4, and Cl^- present (Helene, 1986).

For Medeiros (2014), these oxides are extremely aggressive and contribute to the acceleration of the process of corrosion of the embedded reinforcements, even in small proportions. As a reference, it is possible for the corrosion rate in a marine atmosphere to be on the order of 30 to 40 times higher than that of a pure rural atmosphere (Verás Ribeiro, (2014).
In cities that are subject to such saline exposure, constructions of concrete or reinforced concrete, whether in contact with sea water or not, always suffer pathological manifestations and mechanical degradation that require permanent maintenance (Cascudo et al., 2014).
Some projects locate concrete structures directly in the marine environment: submerged or partially-submerged in sea water, within the high or low tide zone, the atmosphere zone, the splash zone, or the mist zone (Cascudo et al., 2014).
Sea water is one of the elements of nature most damaging to concrete structures. In its composition, it is possible to find constituent elements of many chemical compounds.
According to Lima and Morelli (2005), oceanographers have identified the elements distributed in ocean waters, as well as their various states and components of chemical compounds. Some compounds are stable, such as those containing sodium and potassium; while others are relatively unstable, such as those containing silicon and magnesium. The magnitude of concentration can be divided into three groups:

- Major Inorganic Elements - Cl, Na, S, Mg, Ca, K - found in amounts greater than 100 parts per million (ppm), or 100 mg per liter (mg/L) equivalent to 10% by mass.
- Minor elements - Br, C, Sr, B, Si, F - found in amounts greater than 1 and less than 100 mg/L or 0.1% to 10%.
- Trace Elements - N, Li, Rb, P, I, Fe, Zn, Mb - found in amounts less than 0.1%).

The composition of sea water, which can vary according to temperature, latitude, depth, and proximity to land, has been researched over a long period of time. Dittmar, in 1870, after analyzing thousands of water samples from all seas, found that, despite varying amounts of salts dissolved, the proportions of the main elements were constant. Salinity varies from 3.3% to 3.7% in the open ocean; with the overall average salinity for all oceans being 3.5%.

1.2 The City of Recife and Contact with the Sea

Recife, the capital of the state of Pernambuco, is popularly known as the “Brazilian Venice” because of its buildings along rivers and by the sea, and its numerous bridges that dominate the urban landscape, being one of the cities with most urban equipment in contact with sea water. Fig. 1 shows a panoramic view of the municipality of Recife.

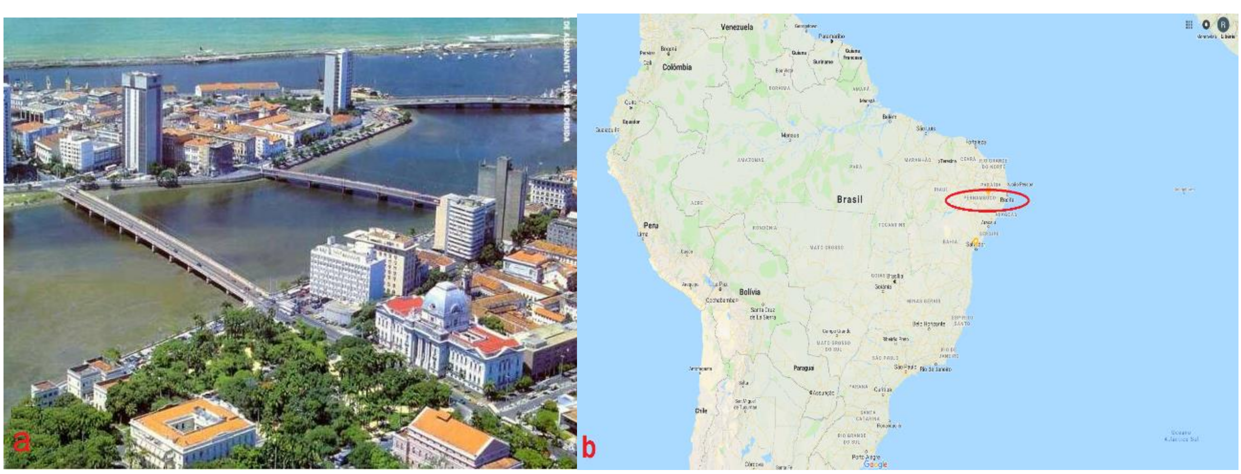

Figure 1. a) Panoramic view of Recife, PE. Source: Google Maps (2017) Available at: <http://embrasil.s3.amazonaws.com/upload/ciudad/81C-37.jpg >. Accessed on: 11/07/2017. b) Map of Brazil with location of Recife, Pernambuco highlighted.

Recife, because it is a coastal city, with a warm climate, high humidity, and predominance of the winds coming from the direction of the Atlantic Ocean, Recife's concrete structures suffer aggressions from agents of diverse types of pathological manifestations. According to NBR 6118: 2014, Lima and Morelli (2004), Verás Ribeiro (2014) and Medeiros (2014) classified and defined four zones of aggressiveness that fit well with what happens to the existing concrete structures in the city. These regions are:

- Marine atmosphere zone: in this region, despite not being in contact with sea water, the structure receives a considerable amount of salts, mainly chloride, that are able to produce salt deposits on its surface, in the form of solid particles or as drops of a saline solution. The quantity of salts present decreases as a function of the distance from the sea, being influenced by the speed and direction of the prevailing winds. The principal mechanism of degradation present in this zone is corrosion of the reinforcement by the action of the chloride ions.
- Splash zone: in this region, the structure received direct contact with the action of the sea, due to waves and their splashes. The most significant damages are produced by corrosion of reinforcement by chloride ions and by erosion due to the waves.
- Tidal variation zone: this region is bounded by the maximum and minimum levels reached by the tides and, because of this, the concrete is almost always saturated, depending on the climatic conditions and will have a growing concentration of salts. Degradation occurs due to the action of aggressive salts (chemical attack), corrosion of reinforcement (due to the presence of chloride ions), waves action, other substances in suspension (abrasion), and microorganisms.
- Submerged zone: the concrete in this region is permanently underwater. The degradation occurs by the action of aggressive salts (sulfate and magnesium ions) and by the action of microorganisms, which in extreme cases, can generate biological corrosion of the reinforcement.

1.3 Mohr method

The need to identify how the chlorides penetrate into reinforced concrete structures is necessary because of the subsequent corrosion that it provokes. Several methods have been developed for this, including the colorimetric silver nitrate spray method, which is a qualitative test to identify free chlorides in concrete, and the Mohr method, which is a laboratory test using titration, also with silver nitrate.

According to Mota (2011), the colorimetric silver nitrate spray method uses a methodology based on the application of a chemical indicator capable of altering the coloration of the concrete in the presence of chlorides. According to studies by Otsuki, Andrade, and Meck, this can vary based on factors such as cement type, water/cement ratio, and type of material used, as shown in Table 1.

This method was developed in 1970 by Dr. Mário Collepardi in order to verify the presence or absence of chlorides in concrete samples and, therefore, to be able to determine the penetration front of chlorides into the structures exposed to marine environments. This technique also contributed to the development of the process of fixation of free chlorides in the cement matrix (MOTA, 2011).

To carry out the MOHR method, the 5% K_2CrO_4 (potassium chromate) solution, which acts as an indicator, is used to stain samples yellow, and then a solution of 0.0141 M silver nitrate ($AgNO_3$) is used until the liquid sample obtains a "brick red" color in titration combining with the free ions in the concrete sample.

Table1. Summary of variables involved in the colorimetric silver nitrate spraying method.

Cement Type	Type of specimen	w/c	Chloride content limit for color change	Year	Country	Researcher
Common Portland Cement	Plaster Mortar Concrete	0.4 0.5 and 0.6	0.15%	1992	Japan	Otsuki et al.
Common Portland Cement and Portland Cement with additive	Concrete	0.4 and 0.7	1.13 to 1.4%	1999	Spain	Andrade et al.
Common Portland Cement and Portland Cement with additive	Concrete	-	0.90%	2003	Australia	Meck

Source: Mota (2011).

1.4 Standardization: ISO TC71/SC 1(26-07-2010) and ISO/WD 1920-11

According to this ISO, reinforced concrete structures exposed to chlorides, whether from marine waters or other sources, must meet the durability criteria for which they have been designed for the entire life of the project. The possibility of corrosion of the reinforcement increases significantly as the chloride content gradually accumulates inside these structures. For this reason, the degree of diffusion or penetrability of the concrete represents important properties to be evaluated, whereas these technical specifications establish a test method that can be applied to samples prepared for the evaluation of the potential properties of resistance to chloride that a given concrete mix will present.

For this reason, the degree of diffusion or penetrability of the concrete represent critically important properties to be evaluated. These technical specifications establish a test method that can be applied to prepared samples in order to evaluate the potential resistance to chloride that a given concrete mix will present.

These technical specifications represent a method for determining the unidirectional chloride penetration parameters in the non-continuous state in preconditioned hardened concrete specimens.

2. MATERIALS AND METHODS

This study aims to determine the quantitative penetration of chlorides in test bodies having different resistances at various depths. For this, tests were carried out at the laboratories of the Catholic University of Pernambuco. In the Materials Laboratory, the specimens were prepared using tests with partial immersion in sea water and with reference to ISO TC 71/SC 1 of 26/07/2010, ISO/WD 1920-1, and ISO TC 71/SC 1/WG SII NBR-9779. Then, the Mohr method was carried out in the Chemistry Laboratory.

To calculate the percentage of chloride absorbed by the samples, equation 1 below was used. Because the aggregate material is considered to be "inert", only the mass of the cement itself is taken into account. Only the chemical components present in the cement react with chlorides, especially the C_3A.

$$\frac{mg}{L} Cl^{-} = \frac{(V1 - V2) \times m \times mm \times 1000}{V_{amostra} \times \text{ dilution factor}} \quad (1)$$

Where:

- V1 = volume of $AgNO_3$ solution used to titrate the sample, in ml
- V2 = volume of $AgNO_3$ solution used to titrate the blank control, in ml
- m = molar concentration of the $AgNO_3$ solution
- mm = molar mass of Cl
- $V_{amostra}$ = sample volume = 0.10 ml
- Dilution factor = 1000/250 = 4

2.1 Characterization of materials utilized

- **Cement:** CP II-F-32 was used in this study, determined according to the ABNT of Portland Cement compound with filler (NBR 11578/91).
- **Coarse sand:** The fine aggregate used in this research is natural from a riverbed in the city of Pombos, Pernambuco. The sand was tested in the materials laboratory following the standards of granulometric characterization and distribution.
- **Gravel:** The coarse aggregate used was crushed stone of size 25 mm, grade 1 according to NBR 7211 (ABNT, 2009).
- **Potable water:** Water used was from COMPESA, the public water supply network of the city of Recife.
- **Seawater:** The seawater used was from the Boa Viagem beach, Recife, Pernambuco.

2.2 Molding the test specimens

Nine cylindrical concrete specimens (10x20 cm) were molded for three different mechanical strengths> low, medium, and high; with three specimens for each (See Table 2). After being removed from the mold, all specimens were submitted to wet curing for 14 days. One of each type remained in the wet curing until 28 days in order to maintain all types equal and to measure mechanical resistance.

The other six test specimens were divided in half, with their ends aligned and left in a dry environment for another 14 days, resulting in a total of 12 10x10 cm specimens. At 21 days they were waterproofed on all sides except for the top and bottom, as shown in Figure 2. At 28 days of age, they were submerged in fresh water, remaining there until 35 days, when they were removed and placed partially submerged in sea water with one of their ends on a fine bed of crushed stone for another 7 days, according to Figure 3. At 42 days, they were removed from the sea water, allowed to dry for 24 hours in the natural environment, and each identified by type of concrete and the division made.

Table 2 shows the unit ratio of the materials used in relation to the cement, by mass. The slump values were kept fixed at 160 ± 20 (mm), by varying the amount of dry materials.

Table 2. Concrete mixes (unitary)

Type	Ratio	Slump	w/c	Cement	sand	gravel	Average Resistance (MPa)
Poor	1:3	160 ± 20	0.516	1	1.6	1.40	26.67
Medium	1:2	160 ± 20	0.370	1	0.95	1.05	32.33
Rich	1:1	160 ± 20	0.259	1	0.3	0.70	40.87

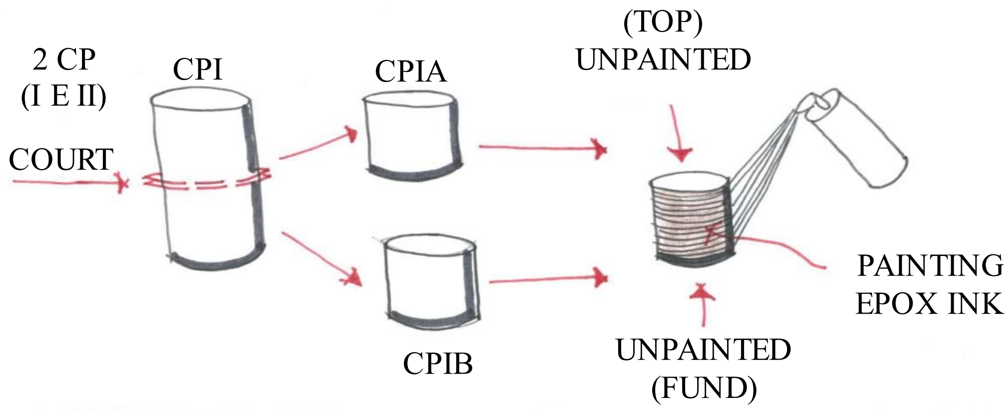

Figure 2. Cutting, naming, and painting the test specimens.

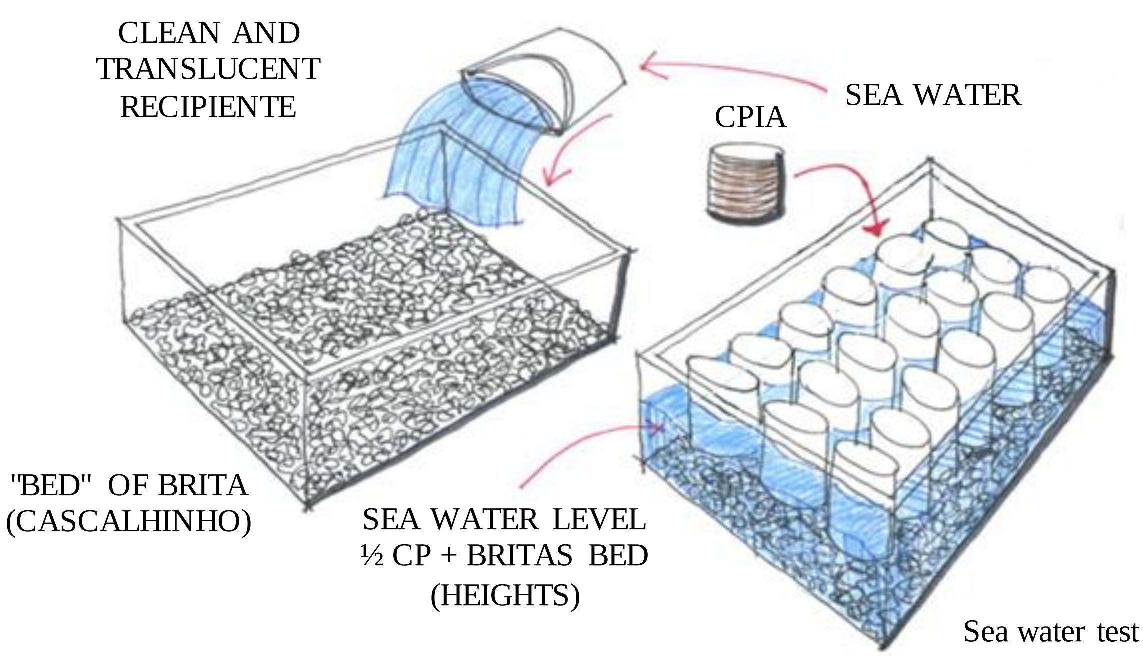

Figure 3. Seawater test (schematic design).

After completing these processes, holes were drilled in each test piece on the end that was in contact with sea water and were drilled from largest to smallest with depths of 1, 2, and 3 centimeters, respectively. An impact drill was used to make the holes, a ruler for measuring, a bench drill for greater precision and drill bits for concrete of gauges 14, 10, and 8 mm. From each hole, all material (powder) was collected and packaged in individual bags, named and numbered for identification when tested in the chemical laboratory (see Figure 4).

Figure 4. Drilling tests with fixed drill.

2.3 Performing the Mohr method

The second part of the study was carried out in the chemical laboratory at the Catholic University of Pernambuco, under the guidance of Professor Sérgio Paiva. The purpose of the tests was to use the Mohr method, titration by silver nitrate, to determine the amount of chloride ions that penetrated to the depths drilled in the specimens (1, 2, and 3 cm).

In Table 3, it can be seen that 45 samples were cataloged, 36 of the partially immersed specimens and 9 of the non-immersed specimens.

Table 3. Sample test specimens

Type	Ratio	Specimens (10x10)	Drill holes (3 p/ specimen)
Poor	1:3	4	12
Medium	1:2	4	12
Rich	1:1	4	12
Not submerged	-	3 (10x20)	9
Total Samples			45

Parts of 45 samples were placed in beakers, weighing 0.5 grams. After this, the drilled powder from each test specimen, parts A and B (two pieces of 10 x 10 cm), was placed in three flasks and numbered from 1 to 18, with a pipette of 50 ml distilled water, and stirred to mix.

Then this heavy "powder" was diluted with distilled water in a 250 ml volumetric flask. The contents of the volumetric flasks were left to rest for at least 24 hours and were then diluted with distilled water to 250 ml and shaken individually to homogenize them.

Of this 250 ml, three samples of 10 ml each were withdrawn and placed in flasks. In each of these samples, 1 ml of potassium chromate (K_2CrO_4, 5%, 99% pure) was placed, which worked as indicator and left a yellow coloration. After this, each sample was titrated with silver nitrate ($AgNO_3$ - 0.0141 mol/l, 97.8% pure) until reaching a red brick color. This would show the amount of silver nitrate needed to associate with the free chloride ions in the cement mass of each sample.

The results were plotted individually in spreadsheets and the amount of chloride ions in each sample that reacted with the cement mass was calculated according to the ratio (poor, medium and rich) and depth of penetration (1, 2, and 3 centimeters). The process is detailed in Fig. 5.

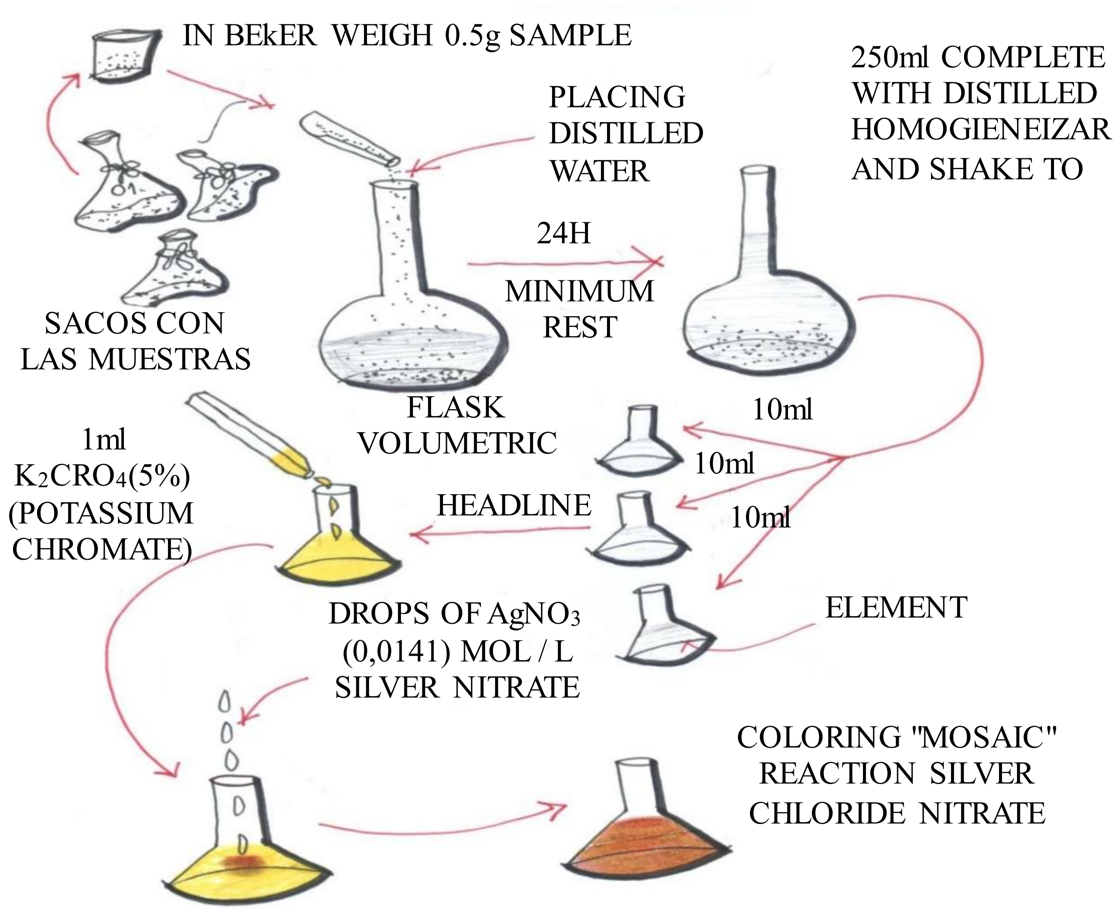

Figure 5. Diagram of the tests carried out in the chemistry laboratory

3. RESULTS

In this section, the results and analyses of the tests performed with silver nitrate titration using the Mohr method will be presented.

First, Tables 4, 5, and 6 will be presented showing the weight, the sample identification, the consumed volume of $AgNO_3$ (silver nitrate) per sample, and the relationship between the three, specifically between the poor and the rich and between the average and the rich.

Tables 6, 7, and 8 show the results obtained from the powder samples taken from the drilling of each test specimen, the laboratory results of titration by silver nitrate, and the percentage of chlorides in the cement by mass.

Because the sample weights varied, three titrations were made with silver nitrate and the arithmetic mean of these values was calculated so that the margin of error would be smaller.

In all of the samples, it can be seen that the one-centimeter depth had the highest concentration of chlorides, due to being closer to the surface.

Table 4. Results of the chemical laboratory tests - Samples of test specimens of poor concrete mix immersed in sea water.

CP	MIX TYPE	DEPTH (cm)	SAMPLE No.	MASS (g)	$AgNO_3$ (ml) (Used)				CHLORIDE ($\%Cl^-$) In relation to cement mass
					1st Tit.	2nd Tit.	3rd Tit.	Avg.	
POOR CONCRETE MIX									
1	**CP 1A**	1	1	0.52	0.50	0.50	0.50	0.50	0.0234
		2	2	0.52	0.50	0.50	0.50	0.50	0.0234
		3	3	0.50	0.60	0.60	0.60	0.60	0.0292
2	**CP 1B**	1	4	0.51	0.60	0.60	0.70	0.63	0.0311
		2	5	0.50	0.50	0.50	0.50	0.50	0.0234
		3	6	0.52	0.70	0.50	0.50	0.57	0.0273
3	**CP IIC**	1	7	0.50	0.50	0.40	0.60	0.50	0.0234
		2	8	0.50	0.50	0.40	0.40	0.43	0.0195
		3	9	0.51	0.30	0.40	0.30	0.33	0.0136
4	**CP IID**	1	10	0.54	0.70	0.60	0.60	0.63	0.0311
		2	11	0.52	0.40	0.40	0.50	0.43	0.0195
		3	12	0.50	0.30	0.40	0.30	0.33	0.0136

*CP IA, CP IB, CP IIC, CP IID – Identification of test specimens of poor concrete mix.

Table 5. Results of the chemical laboratory tests - Samples of test specimens of medium concrete mix immersed in sea water.

CP	MIX TYPE	DEPTH (cm)	SAMPLE No.	MASS (g)	$AgNO_3$ (ml) (Used)				CHLORIDE ($\%Cl^-$) In relation to cement mass
					1st Tit.	2nd Tit.	3rd Tit.	Avg.	
MEDIUM CONCRETE MIX									
5	**CP IIIE**	1	13	0.55	0.70	0.70	0.80	0.73	0.0272
		2	14	0.54	0.60	0.50	0.40	0.50	0.0172
		3	15	0.55	0.50	0.60	0.50	0.53	0.0186
6	**CP IIIF**	1	16	0.52	0.50	0.60	0.50	0.53	0.0186
		2	17	0.56	0.60	0.40	0.50	0.50	0.0172
		3	18	0.56	0.40	0.40	0.30	0.37	0.0114
7	**CP IVG**	1	19	0.56	0.80	0.60	0.80	0.73	0.0272
		2	20	0.58	0.60	0.60	0.60	0.60	0.0214
		3	21	0.57	0.40	0.50	0.60	0.50	0.0172
8	**CP IVH**	1	22	0.63	0.80	0.70	0.80	0.77	0.0286
		2	23	0.55	0.50	0.50	0.50	0.50	0.0172
		3	24	0.56	0.30	0.40	0.40	0.37	0.0114

*CP IIIE, CP IIIF, CP IVG, CP IVH – Identification of test specimens of medium concrete mix.

Table 6. Results of the chemical laboratory tests - Samples of test specimens of rich concrete mix immersed in sea water.

	MIX TYPE	DEPTH (cm)	SAMPLE No.	MASS (g)	AgNO$_3$ (ml) (Used)				CHLORIDE (%Cl$^-$) In relation to cement mass
					1st Tit.	2nd Tit.	3rd Tit.	Avg.	
RICH CONCRETE MIX									
9	**CP VI**	1	25	0.53	0.80	0.70	0.50	0.67	0.0161
		2	26	0.52	0.30	0.40	0.40	0.37	0.0076
		3	27	0.55	0.30	0.40	0.40	0.37	0.0076
10	**CP VJ**	1	28	0.52	0.70	0.60	0.70	0.67	0.0161
		2	29	0.50	0.50	0.60	0.60	0.57	0.0132
		3	30	0.52	0.50	0.60	0.60	0.57	0.0132
11	**CP VIL**	1	31	0.50	0.70	0.70	0.50	0.63	0.0151
		2	32	0.56	0.60	0.50	0.50	0.53	0.0123
		3	33	0.53	0.60	0.60	0.70	0.63	0.0151
12	**CP VIM**	1	34	0.52	0.70	0.50	0.50	0.57	0.0132
		2	35	0.54	0.40	0.50	0.50	0.47	0.0104
		3	36	0.53	0.30	0.30	0.40	0.33	0.0066

*CP VI, CP VJ, CP VIL, CP VIM – Identification of test specimens of rich concrete mix.

Table 7. Results of the chemical laboratory tests - Samples of rich, médium, and poor concrete test specimens without immersion in sea water.

SP.	MIX TYPE	DEPTH (cm)	SAMPLE No.	MASS (g)	AgNO$_3$ (ml) (Used)				(%Cl$^-$) In rel. to cement mass	(%Cl$^-$) In rel. to cement mass
					1st Tit.	2nd Tit.	3rd Tit.	Avg.		
POOR CONCRETE MIX				**W/O IMMERSION**						
13	**CP VII**	1	37	0.50	0.40	0.30	0.40	0.37	0.0033	0.0156
		2	38	0.50	0.30	0.30	0.40	0.33	0.0029	0.0136
		3	39	0.54	0.40	0.30	0.40	0.37	0.0033	0.0156
MEDIUM CONCRETE MIX				**W/O IMMERSION**						
14	**CP VIII**	1	40	0.55	0.40	0.50	0.30	0.40	0.0037	0.0129
		2	41	0.54	0.40	0.40	0.50	0.43	0.0042	0.0143
		3	42	0.56	0.40	0.50	0.40	0.43	0.0042	0.0143
RICH CONCRETE MIX				**W/O IMMERSION**						
15	**CP IX**	1	43	0.53	0.30	0.30	0.40	0.33	0.0029	0.0066
		2	44	0.53	0.40	0.40	0.40	0.40	0.0037	0.0085
		3	45	0.54	0.40	0.40	0.40	0.40	0.0037	0.0085
SEAWATER – ATLANTIC OCEAN										
16	**SAMPLE**		46						-0.0012	

After applying the formula, the percentage of chloride by mass was found. The cement mass used for the chloride penetration analysis was found from the cement consumption of the samples, where the poor mix consumes 503 kg/m³ of concrete, the medium mix consumes 685 kg/m³, and the specific mass of the concrete is 2,350 kg/m³, making it possible to obtain the percentage of chloride. An arithmetic mean was obtained and is shown in Table 8.

Table 8. Chloride by mass (%Cl^-) in test specimens

Mix	**Depth**					
	Immersed			**Not immersed**		
	1 cm	**2 cm**	**3 cm**	**1 cm**	**2 cm**	**3 cm**
Poor	0.0273	0.0214	0.0209	0.0156	0.0136	0.0156
Medium	0.0254	0.0182	0.0147	0.0129	0.0143	0.0143
Rich	0.0151	0.0109	0.0106	0.0066	0.0085	0.0085

According to the laboratory results obtained through the aforementioned experiment, the following considerations should be highlighted: the technique used is a qualitative technique, with low cost, and one that quickly determines the presence of free chlorides, giving support to the application of other more quantitatively-refined techniques. On the other hand, it is important to note that there are limitations to the technique. For example, when the structure is carbonated, producing confusing results.

4. CONCLUSIONS

The results show that chloride penetration is lower in the partially-immersed concrete test specimens in the following order:

- Rich mix
- Medium mix
- Poor mix

For all mixes that were partially immersed, the penetration of chlorides was greatest at the depth of 1 cm. The specimens not immersed in sea water presented, on average, 50% less chloride than those partially immersed.

It can therefore be concluded that concrete structures that are partially immersed in sea water require special care in their design (mix, façade covering, protective paint) as well as periodic maintenance for their entire lifetime to avoid potential collapses.

From the survey, results were obtained on the depth and the penetration of chlorides for rich, medium, and poor concrete mixes, which should assist professionals to designing parameters so that the useful life of constructions in contact with this aggressive environment can be increased. Care is important with regard to the materials used, the type of cement, and concrete resistance when developing activities in partial contact with sea water in the metropolitan area of Recife or in any other coastal city.

From the tests carried out, it can be concluded that the greater the concrete resistance, the lower the level of chloride ion penetration, when maintaining the same materials in the mix.

It is known that the chemical compounds in the cement and their respective phases will have a significant influence on the ability to combine chemically (to bond) with the chlorides. The aluminate phases (C_3A and C_4AF) are those that bond chemically with chlorides to form the chloroaluminates. On the other hand, the principal phases responsible for generating the C-S-H gel are C_3S and C_2S, with their hydrations consequently generating resistance to compression.

Therefore, there is a greater influence on the ability of cement compounds to chemically combine with chlorides than on their compressive strength.
This result was expected because smaller pores generally indicate greater resistance by increasing the difficulty of penetration by chloride ions. This case study sought to compare concrete samples having different cement contents in their composition with regard to the penetration of chloride ions when immersed or not in seawater.
With the results, it was concluded that concretes with higher strength (smaller water/cement ratio) have a greater resistance to penetration by chloride ions, as concrete with greater resistance tends to have pores of considerably reduced size, thereby hindering the entry of chloride ions into the structure. It is important to highlight that the concrete studied in this research can be used in structural reinforcements.

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Evaluation of the penetration of chlorides in concrete elements in the city of Pelotas / RS

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ABSTRACT
This research aims to verify the compatibility of an existing predictive model of life with the penetration of chlorides in exposed concrete elements in the city of Pelotas / RS. To this end, the samples were exposed at different locations in the city for a period of 16 months and silver nitrate solution was applied to determine the depth of the chlorides. The Bob model (1996) was used for comparison and analysis of the results. Significant values of chloride were found in the elements and a great potential of the model applied when describing the behavior of the depth of chlorides over time, despite the differences found.
Keywords: conservation; concrete structures; chlorides; natural test; prediction models.

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Avaliação da penetração de cloretos em elementos de concreto na cidade de Pelotas/RS

RESUMO

Esta pesquisa tem como objetivo verificar a compatibilidade de um modelo de previsão de vida útil existente com a penetração de cloretos em elementos de concreto expostos na cidade de Pelotas/RS. Para tanto, foram expostos corpos-de-prova em diferentes locais da cidade por um período de 16 meses, sendo aplicada a solução de nitrato de prata para determinação da profundidade de cloretos. Foi utilizado o modelo de Bob (1996), para comparação e análise dos resultados. Foram encontrados valores significativos de cloreto nos elementos e um potencial do modelo aplicado em descrever o comportamento da profundidade de cloretos ao longo do tempo, apesar das diferenças encontradas.

Palavras-chave: conservação; estruturas de concreto; cloretos; ensaio natural; modelos de previsão

Evaluación de la penetración de cloruros en elementos de hormigón en la ciudad de Pelotas / RS

RESUMEN

Esta investigación tiene como objetivo verificar la compatibilidad de un modelo de expectativa de vida útil existente con la penetración de cloruros en elementos de concreto expuestos en la ciudad de Pelotas / RS. Para hacer esto, los cuerpos de prueba fueron expuestos en diferentes partes de la ciudad por un período de 16 meses, aplicando la solución de nitrato de plata para determinar la profundidad de los cloruros. El modelo de Bob (1996) fue utilizado para la comparación y el análisis de los resultados. Se encontraron valores significativos de cloruro en los elementos y potencialidad de aplicación del modelo en describir el comportamiento de la profundidad de los cloruros a lo largo del tiempo, a pesar de las diferencias encontradas.

Palabras clave: conservación; estructuras de hormigón; cloruros; ensayo natural; modelos de previsión.

1. INTRODUCTION

Concrete is a widely used material applied worldwide in construction due to advantages such as good resistance to compression, low cost and ease of production. This last feature in conjunction with performance is directly linked to the useful life of the building, which can be defined as the period in which the structure is able to guarantee not only its stability but all the functions for which it was designed (Bertolini, 2010). The degradation of concrete structures and the consequent reduction of their performance is a frequent problem worldwide. Durability problems in these structures can be caused by a number of factors including lack of knowledge of the environment that will be exposed, inadequate specifications and / or poor execution.

The environment in which the structures will be exposed exerts a direct influence on the behavior of the material used. In this sense, the 1990s showed that concrete as a building material is unstable over time, and its physical and chemical properties are altered in function of the characteristics of its components and their responses to the environmental conditions (Souza and Ripper, 2009).

The form of deterioration that has shown to be of greater incidence and with greater economic losses in several countries is the corrosion of reinforcements (Carmona, 2005). This mechanism of deterioration is a consequence of the interaction of the material with the medium, allied or not to

mechanical stresses (Gentil, 2003). One of the main aggressive agents that can generate this process of deterioration are the chloride ions (Helene, 1997). The corrosion caused by the penetration of these ions inside the concrete is of electrochemical nature, involving an anodic reaction where the oxidation of the metal occurs, and another one of cathodic nature, occurring simultaneously. In order for corrosion of steel reinforcement to occur, it is necessary to have four elements: the conductor, which is the steel bar itself, the electrolyte (water) to conduct the ions, the oxygen that forms the corrosion products and a difference of potential for formation of two distinct areas (the ones of anodic and cathodic nature). This latter factor can be caused by different intensities of concrete densification, differences in aeration, humidity or salt concentrations (Silva, 2006).
The frequency of corrosion and the problems associated with it show the need to find solutions that contribute to minimize this deterioration process and its evolution in reinforced concrete structures (Vieira, 2003). Life expectancy models play an important role both in assisting existing structures, evaluating their deterioration and in new constructions, collaborating in the design stage, so that according to the environment in which they will be exposed, they have the expected life. It is also of fundamental importance that the application of the models of prediction of useful life is associated with the natural degradation of the structure, where the real interaction of this with the environment in which it is exposed occurs.
From the above mentioned, this study had as objective to verify the compatibility of a model of prediction of useful life, existing in the literature, with the penetration of chlorides in concrete elements, exposed in an urban environment in the city of Pelotas / RS.

2. PROCEDURE

The methodology of this work was divided into two stages. The first one refers to the natural test, through the exhibition of concrete bodies-of-proof in different places of the city of Pelotas / RS. The second stage is based on the application of a predictive model of useful life and later comparison of the results with the values found in the natural exposure of the samples.

2.1 Natural test

2.1.1 Exposure of bodies-of-proof

For this work, 60 cylindrical bodies-of-proof (10 x 20 cm) of concrete were used, provided by a local construction company as a way of simulating real concrete used in the city and its interaction with the environment. The samples were made with water / cement ratio of 0.6, CP IV - 32 cement from Votoran (most common cement in the region) and resistance to compression (fck) of 20MPa (minimum value considered for structural concrete according to NBR 6118).
The city of Pelotas / RS is located approximately 60km from the sea region and is located on the banks of the São Gonçalo channel that connects the Patos and Mirim Lagoons. Thus, the samples were exposed in an urban environment with annual relative humidity above 70% and unprotected from the environment (rainwater, temperature and rainfall), and could be classified as C3 according to NTF 4015 (Technical Standard Fondonorma, 2012). Strategic points of the city were determined, due to the greater circulation of vehicles and greater concentration of dwellings. The choice of sites, which represent each region, was influenced by the ease of access, as well as availability of physical space due to the large number of bodies-of-proof that would be placed at each site. Thus, the bodies-of-proof were divided into five different locations in the city: downtown, Porto neighborhood, Fragata neighborhood and Três Vendas neighborhood (due to this last neighborhood extension, two sites were chosen for the exhibition of the bodies-of-proof). Thus, 12 bodies-of-proof were placed in each locality. Figure 1 shows the location of the different points analyzed.

Figure 1. Mapping of the location of the bodies-of-proof in the city of Pelotas / RS. (Adapted from Google Earth).

The Três Vendas neighborhood is located in the northern part of the city. The first site, shown in Figures 2 and 3, is further away from the central area, but where all the traffic from the city's potteries flows. The second location of this neighborhood (Figures 4 and 5) is located in the most central part where the meeting of two of the main avenues occurs, with intense traffic around them.

Figure 2. Location of the first environment of exposure of the samples in the Três Vendas neighboorhood (Adapted from Google Earth).

Figure 3. First location of exposure in Três Vendas neighboorhood

Figure 4. Location of the second environment of exposure of samples in neighborhood Três Vendas (Adapted from Google Earth).

Figure 5. Second location of exposure in neighborhood Três Vendas

The Fragata neighborhood, located in the western zone, is one of the most populous neighborhoods in the city. Despite its extension, only one place was chosen for its analysis, due to its easy access, which is the city's Bus Terminal, shown in Figures 6 and 7.

Figure 6. Location of the environment of exposure of samples in neighborhood (Adapted from Google Earth).

Figure 7. Location of exposure in Fragata neighborhood Fragata

The downtown district test site is located in the main street of the neighborhood, being highly populated and of intense traffic, as shown in Figures 8 and 9.

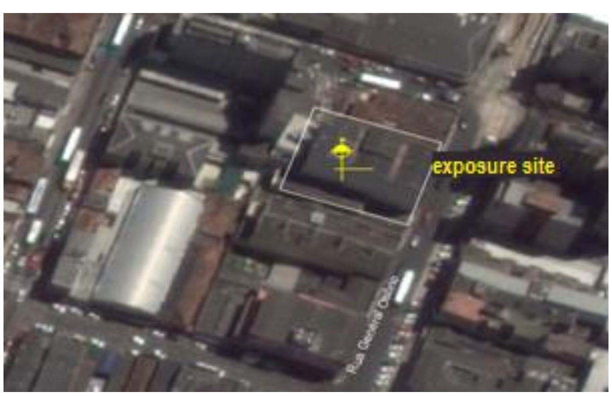

Figure 8. Location of the environment of exposure of samples in downtown neighborhood (Adapted from Google Earth).

Figure 9. Location of exposure in downtown neighborhood

Unlike the other sites, in the Porto district, located in the south of the city, the bodies-of-proof were exposed at the edge of the São Gonçalo channel (Figures 10 and 11).

Figure 10. Location of samples exposure in Porto neighborhood (Adapted from Google Earth).

Figure 11**.** Exposure location in Porto neighborhood

2.1.2 Compression resistance test

The Forney brand hydraulic press was used to test the resistance to compression of the samples from each locality, the test was performed according to NBR 5739 (ABNT, 2007). This test was done with three bodies-of-proof from each locality every 4 months, being performed to verify the resistance, which should be at least 20 MPa, and opening the sample to perform the colorimetric test. The average evolution of the resistance to compression throughout the test is presented in Table 1, where it is noticed that all the samples reached the minimum resistance and were then submitted to the colorimetric test. Measurements of dispersion were not performed for this test, due to the fact that this characteristic is not the focus of the analysis.

Table 1. Average resistance to compression of concrete bodies-of-proof

Location	**Time of exposure**			
	4 months	**8 months**	**12 months**	**16 months**
Fragata	27.44	32.17	34.05	35.47
Downtown	24.48	30.52	31.61	30.28
Porto	26.99	33.22	32.34	32.87
Três Vendas 1	26.99	34.33	33.39	35.37
Três Vendas 2	28.65	33.99	30.85	35.70

With the value of the resistance to compression of each site the average per period was made, and based on the NBR 6118 (ABNT, 2014) the curve of evolution of this characteristic was traced over time for the type of cement used in the bodies-of-proof (CP IV).

2.1.3 Depth measurement of chlorides

After the rupture of the bodies-of-proof, silver nitrate was applied to the whole newly fractured face. When this solution is sprayed on the concrete surface a photochemical reaction occurs, where in the presence of free chlorides, a white precipitate of silver chloride occurs and in the region without chlorides or with combined chlorides, a brown precipitate is formed, the silver oxide (Real et al., 2015). The appearance of the samples after the procedure, the chloride penetration front and the depth measurement are shown in Figures 12 and 13.

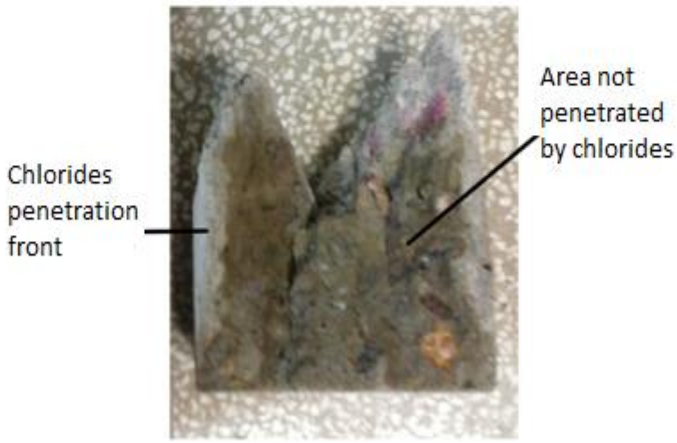

Figure 12. Example of the chlorides penetration front in the fractured simple

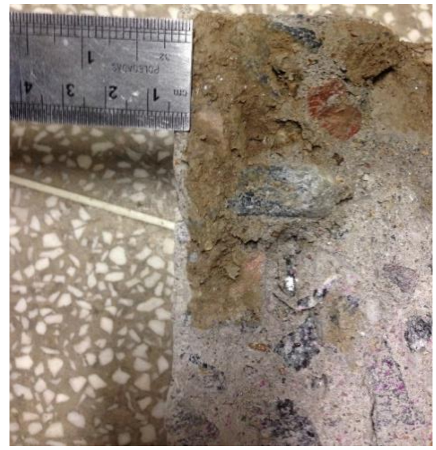

Figure 13. Example of the chlorides penetrated depth in the fractured sample

After the silver nitrate was sprayed, we waited about 5 minutes until the solution reacted with the concrete. Then the measurement was performed, being made two in each body-of-proof, resulting in 6 values of chlorides depth per site of exposure. In order to predict depth of aggressive agents, we assumed that the greater depth has greater relevance, this, therefore, was the measure used to analyze the results.

2.1.4 Statistical analysis

For the evaluation of the influence of the study variables on the chloride depth data obtained in the tests, the two-way ANOVA test was performed. For that, the SPSS 20.0 (Statistical Package for Social Sciences for Windows) software was used. For all the analyzes a level of significance (α) of 5% was used, that is, from this value the deviations are considered not significant, presenting a confidence level of 95%. Thus, one can reject the hypothesis that the averages are all equal to 5% if the value of "p" found is less than this value. For statistical analysis, the sample location (Fragata neighborhood, Downtown, Porto, Três Vendas 1 and Três Vendas 2) and the time at which they were exposed (4, 8, 12 and 16 months) were considered as independent variables. The penetration depth of chlorides was considered as a dependent variable.

2.1.5 Climatic characterization of the city of Pelotas / RS

Data were collected to characterize the local atmosphere in order to verify the aggressiveness of the samples' exposure environment. The relative humidity of the air, temperature and precipitation quantitative were highlighted as factors of greater influence. It is important to highlight that the monitoring was performed in the macro-climate of the sample exposure environment, in this case the city of Pelotas / RS. These data were obtained through the Pelotas Agroclimatological Station website, located in Capão do Leão, which provides daily and monthly meteorological variables. Figures 14, 15 and 16 show the accumulated precipitation, the mean relative humidity and the maximum and minimum temperature in the months for the 4 periods studied (4 months, from May to September, from 4 to 8 months, being September to January, from 8 to 12 months, referring from January to May, and from 12 to 16 months, from May to September). For the application of the useful life model, we used data of the relative humidity and maximum and minimum daily temperature, for which the average was calculated. No information was collected regarding the orientation of the winds during the studied period, due to the difficulty of analyzing this variable in relation to the different exposure sites.

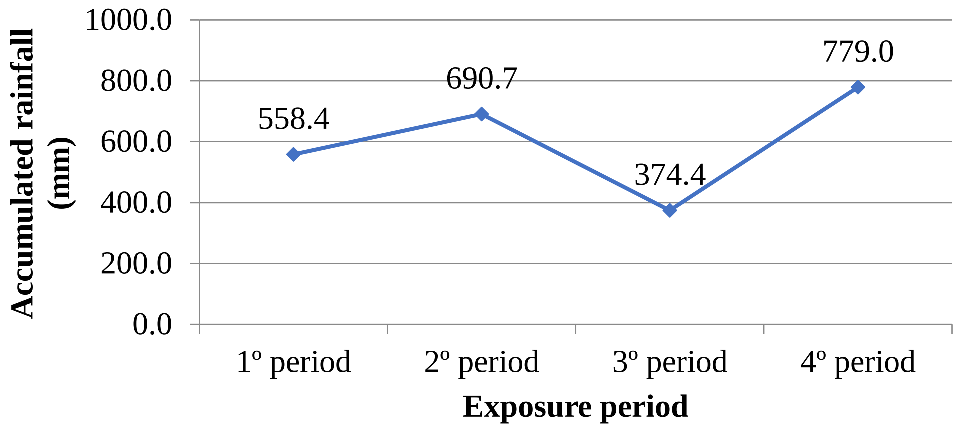

Figure 14. Cumulative rainfall for each sample exposure period

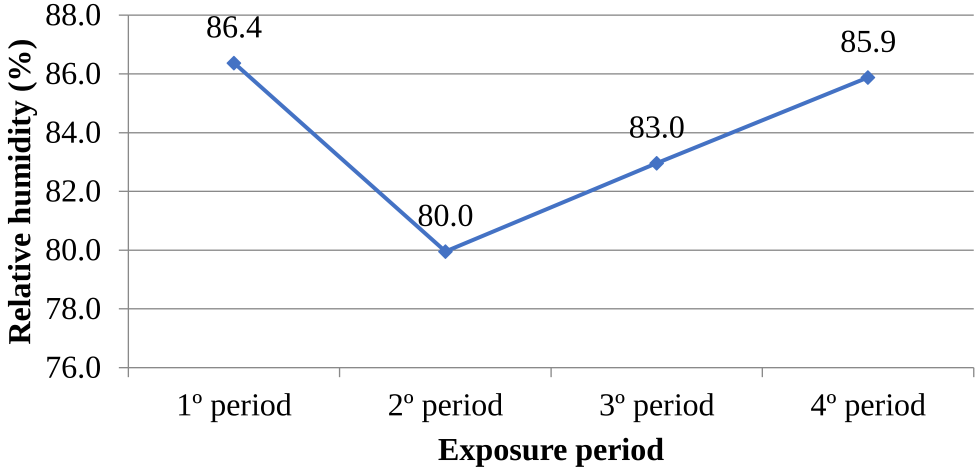

Figure 15. Average relative humidity for each sample exposure period

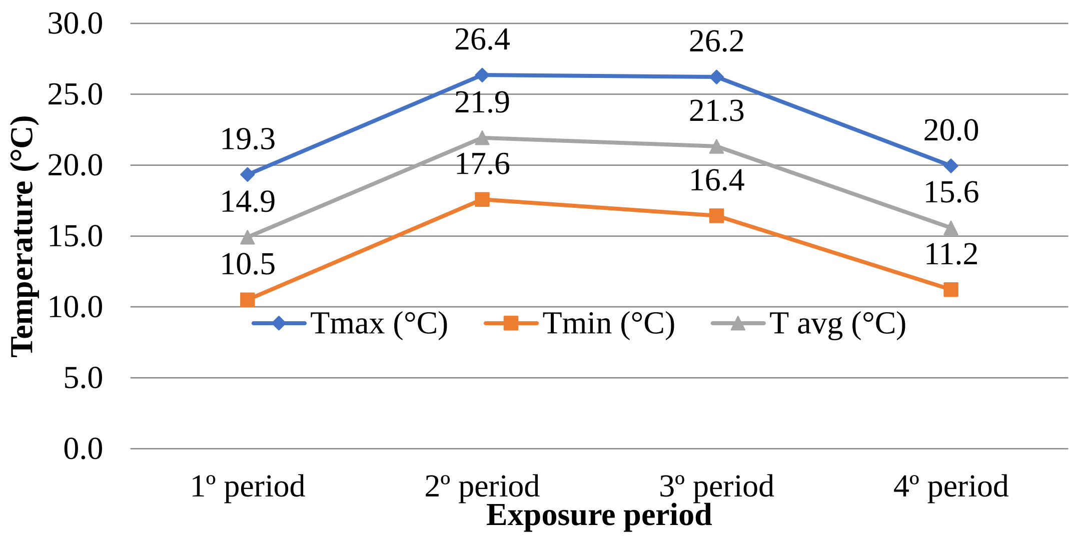

Figure 16. Average temperature in each sample exposure period

2.2 Useful life expectancy model

For the analysis of chlorides in concrete structures, the model of Bob (1996) was chosen, since the estimation made by this method is carried out in terms of the depth covered by the contaminant, rather than the analysis in terms of concentration, as a large part of the models for chloride analysis. Bob (1996) initially presented a model used for analyzing the carbonation depth in the structures, and after verifications based on experimental long term data, noted that equation (1) could be used for modeling the chloride process of penetration (Andrade , 2001). This model considers concrete properties, such as compressive strength, and environmental characteristics, such as temperature and relative humidity.

$$x_m = 150\left(\frac{c k_1 k_2 d}{f_c}\right)\sqrt{t} \tag{1}$$

Onde:
At where:
xm = average depth of penetration of chlorides (mm);
fc = compressive strength of concrete (N / mm²);
c = ability to fix chlorides according to the type of cement;
k1 = coefficient of influence of temperature;
k2 = coefficient of influence of relative humidity;
t = time (years);
d = ratio between the critical concentration and the surface concentration of chlorides in the structure.

For the application of this model, we used the average temperature and daily relative humidity of the city of Pelotas / RS during the period of exposure of the samples, as well as the average daily resistance to compression (fck) of the concrete obtained through the evolution curve of this characteristic. The parameters c, k1 and k2 are presented in Table 2. The model was applied to different values of parameter d as a way of analyzing different critical and superficial concentrations of chlorides in the structure, since this variable represents the relation between the two concentrations.

Table 2. Parameters related to Bob's model, 1996 (Andrade, 2011)

Parameter k_1		**Parameter c**		**Parameter k_2**		**Parameter d**	
k_1	**T(°C)**	**c**	**(%) additions in cement**	**k_2**	**UR (%)**	**D**	**r**
0.67	0 to 5	1	0	0.75	50	2	0 to 19
0.75	5 to 15	0.9	15	1	85	1	20
1	15 to 25	0.75	30	0.75	100	0.5	50
1.25	25 to 35	0.67	50	-	-	0.33	65
1.5	35 to 45	-	-	-	-	0.16	85

3. RESULTS

3.1 Depth of chlorides by the natural test method

The maximum penetration depths of chlorides for the different exposure sites and the different times are shown in Figure 17.

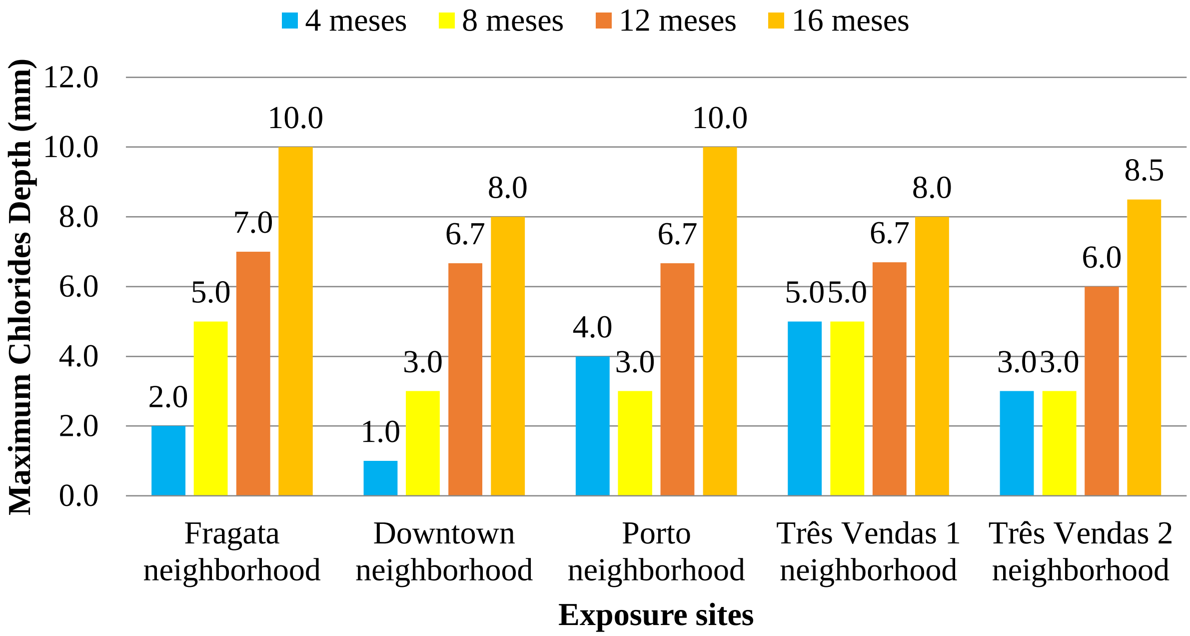

Figure 17. Depth of penetration of chlorides for each location and time of exposure

Evaluating the data, one observes, as expected, a tendency of increase of the chlorides front between the first and last measurement for all the localities. It is observed that the greatest depth of penetration of chlorides after the 16 months of exposure in urban environment, were found in the neighborhood Fragata and Porto, being 10mm. This value was surprising, since it was not believed that free chlorides would be found inside the city of Pelotas, since it is a city far from the maritime environment.At the same time, it is known that the Patos lagoon, which surrounds the city, has periods in the year that changes the state from fresh water to salt, and can be an explanation for appearance of chlorides in concrete, being also important to emphasize that, in periods of low rainfall, high chloride values were found at some points from the Mirim lagoon to the Patos Lagoon (Souza, 2015) and chloride values above the value established by CONAMA for fresh water at points on the Bento Gonçalves Avenue extension channel (Santos et al. al., 2012). It can be said that there is an indication that the chlorides are part of the atmosphere of the city of Pelotas / RS, where the lowest depth found for this same exposure time was 8mm for the Downtown neighborhood and for samples 1 of Três Vendas neighborhood.
Through the two-way ANOVA, it was possible to confirm the influence of the time variable on the depth of chlorides, and it was verified that the local variable and the interaction between these variables did not influence. From this analysis it is verified that the entire city of Pelotas / RS has the same behavior regarding the penetration of chlorides, not interfering the change between neighborhoods, only the time of exposure. Analyzing in isolation as a way to verify which variables differ in relation to the depth of chlorides, it was found that time significantly interferes in the results of exposure to chloride penetration. On the other hand, the analysis of the "local" independent variable indicated a significant difference in the first location of the Três Vendas neighborhood in relation to the Porto and Três Vendas 2 sites, indicated by $p \leq 0.05$. For the other sites, no significant difference was found, accepting, then, the hypothesis of equal means between these and the depths of chlorides, being important to emphasize that the results have a confidence level of 95%.

3.2 Application of Bob's model (1996)

The application of the predicted lifetime model for chlorine penetration was performed only for sites that presented significant difference in the statistical analysis of the data, being for the first and second site of the neighborhood Três Vendas and Porto neighborhood. Figures 18, 19 and 20 present the comparison between the results found with the application of the model and the natural test, for the different values of d.

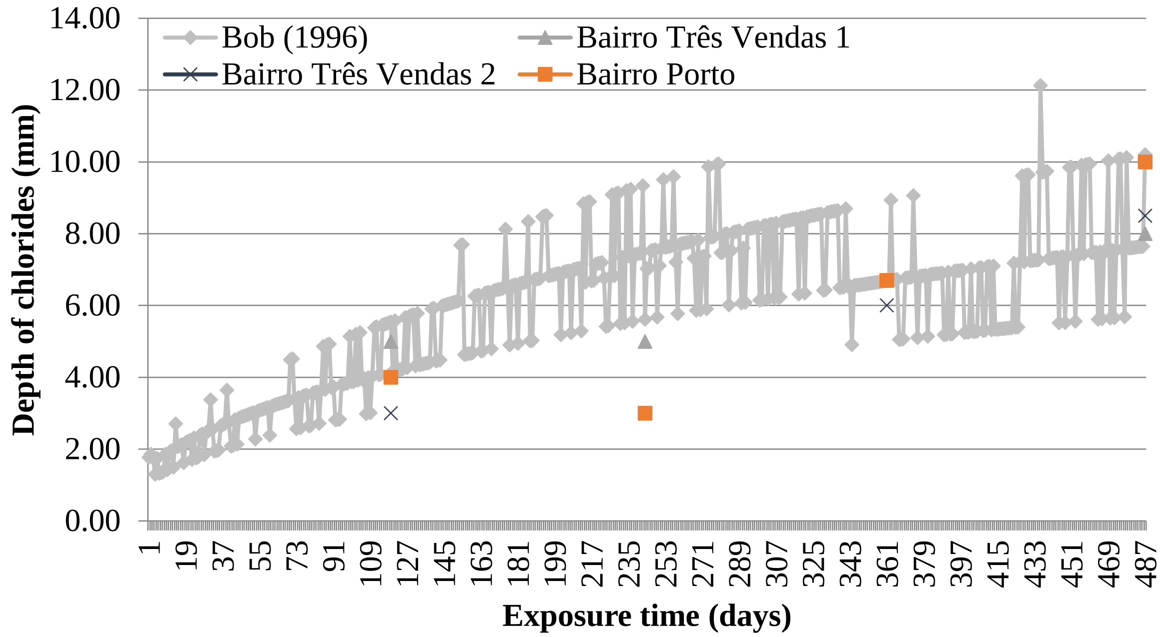

Figure 18.Bob’s model (1996) with parameter d = 2

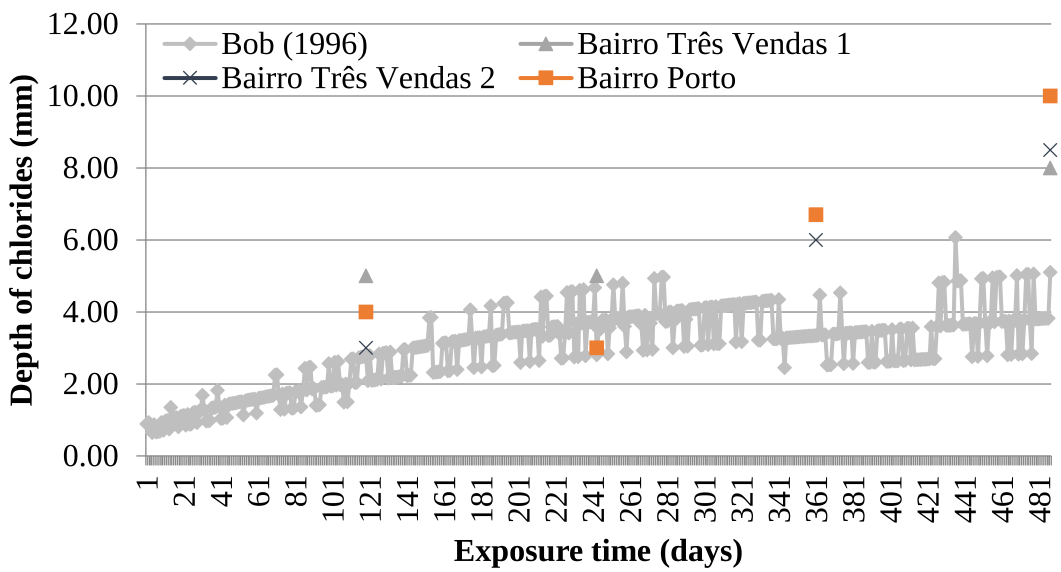

Figure 19.Bob’s model (1996) with parameter d = 1

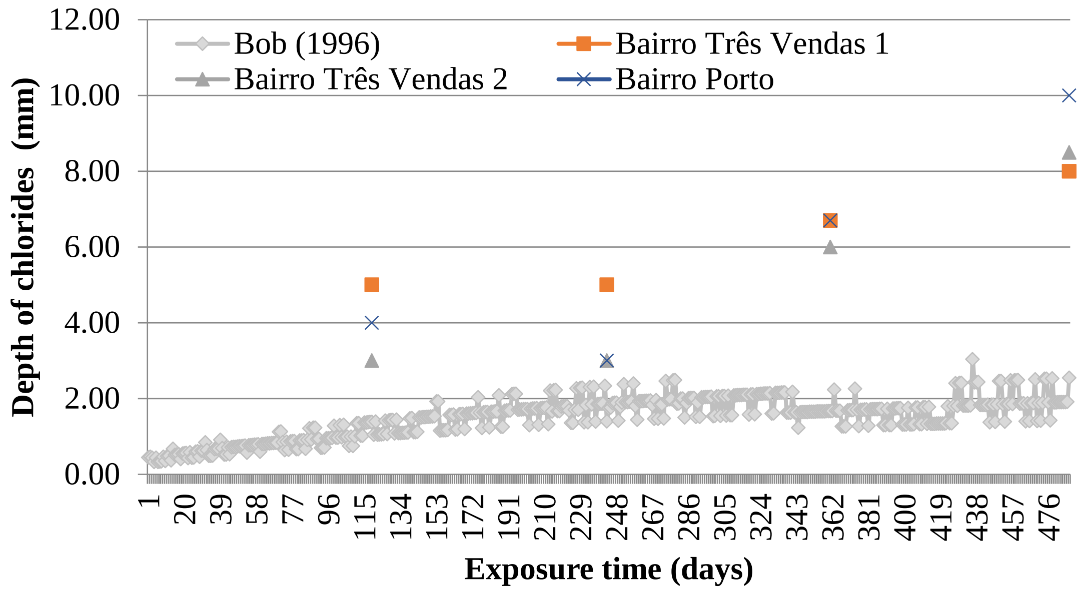

Figure 20. Bob's model (1996) with parameter d = 0.5

It is observed that for all the localities the model that best fit the values found in the natural test was the one with parameter d = 2, that is, with the relation between critical concentration and the superficial concentration of chlorides in the structure between 0 and 19. It was also observed that for the second period none of the sites had their values described by the applied model, unlike the other periods of exposure.

By analyzing each site separately for the best curve found, and based on the input parameters of the model, it can be said that for the neighborhood Três Vendas 1, for the first period (depth of 5mm), we found the approximate value of 4.92mm at 71 days of exposure, with a mean temperature of 16.4ºC and a relative humidity of 85%. For the second period (depth of 5 mm) the approximate value of 4.92 mm depth was also found for 188 days of exposure, mean temperature of 24.9 ° C and relative humidity of 88%. In the 3rd period (depth 6.7 mm), we found 6.69 mm at 340 days of exposure, with a mean temperature of 16.1ºC and relative humidity of 85.8% and 6.71mm at 342 days, mean temperature of 12ºC and relative humidity of 83.8%. For the 4th period (depth of 8mm), we found 7.65mm for 486 days of exposure, average temperature of 17.1ºC and relative humidity of 76%.

For the Três Vendas 2 neighborhood, in the first period where the depth found in the natural test was 3mm, when applying the model, this exact value was found at 47 days of exposure, average temperature of 16.95ºC and relative humidity of 95.20 %. In the 2nd period where the depth of the natural test was the same, the closest value found by the model was 3.93mm with 120 days of exposure, average temperature of 15.7ºC and relative humidity of 86.50%. For the 3rd period, the same value of the natural test (depth of 6mm) was found for 273 days of exposure, average temperature of 25ºC and relative humidity of 86.3%. For the last period (depth of 8.5 mm), the model obtained a depth of 8.81 mm at 363 days of exposure with a mean temperature of 16ºC and a relative humidity of 82.30%.

Finally, for Porto neighborhood in the 1st period, the value of 4mm was found in the natural test, while in the model it was obtained 3,99mm at the 83 days of exposure with average temperature of 17.9ºC and relative humidity of 90,80%. In the second period, this neighborhood had the same behavior of the neighborhood Três Vendas 1, while in the 3rd period the value found was the same for the neighborhood Três Vendas 2. For the 4th period (depth of 10mm), the model found the

approximate value of 10.02 mm for 469 days of exposure, average temperature of 16.9ºC and relative humidity of 83.50%.
In general, for the city of Pelotas / RS, the model of Bob (1996) was applied for each period of exposure of the bodies-of-proof. We used 85% as relative humidity, due to the humidity of all periods being close to that value. As for the temperature, as a great daily variation occurs, the maximum and minimum temperatures of each period were used. As for the resistance to compression, the average of all the sites in each period was used. The result is shown in Table 3 and Figure 21.

Table 3 – Comparison of the results of the natural test with Bob's model, 1996

Exposure time (months)	Depth of chlorides (mm)				
	Três Vendas 1	Três Vendas 2	Porto	Bob (1996)	
				Bob Tmax	Bob Tmin
4	5	3	4	4.8	5.76
8	5	3	3	5.01	5.61
12	6.7	6	6.7	6.19	6.93
16	8	8.5	10	7.65	9.17

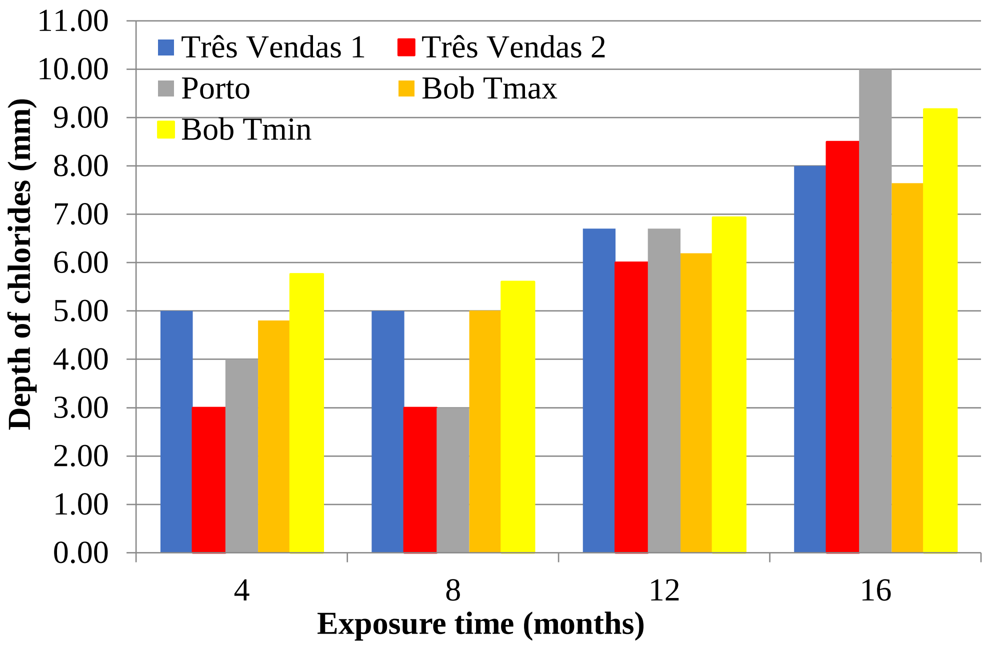

Figure 21. Comparison of the results of the natural test with Bob's model, 1996

By analyzing the results, the period that was closest to the model of Bob (1996), for both temperatures was 12 months, being close to the values found for the neighborhood Porto and Três Vendas 1 using the minimum temperature, and the neighborhood Três Vendas 2 using the maximum temperature. For the 4-month period, the values found only approached the depth found in the neighborhood Três Vendas 1, the closest one being the result found using the maximum temperature. While for 8 months the model also resulted in a value very close to the one from neighborhood Três Vendas 1 for the maximum temperature. After the 16-month period, regardless of temperature, the results obtained were smaller than for the natural test, where the value found with the highest temperature approached the Três Vendas 1 neighborhood and the highest depth

(9.17 mm) was found with the lowest temperature. This difference may be due to the large daily temperature variation of the city of Pelotas / RS, as well as the fact that the model considers only certain values of relative humidity (50%, 85% and 100%), and humidity for all periods is between 85 and 100%.

4. CONCLUSIONS

Firstly, when observing the results found in the natural test for chloride penetration, there is a tendency to increase between the first measurement made after 4 months of exposure and the last one after 16 months for all analyzed sites.

The values obtained for the penetration of chlorides demonstrate that the city of Pelotas / RS, despite being removed from the marine environment, favors the advance of this aggressive agent to the interior of the concrete due to high humidity and temperature variations that lead to wetting / drying cycles of the concrete, facilitating the absorption and advancement of chlorides inside the structure. Analyzing the largest (10mm for the Fragata and Porto neighborhoods) and lowest (8mm for Três Vendas 1) depth value of chlorides for a 16-month exposure time, a variation of approximately 20% was found.

With the use of statistical analysis it was confirmed that the time variable significantly interfered in the results of exposure to chloride penetration, and it was observed that the change between neighborhoods and the interaction between the sites and the time did not have any influence. Through the multiple comparison test we found a significant difference between the Três Vendas 1 site and the Porto and Três Vendas 2 sites..

When applying the model of predicted useful life of Bob (1996) to analyze the penetration of chlorides, it was possible to perceive that for all the places the option that best fit the values found in the natural test was using the parameter d = 2 , that is, with the ratio between the critical concentration and the surface chlorides concentration in the structure ranging from 0 to 19. Analyzing the sites separately, and each exposure period, it is noticed that depending on the values of the input variables (time, temperature and relative humidity) were found to be close to depth over time for all localities. However, when applying the prediction model in general for the city of Pelotas, we can see that the values obtained approximated the data collected in the natural trial for the 12 months of exposure in neighborhoods Três Vendas 1 and Porto, using the minimum temperature, and the neighborhood Três Vendas 2 to the maximum temperature. For the 4 and 8 months times, the model presented values very close to the neighborhood Três Vendas 1.

It is concluded that the model of Bob (1996) showed differences between the values obtained with its application and the data of the natural test, probably due to the great daily temperature variation of the city of Pelotas and the fact that the model considers only certain values of humidity (50%, 85% and 100%) and the humidity in the city in question, for all periods, is between 85% and 100%. However, the model applied even with the difference found, showed good adherence to the observed data, showing adequate for some situations, demonstrating the potential to describe the behavior of chlorides depth over time for the city of Pelotas, being necessary some adjustments in the entry parameters.

Thus, with the indicative of the presence of chlorides in the analyzed city and the potential demonstrated by the method studied, it is important for future work, the verification of the chloride content in the exposure environment and the verification of the depth of chlorides in the concrete through other forms that complement the colorimetric test, so that it is possible to refine the variables applied in the model and its better application.

5. ACKNOWLEDGMENTS

We would like to thank Schumman Constructions for the donation of the bodies-of-proof for this research and the Laboratory of Materials and Constructive Techniques of Civil Engineering of UFPel for all assistance and availability during the development of this research.

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Evaluation of nanosilica effects on concrete submitted to chloride ions attack

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ABSTRACT

The present paper studied the influence of nanosilica dispersed on superplasticizer, and its combined effect with silica fume, on different concrete properties. Compressive strength, tensile strength by diametrical compression and water absorption by capillarity tests, as well as accelerated durability tests against chloride ions were carried out. Results indicated that isolated nanosilica addition (0.1 to 0.5%) did not improve concretes in any tests performed. However, for 0.5 and 0.7% content of nanosilica combined with 10% of silica fume, there was an increase in compressive strength, reduction of capillary absorption and reduction of chlorides penetration.
Keywords: concrete; chloride ions; nanoparticles; nanosilica.

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Avaliação dos efeitos da nanosílica em concretos submetidos à ação de íons cloreto

RESUMO

O presente trabalho estudou a influência da nanosílica dispersa em superplastificante, além do seu efeito combinado com a sílica ativa, em diferentes propriedades dos concretos. Foram realizados ensaios de resistência à compressão, resistência à tração por compressão diametral e absorção de água por capilaridade, além de ensaios acelerados de durabilidade frente aos íons cloreto. Os resultados obtidos indicaram que a adição de nanosílica de forma isolada (0,1 a 0,5%) não conferiu melhorias aos concretos, em nenhum dos ensaios realizados. No entanto, para os teores de 0,5 e 0,7% de nanosílica em conjunto com 10% de sílica ativa, houve aumento de resistência à compressão, redução da absorção capilar e redução da frente de penetração de cloretos.

Palavras-chave: concreto; íons cloreto; nanopartículas; nanosílica.

Evaluación de los efectos de la nanosílice en hormigones sometidos a la acción de iones de cloruro

RESUMEN

El presente trabajo estudió la influencia de la nanosílice dispersa en superplastificante, y su efecto combinado con la sílice activa, en diferentes propiedades de los hormigones. Fueron realizados ensayos de resistencia a la compresión, resistencia a la tracción por compresión diametral y absorción de agua por capilaridad, además de ensayos acelerados de durabilidad frente a los iones de cloruro. Los resultados indicaron que la adición de nanosílice (0.1 a 0.5%) no mejoró los hormigones en ninguno de los ensayos realizados. Por otro lado, para los contenidos de 0.5 y 0.7% de nanosílice combinados con 10% de sílice activa, hubo un aumento en la resistencia a la compresión, reducción de la absorción capilar y reducción de la penetración de cloruros.

Palabras clave: hormigón; iones de cloruro; nanopartículas; nanosílice.

1. INTRODUCTION

In recent years, motivated by the increase in deterioration cases of reinforced concrete structures, the study of cementitious materials durability became focus of several researches.

Mineral additions use and their benefits to concrete, among them: better resistance to thermal cracking due to low hydration heat, increase of mechanical strength and reduction of permeability due to pore refinement and strengthening of transition zone, is a consensus in literature (Mehta, Monteiro, 2014).

Silica fume is a mineral addition classified as super pozzolana and due to its particles being finer than cement particles, with average diameter between 0.1 and 0.2 μm, it also considered a filler (Dal Molin, 2011).

At nanotechnology era, silica nanoparticles have been incorporated in cementitious materials. Li et al. (2017a) explain that, because their granulometry is lower than silica fume, nanosilica has a larger specific surface, which potentiates its pozzolanic effect. Authors also comment that, if used together, the synergistic effects of nanosilica and silica fume can make them even more effective in filling cementitious matrix voids and in microstructure densification.

Silica fume has already been established as an effective mineral addition in improving cementitious materials properties. However, nanosilica has still been subject of recent research that aims to study its effects on concrete properties, both in fresh and hardened state, in addition to durability parameters against different aggressive agents (Berra et al., 2012; Lim; Mondal, 2015; Ganesh et

al., 2016; Ghafoori; Batilov; Najimi, 2016; Joshaghani; Moeini, 2017; Li et al., 2017a; Li et al., 2017b).
Among these different aggressive agents present in environment are chloride ions and their ability to initiate reinforcement corrosion, even when the solution contained in concrete pores has high pH. In addition, after their reaction with steel, chloride ions are not fixed and are available to continue the reaction (Silva, 2006). These peculiarities make chloride's attack one of the main mechanisms of concrete structures degradation.
Therefore, this paper aims to evaluate the influence of nanosilica addition, as well as its combined effect with silica fume, on mechanical and physical properties and on durability parameters of concrete subjected to chlorides attack.

2. MATERIALS AND METHOD

1.1. Materials

For this research, following materials were used: Portland cement, fine and coarse aggregates, nanosilica, silica fume and superplasticizer additive.
An early high strength cement (CPV ARI) was used. Results of physical and chemical characterization are presented in Table 1.

Table 1. Chemical and physical properties of CPV ARI.

<table>
<tr><th>Chemical properties</th><th>Results (%)</th><th colspan="2">Physical properties</th><th>Results</th></tr>
<tr><td>SiO_2</td><td>19.17</td><td colspan="2">Density (g/cm³)</td><td>3.12</td></tr>
<tr><td>Al_2O_3</td><td>5.03</td><td colspan="2">Initial setting time (min)</td><td>135</td></tr>
<tr><td>Fe_2O_3</td><td>3.21</td><td colspan="2">Final setting time (min)</td><td>210</td></tr>
<tr><td>CaO</td><td>63.97</td><td colspan="2">Normal consistency paste (%)</td><td>31.5</td></tr>
<tr><td>MgO</td><td>0.61</td><td rowspan="2">Fineness</td><td>Retained #200 (%)</td><td>0.1</td></tr>
<tr><td>Na_2O</td><td>0.06</td><td>Blaine (m²/kg)</td><td>473</td></tr>
<tr><td>K_2O</td><td>0.61</td><td rowspan="4">Compressive strength (MPa)</td><td>1 day</td><td>27.5</td></tr>
<tr><td>SO_3</td><td>2.84</td><td>3 days</td><td>42.0</td></tr>
<tr><td>Insoluble residue</td><td>0.85</td><td>7 days</td><td>48.7</td></tr>
<tr><td>Loss on ignition</td><td>3.79</td><td>28 days</td><td>52.2</td></tr>
</table>

Physical characterization of fine and coarse aggregates is shown in Table 2 and granulometric distribution curves, obtained based on NBR NM 248 (ABNT, 2003), are presented in Figures 1 and 2, respectively.

Table 2. Physical characterization of fine and coarse aggregates.

Parameters	Methodology	Fine aggregate	Coarse aggregate
Density (g/cm³)	NBR NM 52 NBR NM 53	2.64	2.77
Dry unit weight (kg/m³)	NBR NM 45	1505	1422
Dry-rodded unit weight (kg/m³)	NBR NM 45	1704	1568
Water absorption (%)	NBR NM 30 NBR NM 53	0.34	2.26
Powder material (%)	NBR NM 46	1.33	1.00

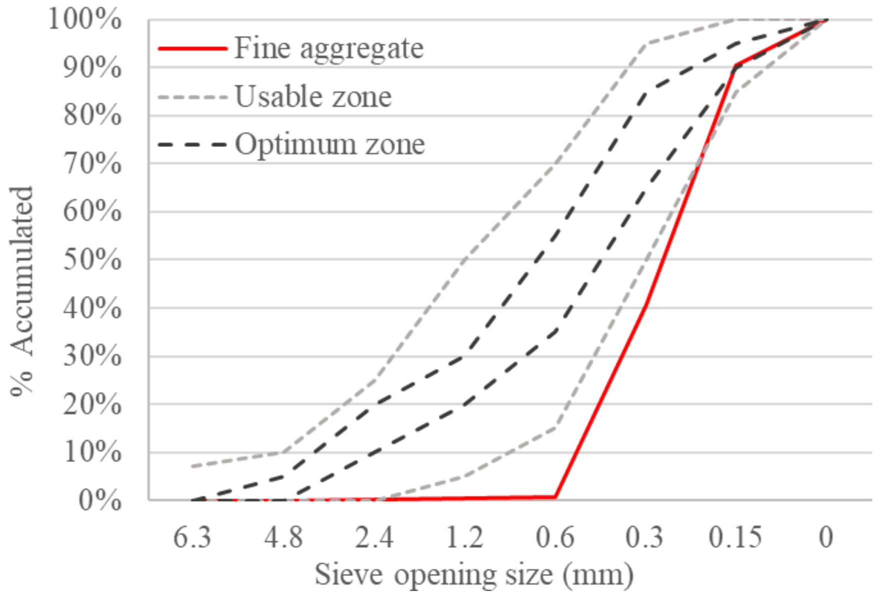


Figure 1. Particle size distribution of fine aggregate.

Fine aggregate had fineness modulus equal to 1.33 and maximum characteristic size equal to 0.6 mm. Although fine aggregate has a particle size distribution outside the usable zone established by NBR 7211 (ABNT, 2009), the same standard allows its use, whereas previous dosage studies prove its applicability. Therefore, and because it is a material commercialized in the region of study development, its use was maintained.

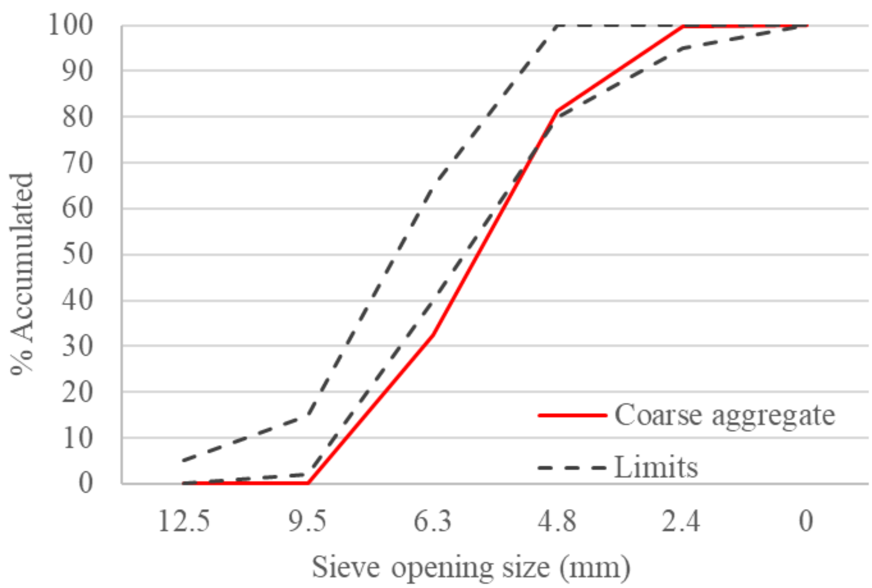


Figure 2. Particle size distribution of coarse aggregate.

A nanosilica dispersed in a polycarboxylate superplasticizer liquid additive was used and the recommended content ranges from 0.5 to 3.0% relative to binder mass. Their characteristics are presented in Table 3. Table 4 shows physical and chemical characteristics of silica fume.

Table 3. Nanosilica characterization.

Product	Nanosilica
Aspect	Homogeneous liquid
Density (g/cm^3)	1.06
Solid content (%)	31.5
pH	2.6
Water-soluble chlorides (%)	≤ 0.15

From: Silicon Industry and Commerce of Chemical Products LTDA.

Table 4. Physical and chemical characterization of silica fume.

Physical parameters		Chemical parameters	
Density (g/cm^3)	2.10	Loss on ignition (%)	3.7
		Na_2O (%)	0.7
Specific surface (m^2/kg)	20000	SiO_2 (%)	93.0
		Na_2O (%)	0.2
Humidity (%)	0.1	Fe_2O_3 (%)	0.5
		CaO (%)	0.5
Retained 45 mm (# 325) (%)	3.7	MgO (%)	0.4
		Al_2O_3 (%)	0.2
		K_2O	0.9

From: Dow Corning Silicon of Brazil.

In reference concrete, without silica fume and nanosilica incorporation, was used a superplasticizer additive (SP) based on polycarboxylic ether, MasterGlenium® Sky 150, which specifications are presented in Table 5.

Table 5. SP additive characterization.

Product	SP additive
Aspect	Cloudy white liquid
Density (g/cm^3)	1.055 – 1.085
pH	7.5 – 9.5
Solid content (%)	28.0 – 31.0

From: BASF S.A.

1.2. Concrete mix proportioning

Nanosilica influence was studied on 1:1.6:1.6 concrete (cement: fine aggregate: coarse aggregate) and water/binder ratio (w/b) equal to 0.4.

As already mentioned, the nanosilica used in this work is dispersed in superplasticizer additive, which limited the contents to be used. As concretes workability, obtained according to NBR 13276 (ABNT, 2016), increase with increasing nanosilica content, the limits (0.5% to 3.0%) recommended were not possible to being explored. SP additive used in reference concrete also has their content defined based on mixture workability.

Therefore, nanosilica contents between 0.1 and 0.7%, isolated and with silica fume, were added to concrete as a partial cement replacement (10% in volume).

Concretes were identified by a C-N-S type nomenclature, where N and S represent nanosilica and silica fume contents used, respectively and reference concrete is identified as REF. Concretes compositions and their flow spread are shown in Table 6.

Table 6. Proportion of materials for concretes mixtures.

Concrete	Materials (kg/m³)							Flow spread (mm)
	Cement	SF	FA	CA	NS	SP	Water	
C-0.1-0	524.90	-	839.84	839.84	0.52	-	209.96	180
C-0.3-0	524.38	-	839.00	839.00	1.57	-	209.75	240
C-0.5-0	523.86	-	838.18	838.18	2.62	-	209.54	285
C-0.5-10	474.76	35.51	844.03	844.03	2.55	-	204.11	220
C-0.7-10	474.31	35.47	843.21	843.21	3.57	-	203.91	250
REF	524.39	-	839.02	839.02	-	1.57	209.75	240

Legend: SF = silica fume; FA = fine aggregate; CA = coarse aggregate; NS = nanosilica.

Total mixing time of materials was 7 minutes, according to following order of placement: fine aggregate, 90% water, cement, additive SP, 10% water and coarse aggregate. In concrete containing silica fume, this material was added to mixture with cement.
After mixing, cylindrical specimens of 50 mm diameter x 100 mm in length were molded. After 24 h, specimens were demoulded and taken to humid chamber, where they remained until tests date.

1.3. Tests

The nanosilica and silica fume influence was evaluated in mechanical and physical properties of concretes, by means of mechanical resistance and water absorption by capillarity tests, and their durability against the chloride attack.

1.3.1. Mechanical strength

Mechanical strength was evaluated by means of compressive strength test at the age of 1, 7 and 28 days (ABNT NBR 5739, 2007) and tensile strength by diametrical compression at the age of 28 days (ABNT NBR 7222, 2011).

1.3.2. Water absorption by capillarity

Water absorption by capillarity test was performed based on NBR 9779 (ABNT, 2012).
After 28 days of curing, concretes were dried at 105 ± 5 ° C until reaching constant mass and then dry mass was determined at 23 ± 2 ° C. Specimens were placed on water above metal supports, to allow water contact with the specimen’s base, avoiding contact with other surfaces. The test lasted for 72 hours and the specimens were weighing at 3h, 6h, 24h, 48h and 72h after test beginning. After last weighing, specimens were broken to visualize maximum capillary rise reached by water.

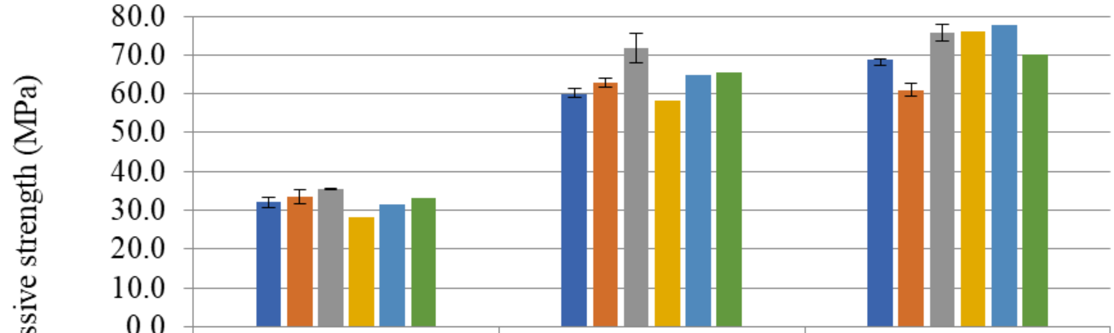
1.3.3. Chloride ions penetration

The deep of chloride ions penetration was determined by drying and wetting cycles in sodium chloride (NaCl) solution.
After 28 days of curing, concretes were left in a laboratory environment for 4-day drying and then immersed up to half the height in the NaCl solution (3.5%) for 3 days. After 3 days, specimens were removed from solution and the cycle was started again, which were repeated for 16 weeks.
After 8 and 16 weeks, specimens were broken and a silver nitrate solution (0.1 M) was sprayed onto fractured surface. In free chlorides presence, silver nitrate reacts and results in silver chloride (light color), and in absence, it generates silver oxide (dark color). The contrasting colors allow the verification of the depth of chloride ions penetration in concrete to be verified.

3. RESULTS AND DISCUSSION

3.1 Mechanical strength

The mean values of results obtained from compressive strength at the ages of 1, 7 and 28 days and 28-day tensile strength by diametrical compression tests are presented in Figures 3 and 4, respectively.



	1 day	7 days	28 days
C-0.1-0	32.0	59.8	68.7
C-0.3-0	33.5	62.9	61.0
C-0.5-0	35.4	71.7	75.7
C-0.5-10	28.2	58.1	76.0
C-0.7-10	31.4	64.9	77.7
REF	33.2	65.4	70.2

Figure 3. Compressive strength of concretes.

Results indicated that 0.5% nanosilica addition to concretes (C-0.5-0) induce a 9.6% and 7.1% increase in 7-day and 28-day compressive strength compared to reference concrete (REF), respectively.
When combining nanosilica with silica fume, it is noticed that in early ages REF reached a higher compressive strength. However, at 28 days, the concretes C-0.5-10 and C-0.7-10 reached 76.0 MPa and 77.7 MPa, respectively, while REF reached 70.2 MPa. The greatest resistance gain at 28 days, and even at 90 days, was also observed by other researchers (Senff et al., 2010; Joshagani; Moeini, 2017).
Evidences of a synergistic effect between these additions was not observed, since when adding silica in the mixture, for the same content of nanosilica (C-0.5-0 and C-0.5-10) there were no compressive strength gains.
Differently from that observed by Li et al. (2017a), who found that addition of 2% powder nanosilica caused a 17% increase in 28-day compressive strength, whereas at 10% silica fume the increase was 11%. By combining two additions, 2% nanosilica + 10% silica fume, the increase was 48%, evidencing the existence of a synergistic effect between the additions.
Regarding tensile strength by diametrical compression (Figure 4), results indicated that additions use did not induce significant improvements, especially when considering the standard deviations. However, Ganesh et al. (2016) observed gains of 17% and 24% in 28-day tensile strength of concrete, incorporating 1% and 2% nanosilica solution, respectively.

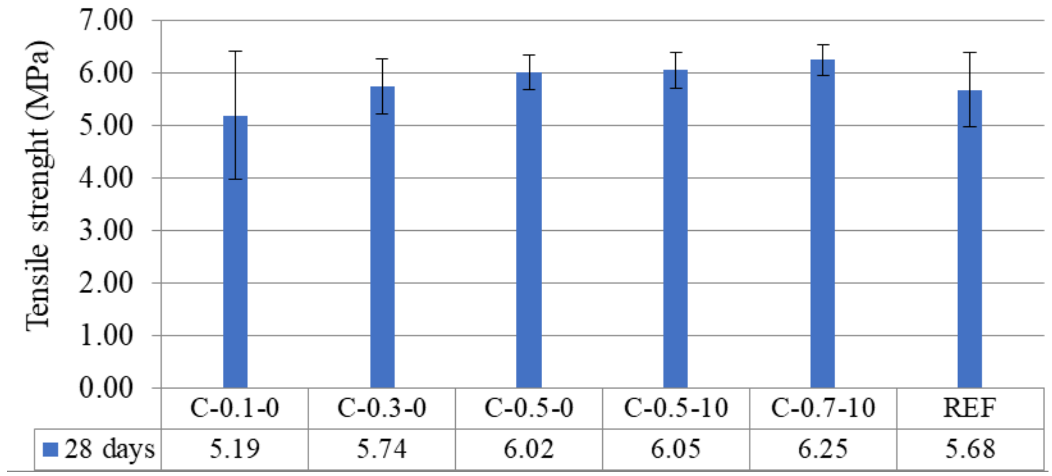


Figure 4. 28-day tensile strength by diametrical compression of concretes.

It should be emphasized that the nanosilica used in this work is dispersed in superplasticizer and it makes the study of its incorporating at higher levels difficult, including the recommended levels. Moreover, the real content of silica present in material is not known, making it impossible to determine its percentage in relation to binder.

3.2 Water absorption by capillarity

The results obtained in water absorption by capillarity test made possible to plot curves of capillary absorption versus square root of time for each studied concrete, during 72 hours of test (Figure 5).

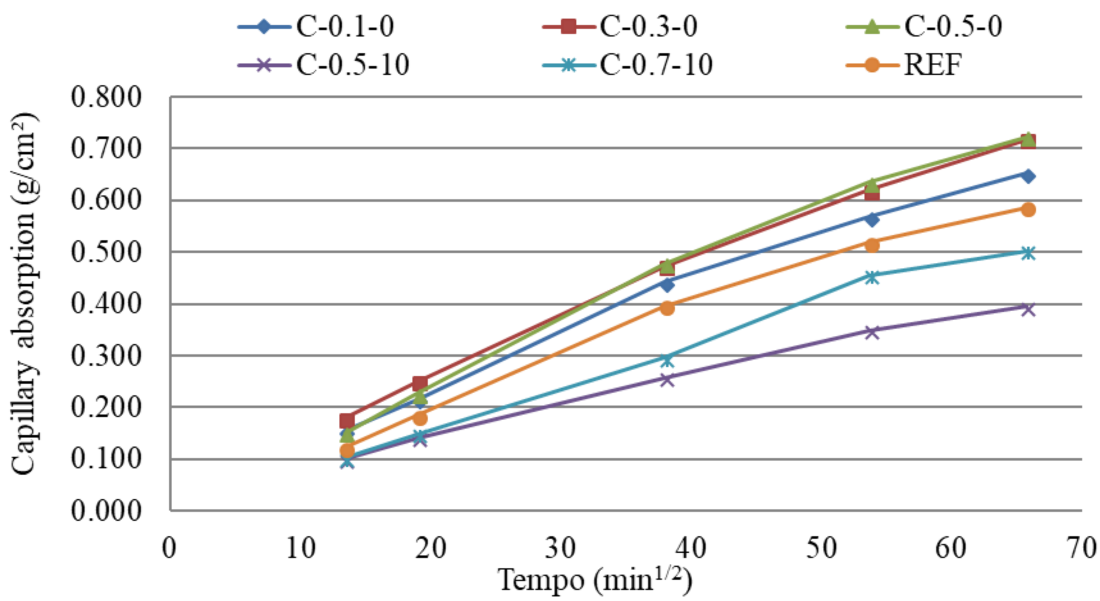


Figure 5. 28-day capillary water absorption of concretes.

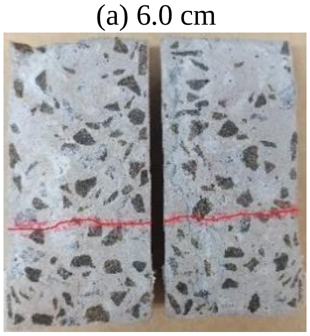
Note that isolated nanosilica addition in the analyzed contents did not improve the water absorption by capillarity, since C-0.1-0, C-0.3-0 and C-0.5-0 presented higher capillary absorption (between 0.652 g/cm² and 0.722 g/cm²) than the REF (0.587 g/cm^2). However, by raising the nanosilica content to 0.7% and adding silica fume (C-0.7-10), it was possible to reduce capillary absorption to 0.395 g/cm².

These results indicate that silica fume, with its filer and pozzolanic effects, was able to refine cementitious matrix microstructure. On the other hand, the nanosilica dispersed in superplasticizer does not have physical and chemical effects expected.
Other researchers studied the nanosilica effects on physical properties of cementitious materials and obtained positive results with reduction of sorptivity, absorption and voids index (Li et al., 2017b, Ganesh et al. 20116, Joshaghani and Moeini, 2017).
Should be commented that in the cited studies, the nanosilica were in powder or solution form. Therefore, it is possible that the dispersion of nanosilica in superplasticizer additive impaired the positive results in this work.
Figure 6 shows maximum capillary rises observed in concretes after 72 hours of test. It was observed that the concretes that had lower capillary absorption index (C-0.5-10 and C-0.7-10) also presented lower ascending height, corroborating the assertion that the silica fume was efficient in microstructure matrix refinement, unlike to concretes with nanosilica only (C-0.1-0, C-0.3-0 and C-0.5-0), which presented a maximum capillary rise higher than the REF.


(a) 6.0 cm


(b) 6.3 cm


(c) 5.0 cm


(d) 3.6 cm


(e) 3.3 cm


(f) 4.0 cm

Figure 6. Fractured specimens after water absorption by capillarity test:
a) C-0.1-0; b) C-0.3-0; c) C-0.5-0; d) C-0.5-10; e) C-0.7-10 e f) REF.

Besides filler effect, responsible for filling voids between cement grains and aggregates, the pozzolanic effect of silica fume also contributes to microstructure densification, due to additional C-S-H formation.

3.3 Chloride ions penetration

The depth of chloride penetration in concretes was determined after 8 and 16 weekly cycles of drying and wetting in NaCl solution. Results are shown in Table 7 and the specimens submitted to the colorimetric test are shown in Figures 7 and 8.

Table 7. Depth of chloride ions penetration

Chloride ions depth (mm)		
Concrete	**After 8 weeks**	**After 16 weeks**
C-0.1-0	9.4	11.7
C-0.3-0	7.6	11.4
C-0.5-0	8.6	12.3
C-0.5-10	5.4	6.4
C-0.7-10	5.6	5.1
REF	8.3	8.0

(a) (b) (c) (d) (e) (f)

Figure 7. Fractured specimens after colorimetric test - 8 weeks:
a) C-0.1-0; b) C-0.3-0; c) C-0.5-0; d) C-0.5-10; e) C-0.7-10; f) REF.

(a) (b) (c) (d) (e) (f)

Figure 8. Fractured specimens after colorimetric test - 16 weeks:
a) C-0.1-0; b) C-0.3-0; c) C-0.5-0; d) C-0.5-10; e) C-0.7-10; f) REF.

Overall, nanosilica addition did not prevent chlorides penetration into concrete. After 8 weeks, the depth of penetration on C-0.1-0, C-0.3-0 and C-0.5-0 concretes were similar to reference concrete (REF). Already after 16 weeks, REF presented a lower value than those containing additions.

On the other hand, concretes with combined addition of nanosilica and silica fume presented reduction in depth of penetration. The values obtained after 16 weeks for concretes C-0.5-10 and C-0.7-10 were 1.6 mm and 2.9 mm smaller than REF, respectively. These results were expected since they were the same concretes that obtained lower capillary absorption index, as discussed previously.

Silva (2006) realized the same tests on high performance concretes with 5 and 10% silica fume, and after 16 cycles drying and wetting cycles, obtained a reduction in the depth of penetration of 1.9 mm and 2.7 mm, respectively, compared to the reference concrete, which had a penetration front of 5.7 mm.

Regarding the nanosilica addition, although the present work has not obtained satisfactory results,

some studies indicate that 3% and 6% colloidal nanosilica addition in mortars could reduce 70% and 77% 28-day chlorides migration, respectively, in comparison to reference mortars (Joshaghani; Moeini, 2017).
Likewise, Ganesh et al. (2016) studied the nanosilica solution on concrete's durability, by means of chloride migration test. The authors observed that, at 28 days, 2% nanosilica addition increased the concrete resistance to aggressive ions penetration. These positive results were attributed to filler effect of nanosilica and its ability to fill the voids present in concrete, thus reducing chlorides penetration.

4. CONCLUSIONS

With obtained results, it was concluded that the addition of nanosilica dispersed in superplasticizer, in contents of 0.1% to 0.5%, did not give improvements to concrete as regards mechanical and physical properties, analyzed compressive strength, tensile strength by diametrical compression and water absorption by capillarity tests. Likewise, nanosilica did not reduce the depth of chloride penetration compared to reference concrete.
However, when used in contents of 0.5% and 0.7%, together with 10% silica fume, improvements were observed in both properties, increasing the mechanical resistance and reducing the water absorption by capillarity, besides reduction in depth of chloride penetration, when compared to reference concrete.
It should be emphasized that as nanosilica is dispersed in superplasticizer additive, it was not possible to evaluate other contents within the limits recommended, since the added content increasing leads to the workability increase, being able to culminate in loss of cohesion and exudation of the mixtures.

5. ACKNOWLEDGEMENTS

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Eccentrically-compressed reinforced concrete columns strengthened with partial jacketing

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ABSTRACT
The behavior of six uniaxial compression columns is investigated. Specimen featured an initial section of (120 x 200) mm^2, a final section of (200 x 200) mm^2 and height of 1.600 mm, strengthened on the tensile and compression sides with plaster or not. Adherence between new and old concrete, and cracking pattern was satisfactory. Although coated columns showed the same behavior to their respective non-coated ones even when concrete area was reduced by approximately 20%, problems consisted in the crushing of the reinforced concrete layer immediately prior to the rupture of the columns. This strengthening proved to be more adequate when undertaken at the columns´ compressed zone and may be executed through conventional procedures with or without mortar coating layer.
Keywords: columns; partial retrofit; partial jacketing; reinforced concrete.

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Pilares de concreto armado reforçados à flexo-compressão com encamisamento parcial

RESUMO

Investiga-se o comportamento de seis pilares à flexo-compressão. As amostras apresentaram uma seção inicial de (120 x 200) mm^2, uma seção final de (200 x 200) mm^2 e altura de 1.600 mm, reforçadas nos lados tracionados e comprimidos com reboco pré-existente ou não. A aderência entre concreto novo e velho, e padrão de fissuração foram satisfatórios. Embora os pilares revestidos tenham o mesmo comportamento dos pilares não revestidos, mesmo quando a área de concreto foi reduzida em aproximadamente 20%, os problemas consistiram no esmagamento da camada de reforço imediatamente antes da ruptura dos pilares. Esse reforço provou ser mais adequado quando realizado na zona comprimida podendo ser executado através de procedimentos convencionais com ou sem camada de argamassa de reboco.
Palavras-chave: pilares; reforço parcial; encamisamento parcial; concreto armado.

Columnas de hormigón armado comprimido de forma excéntrica y reforzados con encamisado parcial

RESUMEN

Se investiga el comportamiento de seis columnas a flexo-compresión con sección inicial (120 x 200) mm^2, sección final (200 x 200) mm^2 y altura de 1.600 mm, reforzadas en los lados traccionados y comprimidos con revoque preexistente o no. La adherencia entre hormigón nuevo y viejo, y patrón de fisuración fueron satisfactorios. Aunque los pilares revestidos tienen el mismo comportamiento de los no revestidos, incluso cuando el área de hormigón se redujo en aproximadamente 20%, los problemas consistieron en el aplastamiento de la capa de refuerzo inmediatamente antes de la ruptura de los pilares. Este refuerzo resultó ser más adecuado cuando se realiza en la zona comprimida, a través de procedimientos convencionales con o sin capa de revoco de mortero.
Palabras clave: pilares; refuerzo parcial; encaje parcial; concreto armado.

1. INTRODUCTION

Although reinforced concrete structures may be considered permanent, they reveal pathological problems during their life span. In fact, some structures behave excellently, while others reveal premature failure. Certain pathologies are long-lasting in spite of unrelenting search for quality. Available methods for their prevention and correction still require improvements. Guimarães *et al*. (2016) report that different types of pathologies may appear in the structure, which, in its turn, causes several problems and may even provoke ruptures. Greater loads than those calculated in the designing state, faults in the project, variations in humidity, corrosion processes in the reinforced concrete, intrinsic and extrinsic thermal variations to the concrete, biological agents and inadequate use of material, may cause pathological problems. The consequences are an inadequate degree of the structure´s safety (ultimate limit state) and of conditions in the use of the construction (service limit state), which influences the structure´s functional conditions. According to Gillum *et al* (2001), a recent development in concrete structures´ repair and rehabilitation consists of thinner strengthening layers of reinforced concrete used as jackets. In view of the relevance of the theme given the frequent demands for structural reinforcement in civil works, this research aims to contribute to the evaluation of the column strengthening and with the analysis of the experimental tests study the structural behavior and the efficiency of the partial jacketing of coated and non-coated reinforced concrete columns, submitted to uniaxial compression. The above justifies the development of research on the structural behavior of reinforced concrete columns, since jacketing technique is normally more adequate to increase resistance to compression, increase of the transversal sections and the strengthening of reinforced concrete (Gomes & Appleton, 1998). So that jacketing may be successful, the rupture of the new concrete should be avoided when the structure returns to service loads.

2. LITERATURE REVIEW

2.1 Calculation method

Axial load and bending moments are predominant in the normal concrete columns. They are called normal loads since they induce normal stress (tensile and compression) to the column´s transversal section, with maximum rates at the surface of the columns. The situation is common and, as a rule, it occurs due to the stiffness of the connection or to the eccentricity of the vertical forces caused by the imperfections of the constructions. Frequently, the columns of buildings are affected by eccentric activities, so that an initial eccentricity (e) should be taken into account for the designing of the column. The columns of buildings generally undergo uniaxial or biaxial compression due to connections between beams and columns, and to the position of them with regard to the main axes of the columns´ transversal section.

The Interaction Diagram Method was employed to calculate the uniaxial compression strength, following recommendations by Wight & Macgregor (2009) and the prescriptions and simplifications of ACI 318 (ACI, 2008), coupled to parameters of NBR 6118 (ABNT, 2014). As an example of the calculation methodology, Figure 1 shows a uniaxial compression transversal section in which two layers of longitudinal reinforced concrete are compressed, whilst the lower layer in the transversal section A_{s3} is tensioned, where F_{s1}, F_{s2} and F_{s3} are the force in each steel layer, and F_c is the compressive force in concrete. The deformation limits adopted takes into account a concrete crushing at 3.5‰ and a steel yielding at 2.62‰ (ε_{s3}, experimentally obtained) for all the reinforcement bars.

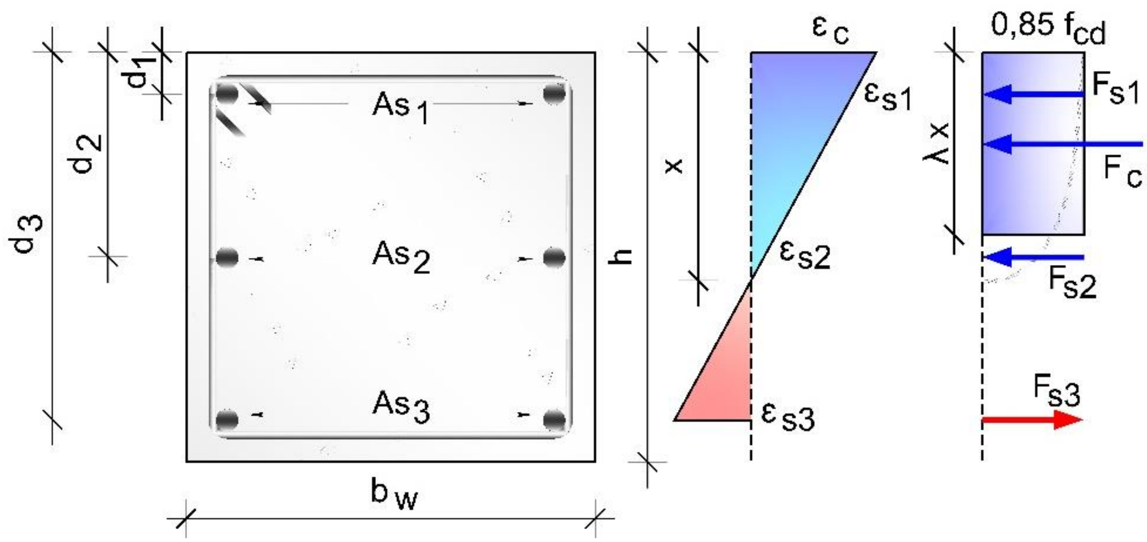

Figure 1. Stress, strain and resultant forces in the transversal section of the column.

Equation 1 determines maximum compression load applied to the column; Equation 2 determines the bending strength, taking into consideration a uniaxial compression, where: f_c is compressive strength; x is the neutral line; b is the section width; ε is the material strain; E is the modulus of elasticity of steel; A_s is the steel area; h is the section height; F is the force in the layer; d is the effective depth.
When deformation limits are established, the interaction diagram may be performed, as Figure 2 shows, where: M is the bending moment; P is the axial load. Figure 2 shows possible interactions and action plane of bending moments (M_x and M_y) and axial load (P), coupled to a simplification so that the bending moment may be considered only at the main direction (M_x), like studied in this current work.

$$P_{RK} = 0.68.f_c.x.b + \sum_{i=1}^{n} \varepsilon_{si}.E_s.A_{si} = F_c + \sum_{i=1}^{n} F_{si} \quad (1)$$

$$M_{RK} = F_c.(\frac{h}{2} - 0.4.x) + \sum_{i=1}^{n} F_{si}.(\frac{h}{2} - d_i) \quad (2)$$

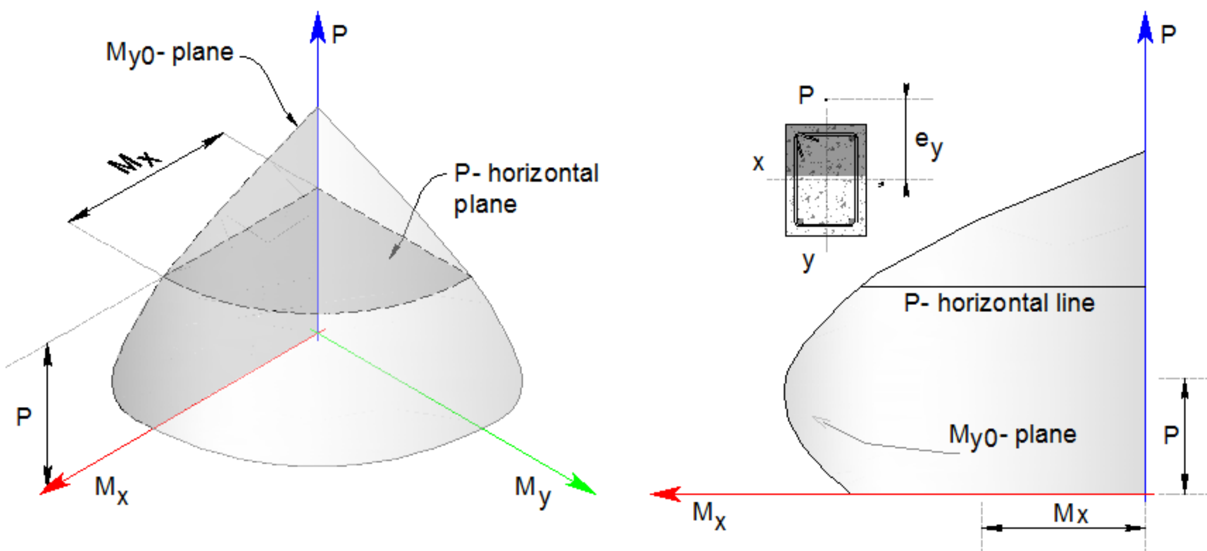

Figure 2. Interaction diagram for biaxially and uniaxially loaded sections (Macgregor, 1996).

Adorno (2004) developed a research of rectangular reinforced concrete columns submitted to uniaxial compression, in order to prove the calculation method developed by Mello (2003). The concrete presented average 40 MPa compressive strength and the experimental program was composed of 12 specimens, divided into two series: PSA and PCA. The PSA series consisted of four columns and the PCA was composed of eight columns. All of them had a rectangular cross section of (250 × 120) mm², subjected to axial load plus uniaxial bending. The bar spacing, and the minimum concrete cover followed the recommendations of NBR 6118 (2007).

By analyzing the ultimate loads, it is possible to observe that the PSA columns crushed with a higher load than the PCA series, due to the increased compressive strength. According to Adorno (2004), the initial eccentricity variation had poor influence on the critical tensile stress which was evidenced by the advanced cracking stage. The author concluded that the models tested kept the proportionality between the longitudinal deformation and the distance from the neutral axis to the rupture, confirming the validity of the Bernoulli's principle, that the plane sections before bending remain plane after bending, which validates the model used in the present research.
Melo (2009) developed an experimental and numerical study of the behavior of hinged reinforced concrete (40 MPa) columns submitted to axial load plus uniaxial moment. In order to continue the research developed by Adorno (2004), columns with the same cross section and longitudinal reinforcement rate (1.57%) were used. The experimental program composed 24 columns divided into three series according to its length, where the main variable was the uniaxial eccentricity. The columns had a cross section of (250 x 120) mm² and bar spacing and minimum concrete cover according to NBR 6118 (ABNT, 2007) recommendations.
The experimental results showed a proper functioning of the test system, which validates the methodological procedures applied in this present research, with columns failure occurring at half height, as expected. Also, the main variable of the tests performed was the uniaxial eccentricity, what shows great influence on the columns ultimate load. A nonlinear response of the bending strength was observed as a function of the slenderness and eccentricity of the force application in the columns. Melo (2009) verified that the conservatism of the ultimate force predictions methods increases as the uniaxial eccentricity is reduced.

3. PROCEDURE

3.1 General characteristics

Six partially jacketed concrete columns were analyzed and submitted to axial load plus uniaxial bending. All columns were monitored by electrical resistance strain gauges (extensometers), placed longitudinally to the column to register concrete and steel's deformation. Digital comparative monitors were employed to obtain displacements. Variables comprised the position of partial jacketing and the presence or absence of a cement-sand mortar coating. Transversal section, longitudinal reinforcement rate, compression strength, and positioning of extensometers used in the tests setup, were constant for all columns.
The eccentricity of axial load was 100 mm when compared to the longitudinal axis of the column´s span. The columns were divided into two groups: a group of columns strengthened in the compression zone (PCR, PCS and PCSR) and another group of columns strengthened in the tensile zone (PTR, PTS and PTSR). A control column was cast in each group, one simulating the column strengthening without the removal of the mortar coating of the original section and the other with the complete removal. Control columns featured a transversal section of (200 × 200) mm² and total length of 1.600 mm, with slenderness index of approximately 28. Strengthened columns had an initial section of (120 × 200) mm² and total length of 1.600 mm, with 80 mm of strengthening layer. After the retrofit, the columns showed a final transversal section identical to that of the reference columns. Figure 3 demonstrates the columns´ size, and the concrete corbel made to prevent premature concrete cracking in the strengthened specimens.

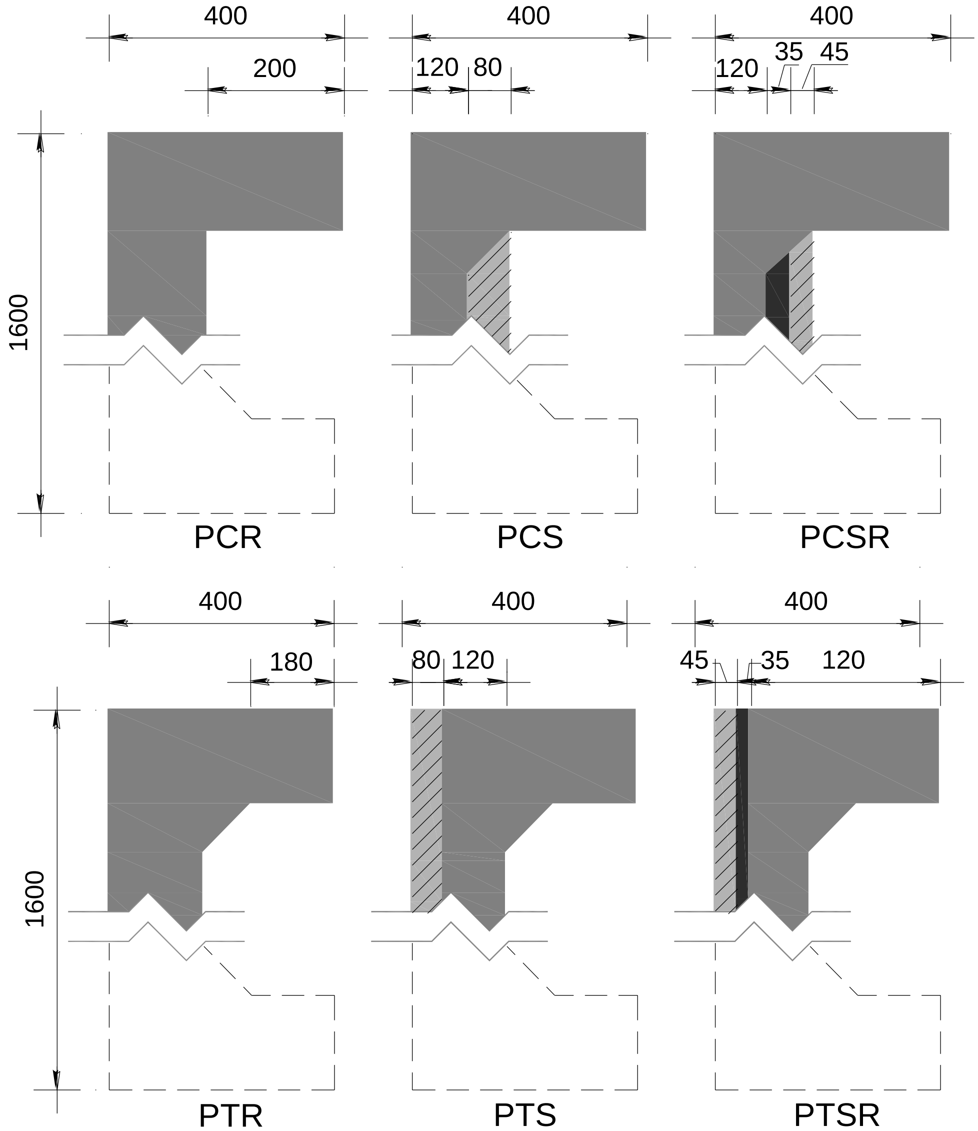

Figure 3. Sizes of columns.

3.2 Reinforcement

Representing conventional situation, the longitudinal reinforcement of reference columns featured 6 Ø 10.0 mm (A_s = 4.71 mm²), with stirrups measuring Ø 5.0 mm spaced at every 100 mm at the center, and Ø 5.0 mm for every 50 mm at the edges. Further, additional open stirrups were employed with epoxy adhesive, measuring Ø 5.0 mm for every 100 mm, later fixed in the hardened concrete to help in adherence between new and old concrete. Initial reinforcement of all columns measured 4 Ø 10.0 mm (A_s= 314 mm²), with two longitudinal bars added for reinforcement, meeting the number of bars used in the reference columns without any reinforcement, or rather, 6 Ø 10.0 mm (A_s = 4.71 mm²). Transversal reinforcement were of the same specification as that in the reference columns (Figure 4).

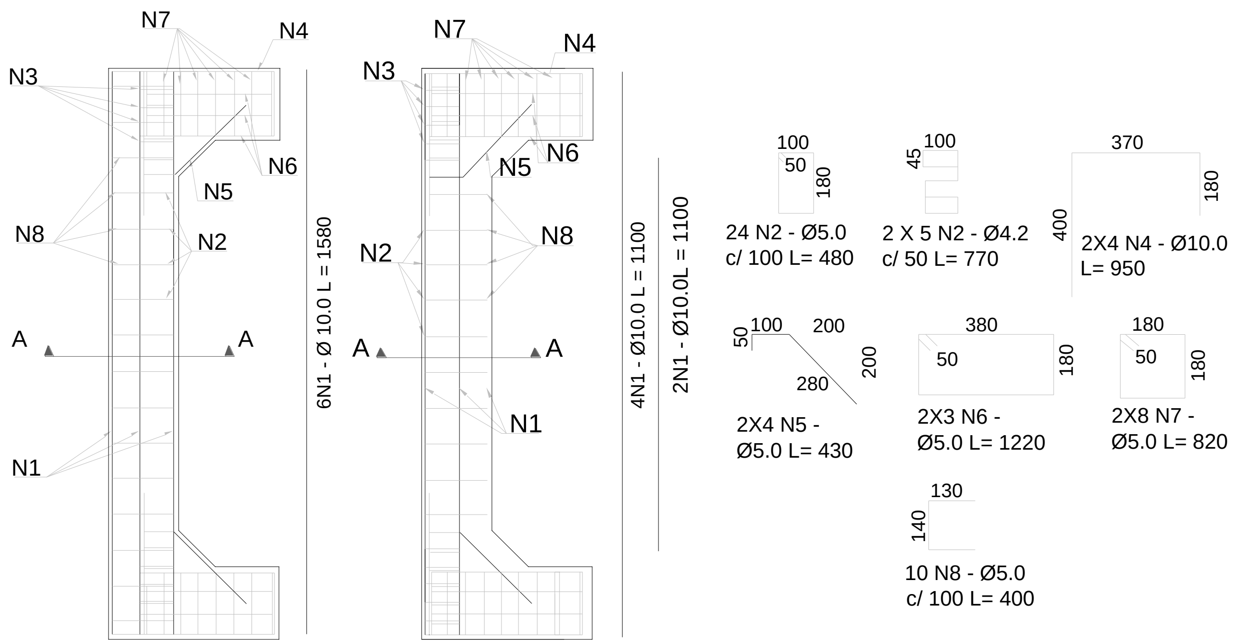

Figure 4. Reinforcement of columns.

3.3 Instrumentation

3.3.1 Concrete

For reinforcement at the tensile and compression region of the columns, the transversal reinforcement (open stirrups) was fixed into the hardened concrete with an epoxy-based structural adhesive in 60 mm-deep holes. It comprised Ø 5.0 mm stirrups every 100 mm, simulating procedures in civil work. Posterior to the fixing of open stirrups (Figure 5), extensometers were placed on the concrete. A cement-sand mortar coating was applied to the PTSR and PCSR columns prior to the installation of the open stirrups. Another extensometer was placed on the coating surface. Longitudinal reinforcements (2 Ø 10.0 mm) were positioned to complete the positioning of the reinforcement by placing the wooden moldings and for the casting of concrete. The instrumentation of the concrete surface was finalized by placing an extensometer on the strengthening layer.

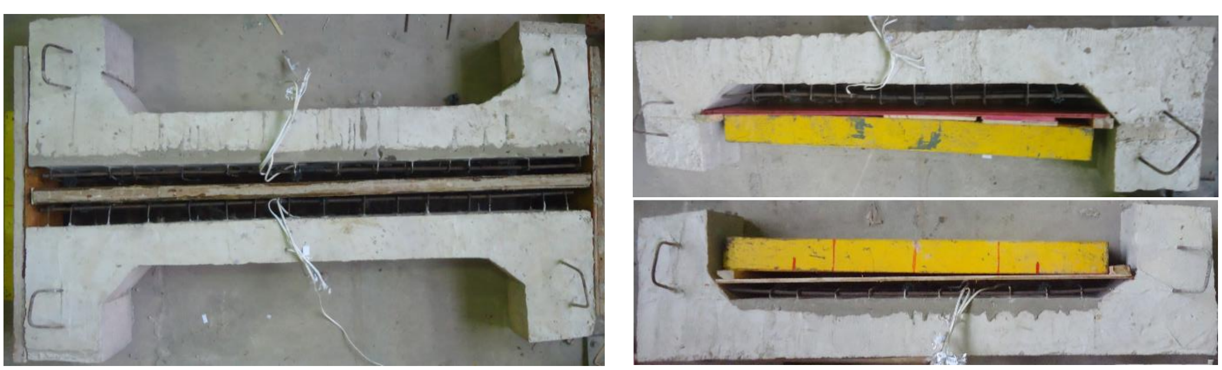

Figure 5. Extensometers installed in the concrete (PTS; PTSR; PCS; PCSR respectively).

3.3.2 Reinforcements

Electrical resistance strain gauges were used on concrete and reinforcement bars to monitor deformations during the tests. Figure 6 shows the positioning of sensors in the columns PTR, PTS and PTSR and Figure 7 displays the placement of sensors in columns PCR, PCS and PCSR. Extensometers were positioned half way the columns´ length.

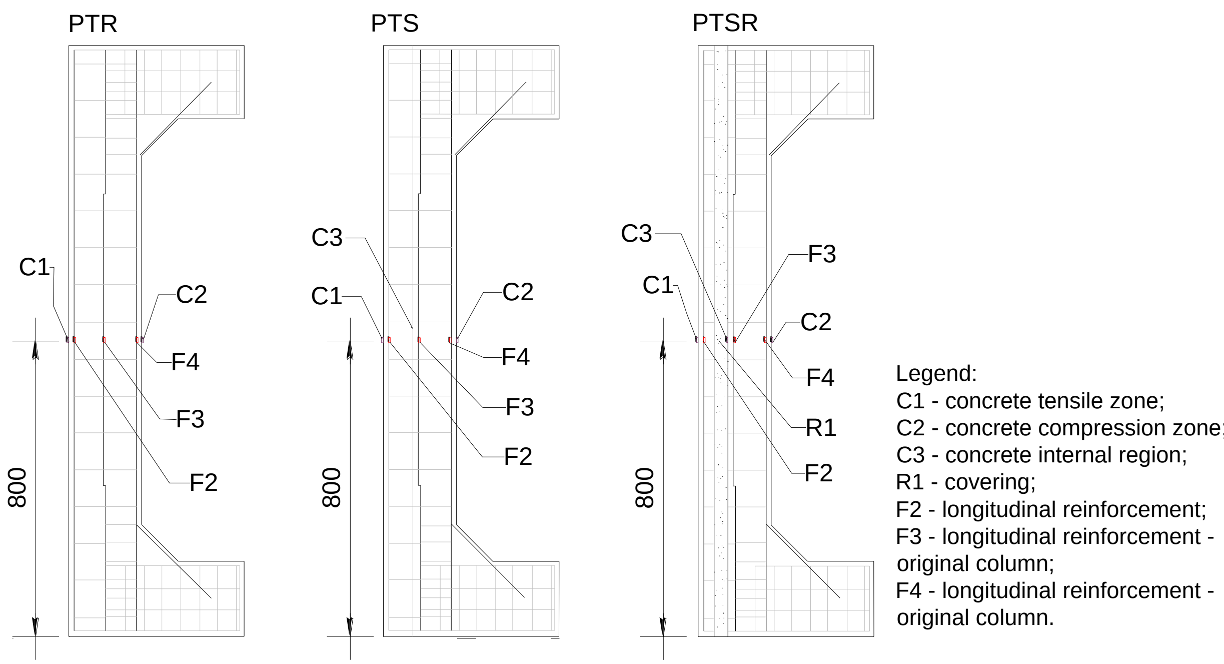

Figure 6. Extensometers on the rebar and concrete of the tensile zone strengthened columns.

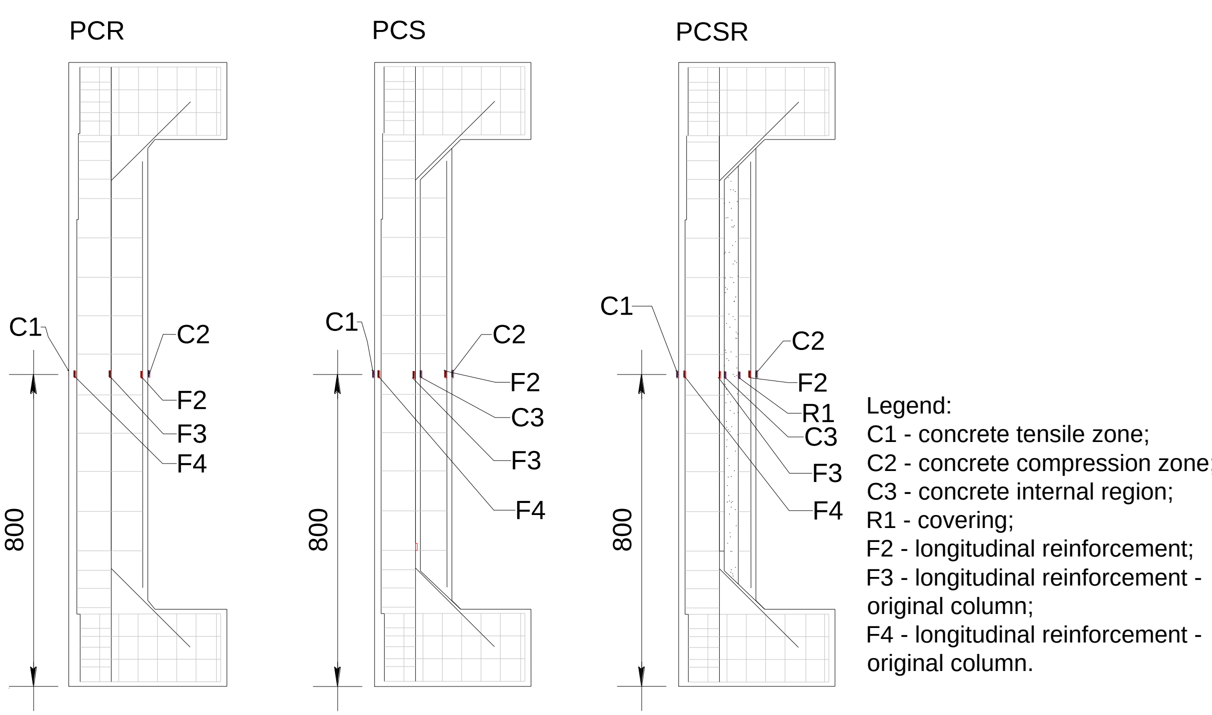

Figure 7. Extensometers on the rebar and concrete of the compression zone strengthened columns.

3.4 Test system

Figure 8 details the test setup used in the experimental analysis of the columns. The system comprised a highly rigid metallic frame fixed to the reaction slab, a 2000 kN hydraulic jack driven by a hydraulic pump for loading, and a 2000 kN load cell with a 0.5 kN precision, locked to a digital indicator for load recording. Columns were coupled in pinned supports, simulating hinges placed eccentrically to the columns´ axis and thus making viable the expected uniaxial compression. Extensometers were read by a computer-connected data logger, for sensors installed in the rebars and for those fixed on the concrete surface.

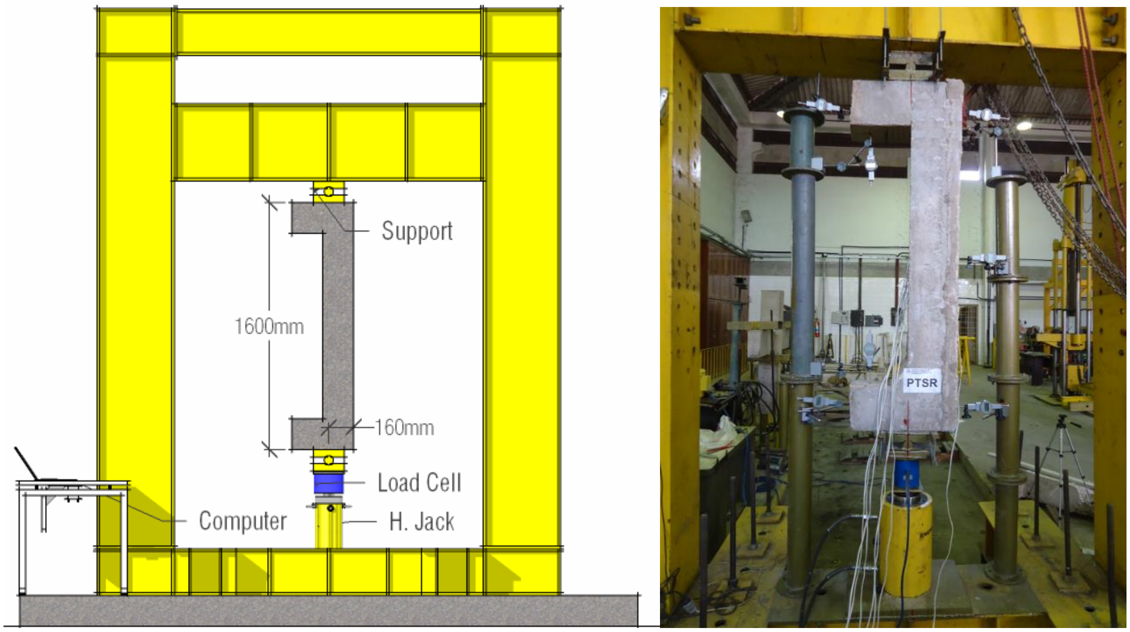

Figure 8. Testing setup system.

4. TEST RESULTS

4.1 Steel and concrete

The columns were pour simultaneously. Column was reinforced after 28 days of cement-sand mortar coating. Three cylindrical specimens were casted at each concreting stage and tested according to NBR 5739 (ABNT, 2007), with compressive strength (f_c) 7.0 MPa and 32.0 MPa respectively for coating mortar and concrete. Concrete modulus (E_{cs}) was equivalent to 28.1 GPa. In the case of the steel bars, tests were performed following NBR 8522 (ABNT, 2008). Results for yielding stress (f_{ys}) and modulus (E_s) were 662.0 MPa and 218.4 GPa for 5.0 mm diameter bars and 548.1 MPa and 209.2 GPa for 10.0 mm diameter bars, respectively.

4.2 Loads and failure modes

Control columns PTR (reference tensile strengthened column) and PCR (reference compressive strengthened column) revealed the concrete´s fragile failure in the compression zone near the middle span. PCR also showed failure close to edge, in the compression zone. Reinforced columns also revealed different failure modes, even though they demonstrated a monolithic behavior during tests immediately before failure. PTS reinforced column behaved monolithically immediately before failure, even though, on this occasion, the loosening of reinforcement occurred at the zone close to the upper end. A similar behavior has been registered for the mortar cover of column PTSR. PCS column, reinforced at the compression zone, revealed monolithic behavior up to column failure, without any loss or crack at the strengthening layer or the concrete interface.

The crushing of the concrete at the zone close to the edge occurred. PCRS column showed cracking pattern on the surface between reinforcement and substrate immediately prior to failure.
Table 1 displays failure loads, maximum tensile strain of the steel (ε_s) and maximum compression strain of the concrete (ε_c), the ultimate axial load (N_u), and the comparison between ultimate load and the load prediction (N_{Ref}) for PTR and PCR columns, and the columns´ failure modes. Failure modes were defined taking into account deformation and failure characteristics, observed experimentally. Control column PTR failed at 340 kN axial load, revealing steel deformations higher than yield ($\varepsilon_s \geq \varepsilon_{ys}$=2.62‰). Reference column PCR crushed at 400 kN axial load, corresponding to approximately 120% of last load provided by column PTR. Tensile strengthened columns PTS and PTSR presented failure by detachment of strengthening layer. Further, compression-reinforced columns PCS and PCSR were failed at the tensile zone with steel yielding and crushing of concrete at the compression zone, no signs of detachment were registered.

Table 1. Loads and failure modes.

Column	Strengthened zone	coating	ε_s (‰)	ε_c (‰)	N_u (kN)	N_u/N_{Ref}	Failure mode
PTR	-	No	3.2	3.6	340	-	Yield and crushing
PTS	Tensile	No	2.4	1.9	300	0.88	Strengthening failure
PTSR	Tensile	Yes	2.8	2.3	320	0.94	Strengthening failure
PCR	-	No	4.9	1.9	400	-	Concrete crushing
PCS	Compression	No	4.0	3.5	400	1.01	Yield and crushing
PCSR	Compression	Yes	3.4	2.0	370	0.92	Yielding

5. ANALYSIS OF RESULTS

Table 2 displays experimental failure loads (N_u), experimental bending moment (M_u), initial (e_i) and final (e_f) eccentricities, theoretical failure load (N) and flexural strength (M) estimated by the interaction diagram, the relationship between experimental failure load and estimated load (N_u/N) and the relationship between theoretical and experimental bending moments (M_u/M). Results for the theoretical bending moment were satisfactory for the PTR, PTS and PTSR columns, at mean rate 1.09 for M_u/M; rate reached 1.36 for the PCR, PCS and PCSR columns. Cement-sand mortar covering was not significantly damaged in the two reinforcement conditions. In other words, columns reached or went beyond estimates. In the case of axial load, columns revealed experimental loads lower than the theoretical estimates. Mean result (0.88) for Nu/N was better for the columns strengthened in compression zone.
Figure 9 shows an interaction diagram (based on MacGregor & Ibrahim, 1996) of the transversal section common to all columns and their respective final experimental resistance. For any eccentricity there is a unique pair (M/N), and plotting these series of pairs corresponding to a different eccentricity the interaction diagram is obtained. The horizontal axis shows the bending moments values and the vertical axis the axial load values, so the radial lines show constant eccentricity. The more vertical radial lines the smaller eccentricity conducting to compression failure range, so the more horizontal radial lines the bigger eccentricity conducting to tension failure range. The linear load trajectory shows a proportional well balanced failure for both steel and concrete of the columns cross section according to NBR 6118 (2014). When load trajectories were compared, the second order effect, associated to physical non-linearity, decreased estimates of ultimate resistance to normal load up to 28%, whereas a mere 5% reduction occurred.

The above demonstrates that, even at low slenderness indexes, this effect should be taken into account due to decrease in the safety of the columns. Whereas Figure 10 shows post-cracking columns, Figure 11 details damaged zones. The columns strengthened in the tensile zone showed detachment of concrete layer near the column´s edge, due to the pullout of the stirrups with the failure of the column. The failure of the compressed zone at the edge of PCR column may also be noted.

Table 2. Comparison of estimated and experimental results.

Column	f_c (MPa)	N_u (kN)	M_u (kN·m)	e_i (mm)	e_f (mm)	N (kN)	M (kN·m)	N_u/N	M_u/M
PTR	32	340	48.3	100	142	442.7	39.6	0.77	1.22
PTS		300	39.3		131			0.68	1.00
PTSR		320	42.2		132			0.72	1.07
PCR		400	56.4		141			0.90	1.42
PCS		400	56.0		140			0.90	1.41
PCSR		370	48.8		132			0.84	1.23

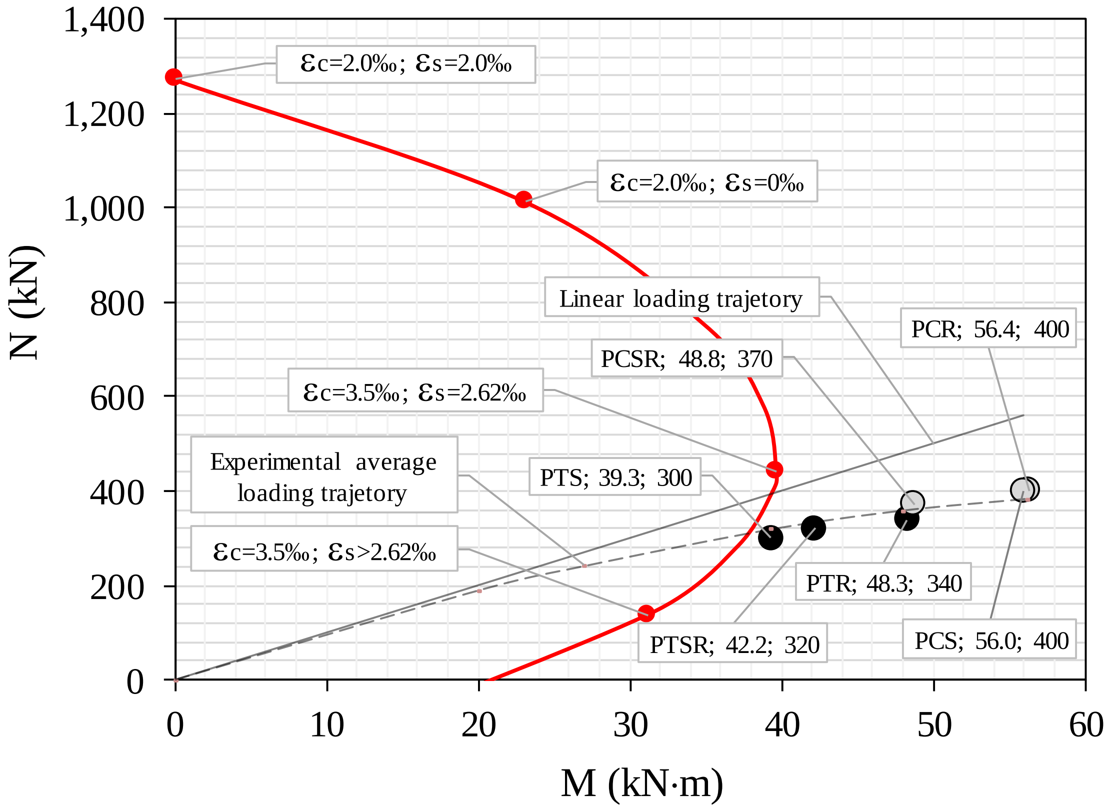

Figure 9. Interaction diagram results.

Figure 10. Columns after failure.

Figure 11. Details of columns after failure.

6. CONCLUSIONS

Current test provides the experimental results of six concrete columns strengthened at different zones, tensile and compression surface, submitted to uniaxial compression. Results were analyzed taking into consideration different compression strength of the columns, strengthening zone and maximum displacements in the central zone of the columns. Maximum displacement of columns reached 44 mm, within the failure estimates and the elaboration of the interaction diagram.

The strengthened columns PTS, PCS, PTSR and PCSR showed a similar behavior, with no evident deformations on the concrete original surface, which indicates that the concrete between the strengthening layers was not crushed. The coating applied on the surface of the original section of the PTSR column did not suffer major deformations, instead of the PCSR column. The results were satisfactory since the column that presented greater loss, the PTS column, had an average loss of 35%.
The PCR, PTR, PTS and PTSR columns provided results beyond the estimates, with maximum loss of 32% for the PTS column, the one without mortar coating, with detachment immediately before failure. The control and strengthened to compression columns had the best performance among the columns under analysis. The above was corroborated by analysis made by the interaction diagram. PTSR and PCSR coated columns had a similar behavior to their respective non-coated ones (PTS and PCS), even when concrete area was reduced by approximately 20%. The partial jacketing under uniaxial compression proved to be more adequate when undertaken at the columns´ compressed zone and may be executed through conventional procedures. Regarding to removal or not of the mortar covering, tests revealed very small influence in the columns´ strength and a behavior similar to that of columns without any covering, occurring detachment immediately prior to the columns failure.

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Colorimetry of clays modified with mineral and organic additives

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ABSTRACT
The objective of this investigation was to quantify the colorimetric values of clay with different types of additives. Aesthetic appreciation, based on the color of clay with different addition percentages (by clay mass), is explored using clay from the Santiago Undameo Bank, Mexico. The clay was kaolinite, and the additions were gypsum, lime, opuntia cactus mucilage, Portland cement, and sodium hydroxide. The addition percentages were 2%, 4%, 6%, 8% and 10%. The best colorimetric performances were obtained from Portland cement at 6%, sodium hydroxide at 4%, lime and gypsum at 8% and opuntia cactus mucilage at 4% and 8%. Some buildings where these clay materials were used are Casas grandes in Paquimé, Chihuahua, La Venta in Tabasco, and Yácatas in Tzintzuntzan, among others.
Keywords: clay; colorimetry; additives; restoration.

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Colorimetría de arcillas modificadas con adiciones minerales y orgánicas.

RESUMEN

El objetivo es cuantificar los valores de los diferentes colores obtenidos en arcillas con adiciones, comparados contra una arcilla base. Se explora la apreciación estética, en base al color de las arcillas con diferentes adiciones usando arcilla del Banco Santiago Undameo, México. Las adiciones son yeso, cal, mucílago de cactus opuntia, cemento portland e hidróxido de sodio. Los porcentajes en peso fueron 2, 4, 6, 8 y 10%. Los mejores comportamientos colorimétricos fueron los resultados obtenidos del cemento portland al 6%, hidróxido de sodio al 4%, cal y yeso al 8% y mucílago de cactus opuntia blanco con porcentajes al 4 y 8%. Algunas construcciones donde se emplearon estos materiales arcillosos son: Casas Grandes en Paquimé, Chihuahua, La Venta en Tabasco; Yácatas en Tzintzuntzán, entre otros.

Palabras clave: arcilla; colorimetría; adiciones; restauración.

Colorimetria de argilas modificadas com adições minerais e orgânicas.

RESUMO

O objetivo é quantificar os valores das diferentes cores obtidas em argilas com adições. Exploramos a apreciação estética de diferentes adições e porcentagens de argilas do Banco Santiago Undameo, no México. As adições são gesso, lima, mucilagem de cítrica de opuntia, cimento portland e hidróxido de sódio; os percentuais em peso da argila são 2, 4, 6, 8 e 10%; os melhores comportamentos colorimétricos foram obtidos a partir de cimento portland a 6%, hidróxido de sódio a 4%, lima e gesso a 8% e mucilagem de branco opuntia cactus com porcentagem de 4% e 8%. Alguns edifícios onde esses materiais de argila foram utilizados são: Casas grandes en Paquimé, Chihuahua, La Venta en Tabasco, Yácatas en Tzintzuntzan, entre outros.

Palavras chave: argila; colorimetria; adições; restauração.

1. INTRODUCTION

Within the field of restoration, it is very important to determine the loss of the color intensity of materials used for restoration or preservation because subjective observation can lead to errors in the appreciation of tonalities.

Due to its availability as well as ease in changing its properties and adapting them to application needs, clay is widely used in construction and pottery.

It should be considered that the restoration of historic buildings is an intervention mainly aiming to respectfully recover such cultural heritage, and thus, it requires specialists on the subject for project writing; research and analysis; and work direction and supervision so that the interventions proposed in the project are applied in a correct, respectful, and socially responsible manner.

1.1 Background

This study was performed to complement studies on buildings constructed from raw earth and adobe. This is relevant for their conservation and restoration in Mexico, Latin America, and the entire world because there is a considerable number of artifacts and structures, especially from the preclassic and epiclassic periods, with great cultural value built from these materials (Cuéllar López, 2014). The clay deposit used to extract the materials of this study was selected based on the existence of important Catholic heritage temples on the shores of Lake Pátzcuaro (Pueblo Mágico), Mexico. These important temples for the colony were constructed with a mixed masonry of clay, ignimbrites, and tufa, with proportions conceived according to the European scholars Vitrubius, Palladio and Alberti but with historic technology modified by the Purhépecha ethnic group. Examples of these types of constructions are the Basilica of Our Lady of Good Health [Basílica de Nuestra Señora de la Salud], the temples of Janitzio, Jeráhuaro, Tzintzuntzán, Quiroga, Santa Fe, Ihuatzio, Cucuchucho, Napízaro, Erongarícuaro, Ichupio, San Andrés, San Jerónimo, and others.

Clay is not a translucent or colorless material; it usually has colors ranging from whitish to black (Eleoterio et. al., 2016), including ochres, browns, reds, grays, and less commonly, greens. It was also used to color decorative paintings (Rathossi et. al., 2010; Lin et. al., 2014; Viscarra et. al., 2009; Hu et. al., 2007). Reddish and ochre colors are formed by iron oxides present in the different clay forms (Mahmoudi et. al., 2016; Hradil et. al., 2016; Valanciene et. al., 2010; Li et. al., 2015). Clay can be composed of crystalline minerals such as quartz, but with dimensions of ≤ 2 µm, and therefore, they are considered to be clay minerals because they are found in clay sediments (Özkan and Zeliha, 2016). Their crystal structure allows them to have hygroscopic volume changes and a large surface area. They are plastic materials, which expand and contract based on their moisture, and thus, this behavior is changed by the addition of different materials to prevent volume changes. These materials are known as volumetric stabilizers or simply just stabilizers. The literature refers to some stabilizers such as lime, which reduces the material's expansion-contraction, suggesting maximum values of 15% of the clay's weight. Stabilizers are also used because clay is not water soluble and has limited durability when exposed to the environment (rain, sun, solar radiation, capillary moisture, precipitation in the form of rain, prevailing winds, etc.) unless it is subjected to a high temperature converting it into a ceramic, which is physically and mechanically more stable (Özkan and Zeliha, 2016). Materials such as hydraulic cement, phosphates, aluminum salts, and recently polymers have been used as stabilizers. These materials modify the physical-chemical properties of the clays, thus reducing their expansion in the presence of water (López et. al, 1999). There are other stabilizing materials such as lime (Anikwe et.al., 2016; Zhang et. al., 2015; Hotineanu et. al., 2015; Khemissa and Mahamedi, 2014; Modarres and Nosoudy, 2015; Sangiorgi et. al., 2016), cement (Vali Vakili et. al., 2016; Wu et. al., 2016: Mardani-Aghabaglou et. al., 2015; Zak et. al., 2016; Gupta et. al., 2017), sodium hydroxide (caustic soda) (Yaowu et. al., 2017; Cong et. al., 2015; Carrol et. al., 1971), white opuntia cactus mucilage and gypsum (Flores Rentería, 2010; Olguín Domínguez, 2008: Velázquez Pérez, 2015; Ahmed et. al., 2014; Kuttah and Sato, 2015; Ahmed and Ugai, 2011). As a result of their studies, these researchers found materials with less changes in volume and similar colors for the formation of adobe and mortars for the reconstruction of cultural heritage in a sustainable and environmentally friendly manner. The addition of organic microfibers to clay does not substantially change the color, and their main benefit lies in supporting dynamic and meteoric requirements (Mattone, 2005), which is not the aim of this study.

Likewise, an earlier study used several additives with proportions between 1% to 10% clay weight. Values above 10% resulted in visual color changes. Smaller changes were observed with percentages of up to 10% clay weight (Flores Rentería, 2010; de León Ambrosio, 2017; Flores Ponce 2018). It was observed that there were no significantly large aesthetic and mechanical changes between the following pairs: 1% and 2%; 3% and 4%; 5% and 6%; 7% and 8%; and 9% and 10%.

The aim is to provide mechanical stability to the clay studied so it can be used, mainly, in restoration but with minimal alteration to the colorimetric properties compared to the original clay.

1.2 Colorimetric Analysis

Colorimetric quantification is a non-destructive test (Gómez 2008; Johnston, 2001; Lamb and Bourriau, 1995), which fortunately can be performed *in situ* in the case of historic buildings. There

are multiple systems to measure color such as the following: Münsell (Albert Henry Münsell, 1915), Ostwald (Friedrich Wilhelm Ostwald, Color Science 1923, Nobel 1909), DIN (Deutsche Institut für Normung or German Standards Institute), Swedish Natural (Skandinaviska Färginstitutet AB, the Scandinavian Institute of Color in 1960, which then changed to NCS), NCS (Natural Color System, USA, 1985), OSA (OSA-UCS, Optical Society of America Uniform Color Space, 1947), Küppers (Harald Küppers, Germany, Color Theory, 1992), etc.
In 1924, the International Commission on Illumination (CIE for its acronym in French, Commission Internationale de l'Éclairage) developed two of the most widely used systems for the evaluation and measurement of color in terms of reflectance, the capacity of surfaces to reflect the spectral light of the sample. The first of them was created in 1931 based on the tri-stimulus values (X, Y, Z), and the second was created in 1976 referring to color spaces (L*, a*, b*).

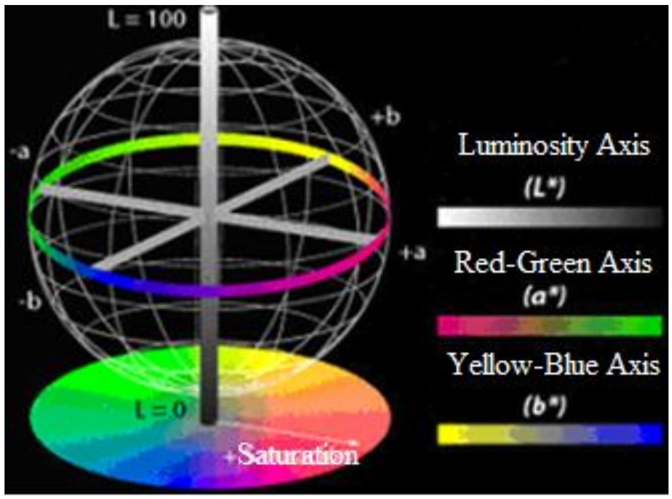

Figure 1. Diagram of the color spaces L*, a*, and b*. The L* axis or luminosity axis ranges from 0 (black) to 100 (white), while the a* and b* axes range from -128 to 127. Those cases in which a* = b* = 0 are achromatic. Therefore, L* represents the gray achromatic scale ranging from white to black, Stephen Westland ©.

The CIE XYZ system specifies chromatic stimuli based on the tri-stimulus values of three primary colors, and the basis of this system was the 2º standard observer. This 2º standard observer is the result of experimentally establishing an equality between monochromatic wavelengths with mixtures of the three additive primary colors (red, green, and blue). On the other hand, the tri-stimulus values are the quantities of these primary colors that specify a color stimulus, and they are known as X (red), Y (green) and Z (blue). For the 2º standard observer, they have values of X = 55.55, Y = 57.33 and Z = 90.25.
Therefore, given the need for a uniform color space, the CIE L*a*b* system, also known as CIELAB, was created. It is a system based on the luminosity L* (light or dark) and the opposing colors a* (a* positive red, and -a* negative green) and b* (b* positive yellow, and -b* negative blue), which indicate the color orientation (Figure 1).
After the color was quantified, it was necessary to quantify the difference between a reference and a sample. The calculation of these differences is one of the most important applications of colorimetry.
Under these terms, colorimetry is a very useful tool in the preservation work of different pieces of art as well as cultural and artistic heritage because during the preservation, the aesthetic or chromatic characteristics of the object cannot be altered, respecting the original work of the creators. To achieve this, a correct choice of the materials to be used during the different interventions must be performed, considering the effectivity of the treatments used and the

chromatic modifications that the work can sustain. Thus, it is necessary to perform a colorimetric study before, during and after each restoration to achieve the least noticeable application of materials in the restoration.

2. METHODS

First, a characterization of the clay using X-ray diffraction was performed. This allowed the base composition of the clay to be determined and was followed by a colorimetric analysis of the clay as well as with the different additives to observe their effects on the colorimetric properties. The mechanical properties were not evaluated because that was not the aim of this study.

2.1 Materials Used

The clay originated from the Santiago Undameo Clay Deposit, Michoacán, Mexico, near the capital, located at the coordinates 19º42' latitude north and 101º11.4' longitude west. In addition to the clay, different mineral and organic material additives were used as mentioned.

In the experimental design, percentages of 2%, 4%, 6%, 8% and 10% were chosen according to studies performed by (Flores Rentería, 2010; de León Ambrosio, 2017; Flores Ponce, 2018), and they were compared against a control with no additives.

2.2 Specimen Preparation

The selected clay was mixed with the stabilizers according to ASTM D 6276 standard, where the additives were added to the mixture when combining the materials (clay-addition) and water for kneading at the indicated percentages. The additives were incorporated dry while maintaining a constant temperature between 23-25°C, and the pH of the mixture was verified to be approximately 12.4 (Flores Rentería, 2010). The specimens used for color quantification were stabilized clay pellets of 1.5 inches in diameter and ¼ inch thick, as observed in Figure 3.

2.3 X-Ray Diffraction Analysis

A non-compacted sample was used in the X-ray diffraction analysis to guarantee the random orientation of the particles with respect to the monochromatic incident beam (Dyson, 2004; Benjamin, 1969; Kittel 2005).

In this case, a Bruker AXS model D8 Advance diffractometer with a Linx detector and a Cu X-ray tube with a monochromator were used. Figure 2 shows the X-ray diffractogram corresponding to the clay studied. The peaks obtained were compared with the reflection patterns of the JCPDF (Joint Committee on Powder Diffraction Standards) database. This comparison allowed it to be established that the clay being studied was mainly composed of quartz (Q) and kaolinite (K). In areas where granite rocks and porphides decompose on a large scale, clay is usually found in large kaolin layers, where it is mixed with free quartz and iron oxides of some other minerals present (Dana, 1986). The XRD was performed at the Institute of Physics of the National Autonomous University of Mexico [Universidad Nacional Autónoma de México, IFUNAM). The kaolinites presented surface areas of 15 to 20 m^2/gr.

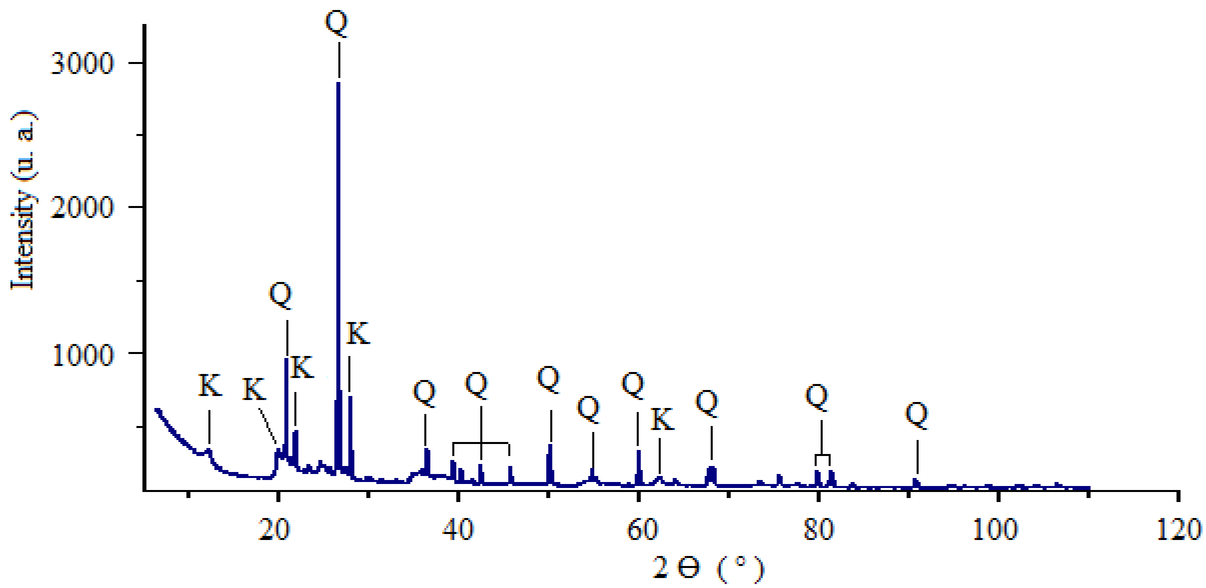

Figure 2. Clay XRD to identify the type of crystal; Q refers to quartz and K refers to kaolinite.

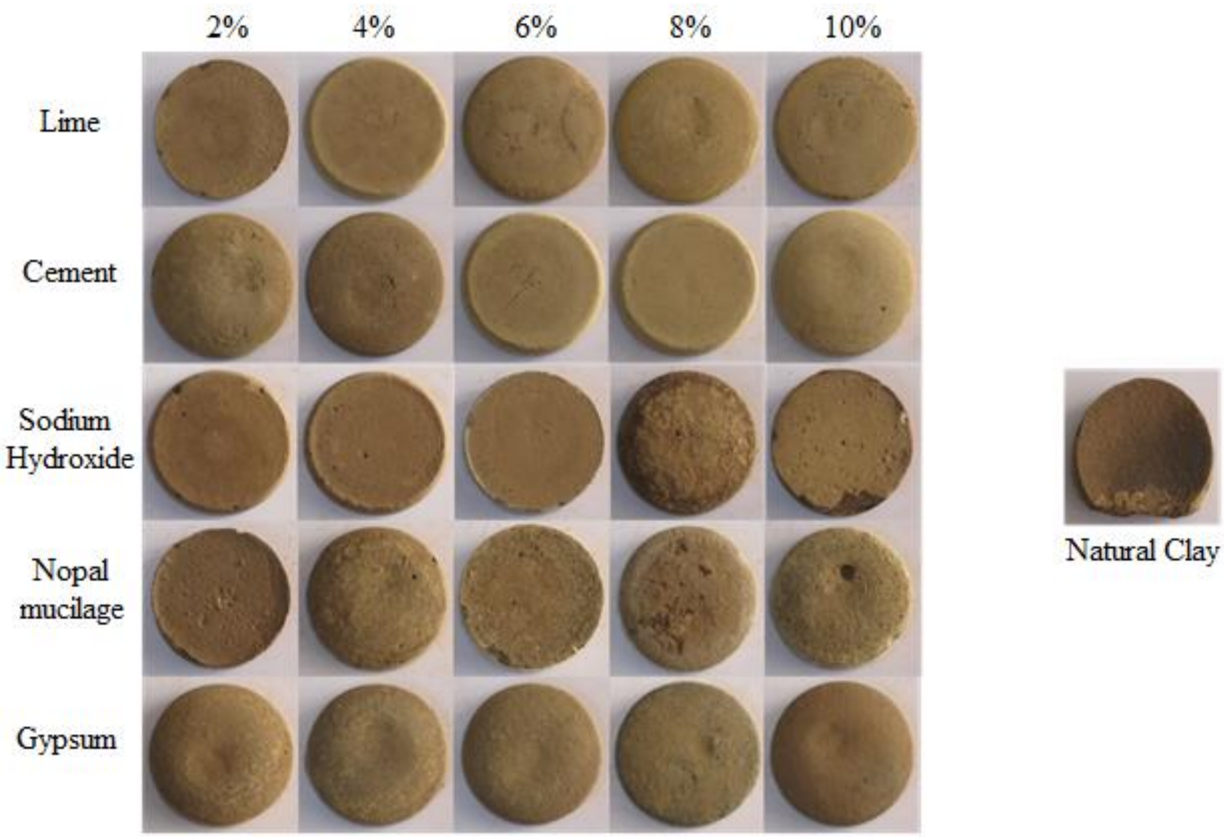

Figure 3. Clay pellets (tablets) supplemented with lime, Portland cement, sodium hydroxide, white opuntia cactus mucilage and gypsum at 2, 4, 6, 8 and 10%.

2.4 Colorimetric Analysis

To stabilize the base clay, 5 different materials or products were added: lime, Portland cement, gypsum, nopal mucilage, and sodium hydroxide (caustic soda). The aim of these colorimetric measurements is to establish the chromatic changes that the different stabilizers and concentrations produce compared to the natural clay.

The colorimetric analyses of natural clay and clay modified with different concentrations of additives were directly performed on the specimens with an Ocean Optics USB2000 spectrophotometer with an optic fiber for visible and infrared light, a silica CCD linear detector and a double probe with 400 µm diameter fibers.
The probe consists of six fibers that illuminate the surface and a central probe that reads the scattered light. The equipment was calibrated with a white reference, and the noise, corresponding to the measurement captured in black with the detector's grating closed, was removed. The integration time for each measurement was 50 ms, and 10 integrations were performed to decrease the noise of the scattered light spectrum.
The specimens were analyzed by the obverse and reverse with three measurements on each side in light, dark and medium zones in order to average the color measurements obtained. Data relating to the luminosity, a* and b* coordinates, chroma (C) and hue (h) were analyzed with the Ocean Optics SpectralSuite® software.

3. RESULTS

The colorimetric measurements of natural clay were established according to Table 1. Plotting these data in the CIE L*a*b* color space (Figure 4) and performing a juxtaposition with the region of the chromatic circle corresponding to these coordinates allowed it to be established that the clay had red and yellow tones, as expected due to the color it obtains when baked.
The clay's luminosity was found in the center of the CIE L*a*b* system, and thus, it can be considered a slightly opaque material. This characteristic is due to the rugosity of the surface of this compound, which impedes the specular reflection of the light it receives. Thus, if the aim is to replicate the colorimetry of this compound, it is not only necessary to find similar colorimetric measurements but also a similar texture. Moreover, for experimental and regulatory purposes, the clay was passed through a 200 ASTM mesh and retained in 400 ASTM mesh, indicating a diameter of 63.5 to 127 microns.

Table 1. CIE L*, a*, and b* chromaticity coordinates of the natural clay used. The table shows the average of luminosity (L*), amount of red–green (a*) and amount of blue–yellow (b*) the sample has as well as its hue (h) and chroma (C).

NATURAL CLAY (CONTROL WITH NO ADDITIVES)				
L*	a*	b*	H	C
43.2± 6.2	11.1± 2.8	11.8± 4.0	46.0± 2.4	16.2± 4.8
37.00 to 49.40	8.30 to 13.90	7.80 to 15.80	43.60 to 48.40	11.40 to 21.00

The previous results in Table 1 and Figure 4 serve as comparison for the colorimetric measurements with the different additives. In the case of the addition of lime to the clay (Figure 5), it was observed that concentrations of 2, 4 and 8% had comparable colorimetric values to those of natural clay, while concentrations of 6 and 10% did not, as their distances to coordinates a* and b* of the clay had higher values than the standard deviations reported for such data.

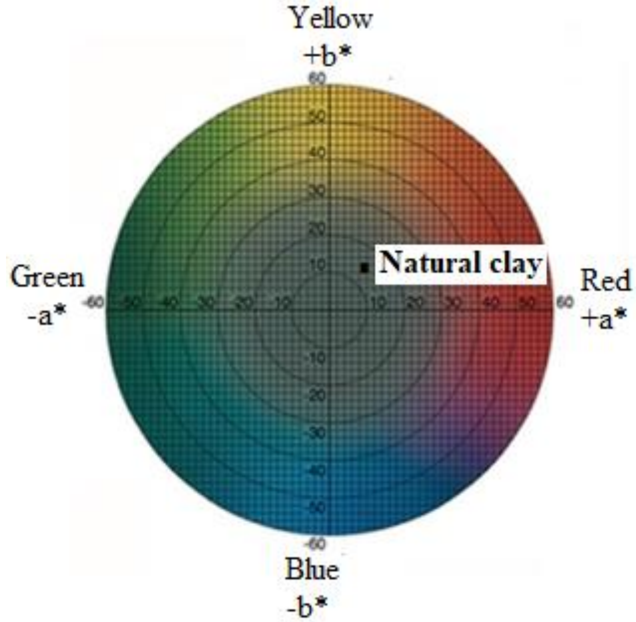

Figure 4. Natural clay average of coordinates a* and b* are shown in addition to its tone with the chromatic circle.

It is possible to analyze this with Figure 5, which indicates the position of the additions compared to the clay. This figure showed that the points corresponding to 6 and 10% additions are the farthest from the clay's colorimetric position. It is considered that a difference of two units in this colorimetric coordinate system is required for a difference in color to be visible with the human eye.

The amount of luminosity of lime-added clay is comparable with the magnitude of the luminosity of the natural clay because the measured values, with their respective standard deviations, are within the interval of uncertainty compared to the value of the clay.

The colorimetric measurements of clay with different amounts of cement added are shown in Figure 6. Analogous to the analysis for lime, coordinates a* and b* of such additions were compared to those of the natural clay. Based on this, it was found that except for coordinate b* of the 8% addition, all colorimetric distances are lower than the deviations of coordinates a* and b* corresponding to each addition. This allows confirmation that the colorimetric measurements of natural clay and samples with cement added at any percentage are quite similar.

This is evident in Figure 6, where although there are points far away from the natural clay, such as the 2% addition, this value falls within the uncertainty. The samples with cement added also showed luminosity values similar to those of natural clay, but in general, they are lighter. However, the deviations of these values include the value of the natural clay.

In clay with sodium hydroxide (caustic soda), there is a similar situation as with cement; all colorimetric distances fall within the standard deviation interval, except for coordinate b* of the 8% addition. This is evident in Figure 7, where the point corresponding to clay only falls outside the uncertainty marked for coordinate b* of the 8% addition.

Except for the 8% addition, the samples with sodium hydroxide added are more luminous than the natural clay, but the standard deviations of all concentrations indicate that such values are comparable with the luminosity of natural clay.

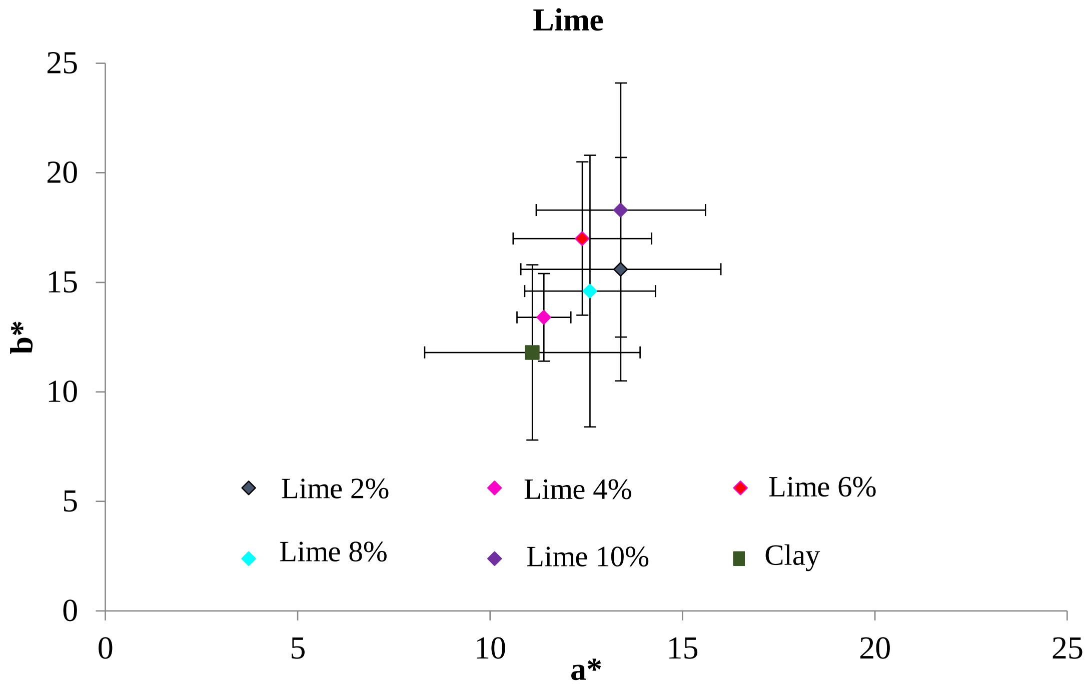

Figure 5. This figure shows, on average, the coordinates a* and b* of the different addition percentages of lime as well as the colorimetric position of natural clay. The tone of the points is summarized using the chromatic circle.

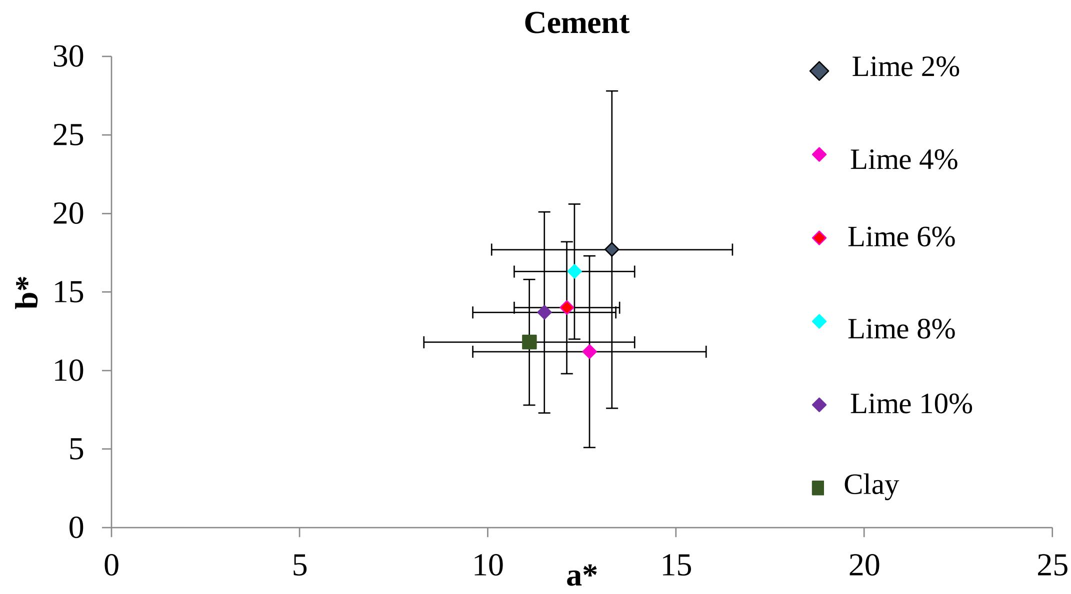

Figure 6. This figure shows, on average, the coordinates a* and b* of the different addition percentages of Portland cement as well as the colorimetric position of natural clay. The tone of the points is summarized using the chromatic circle.

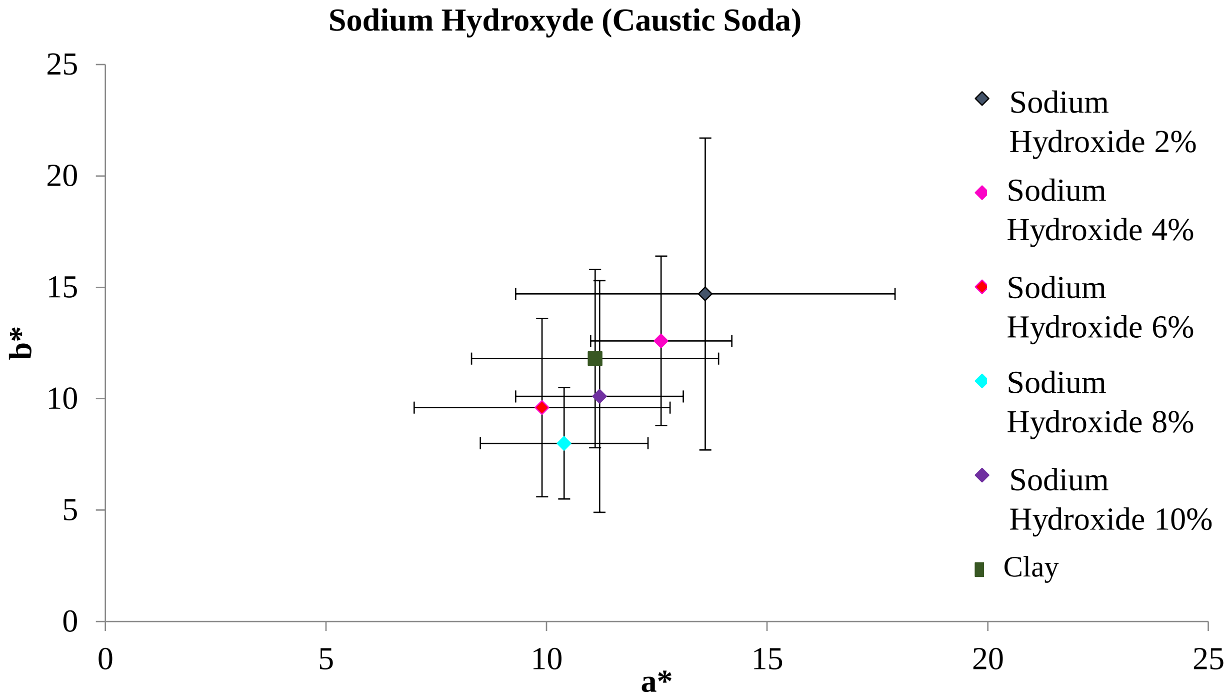

Figure 7. This figure shows, on average, the coordinates a* and b* of the different addition percentages of sodium hydroxide as well as the colorimetric position of natural clay. The tone of the points is summarized using the chromatic circle.

Regarding clay with addition of nopal mucilage, the colorimetric distance between clay and the 6% addition falls outside of the standard deviation (Figure 8). In this case, it is also possible to say that there is satisfactory similarity between the tones of the samples different amounts of nopal mucilage added and clay.

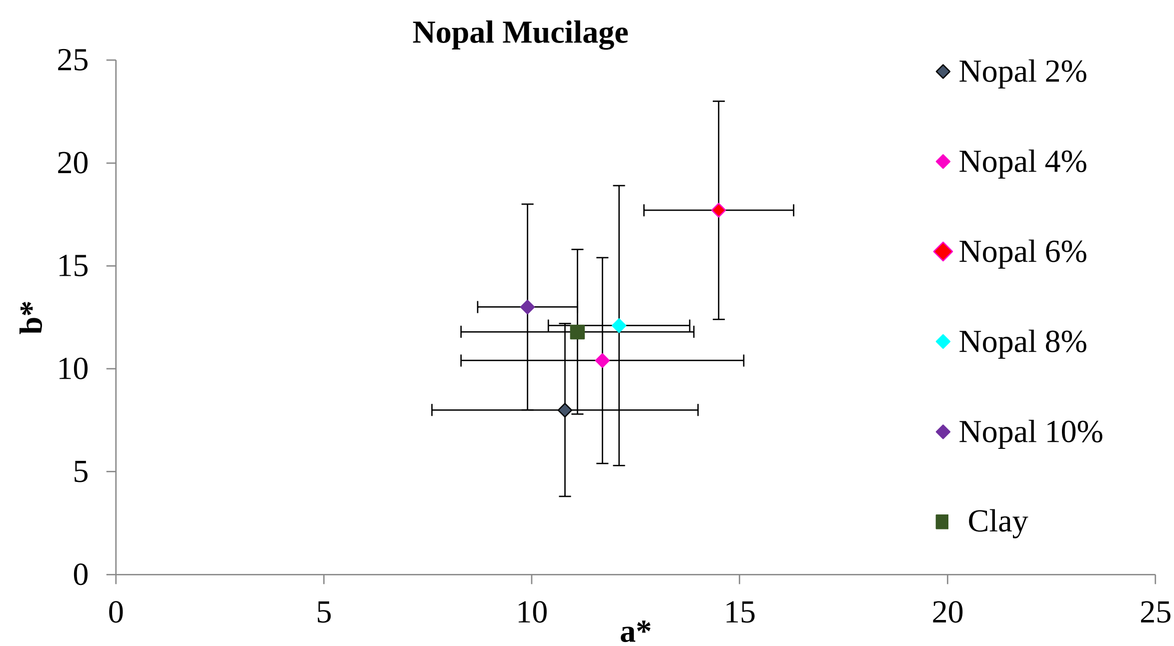

Figure 8. This figure shows, on average, the coordinates a* and b* of the different addition percentages of white opuntia cactus mucilage as well as the colorimetric position of natural clay. The tone of the points is summarized using the chromatic circle.

The luminosities of the samples with nopal mucilage added are similar to those of the natural clay with the exception of the 6% addition, which turns out to be the most luminous addition of all samples and whose value, even with the standard deviation, is higher than the value measured for clay.
For clay with gypsum added, only the 8% addition falls within the standard deviation range. In general, the remaining additions fall outside this range in either one (2 and 10%) or both coordinates (4 and 6%). This is shown in Figure 9, where the points, compared with previous figures, are more distant from the natural clay point, and thus, this element has the least similar colorimetric values compared to clay. The samples with gypsum added are more opaque than natural clay; 6, 8 and 10% have similar values with those of natural clay, but the concentrations of 2 and 4% are more opaque, despite the deviations.
On the other hand, the colorimetric distances between the different concentrations for each addition are shown in Figure 10. This figure shows the comparison of the coordinates a* (red lines), b* (yellow lines) and L* (gray lines) of each additive percentage compared with the same coordinates of natural clay (dotted lines).

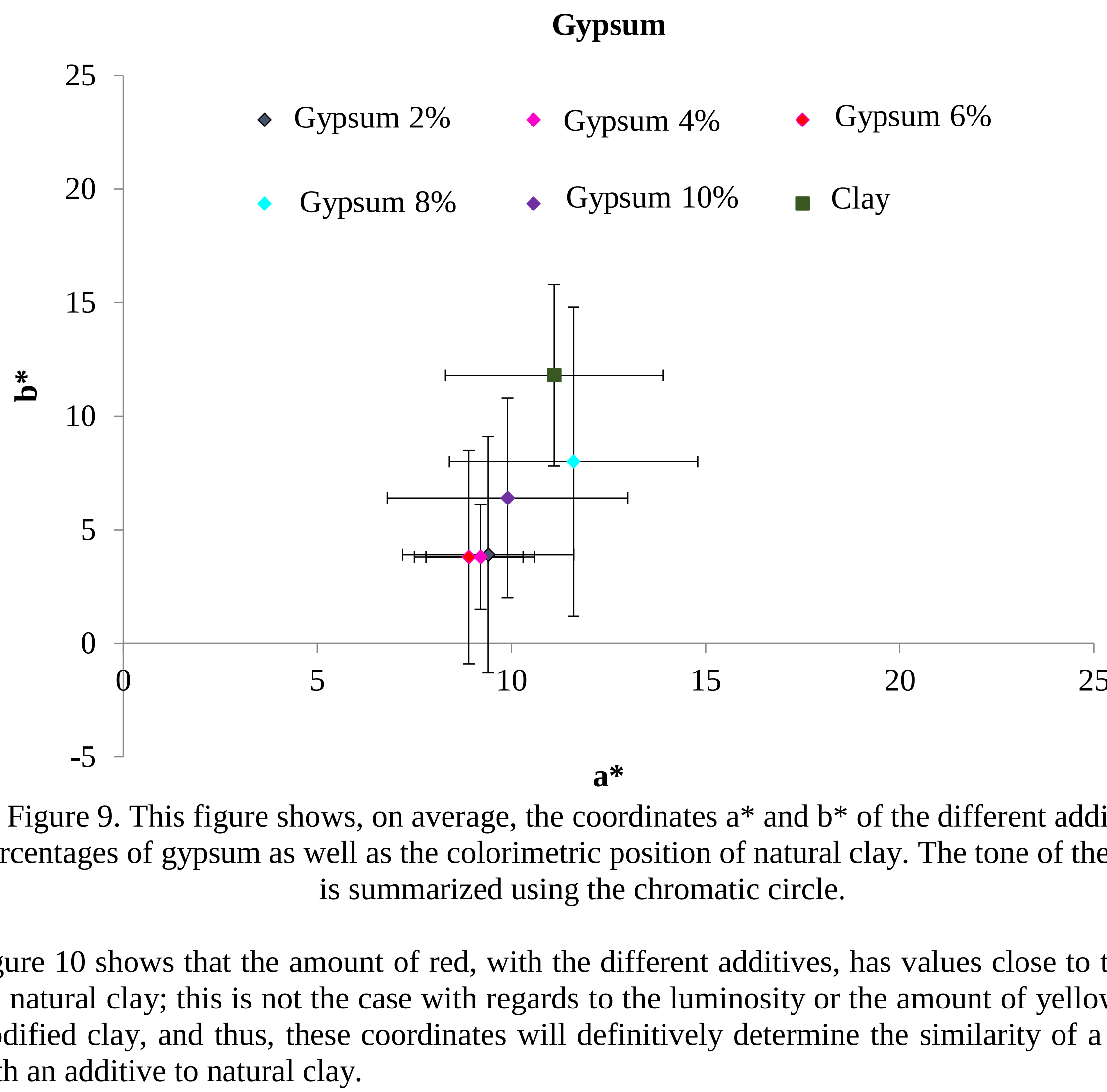

Figure 9. This figure shows, on average, the coordinates a* and b* of the different addition percentages of gypsum as well as the colorimetric position of natural clay. The tone of the points is summarized using the chromatic circle.

Figure 10 shows that the amount of red, with the different additives, has values close to those of the natural clay; this is not the case with regards to the luminosity or the amount of yellow in the modified clay, and thus, these coordinates will definitively determine the similarity of a sample with an additive to natural clay.

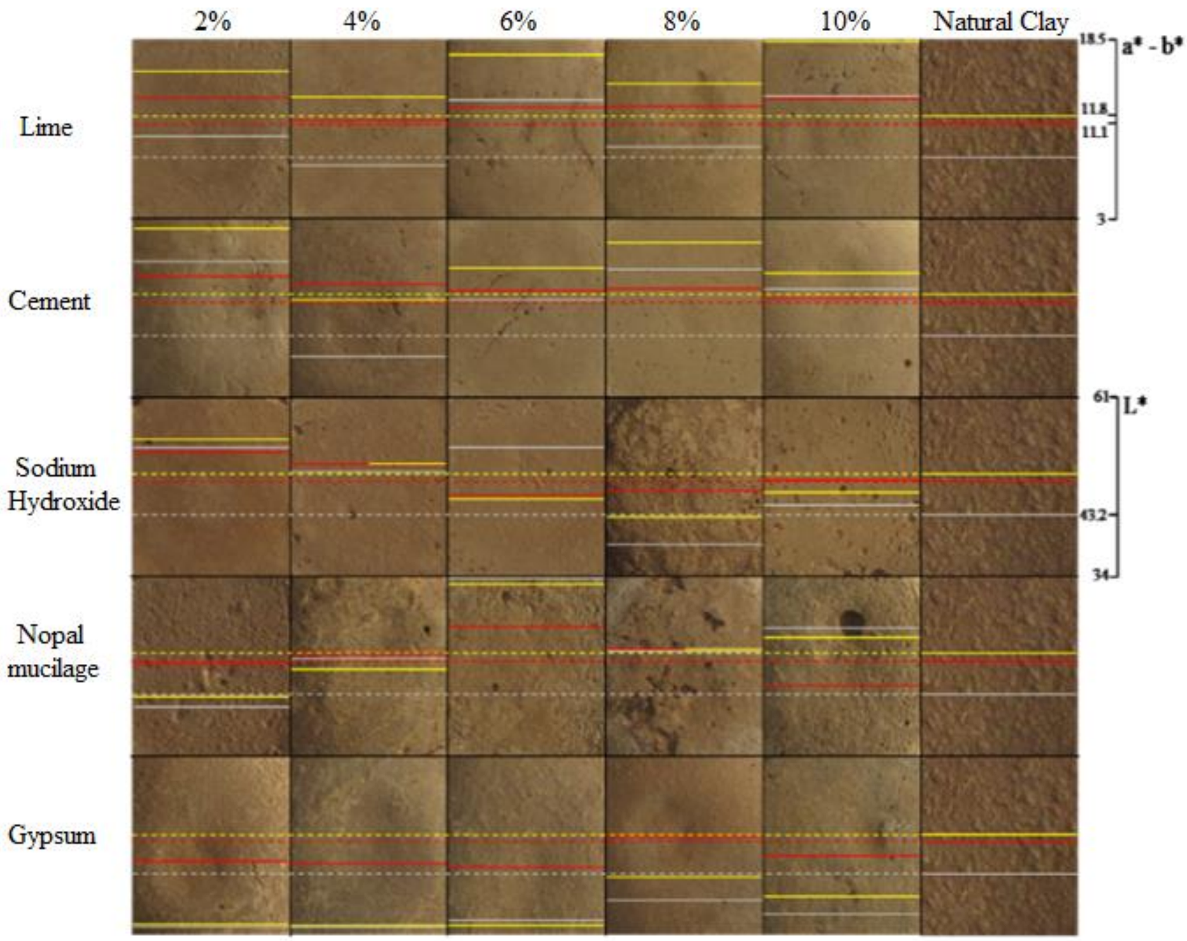

Figure 10. Comparison among different concentrations of the five additives and natural clay.

As seen in this diagram, the differences between clay with different additives and natural clay are more evident. No clay with an additive is close to the base clay with regards to all of the coordinates because, for the most part, the samples studied are more luminous. This could be because the surface of the pellets is, to a greater or lesser extent, smoother than the surface of the natural clay being studied. Therefore, as mentioned previously, it is important to not only consider the colorimetric measurements of the samples with additives but also their textures.

4. CONCLUSIONS

Based on the colorimetric analyses performed on clay with and without additives, we established that samples with the additives Portland cement, sodium hydroxide and nopal mucilage have colorimetric values that are more similar to those of natural clay overall. The colorimetric measurements of samples with lime added are less similar, but they can still give a similar color compared to those samples with gypsum added, whose only similarity in color with the control is in the sample with the 8% addition (in both cases, lime and gypsum), but it does not match the hue. Therefore, to perform restoring treatments of articles made with raw clay, it is advisable to use either a 6% addition of Portland cement, maximum addition of 4% sodium hydroxide or 4%-8% nopal mucilage. This way, the restored object will, for the most part, have its colorimetric properties preserved.

5. ACKNOWLEDGMENTS

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Comparative assessment of the mechanical behaviour of aerated lightweight concrete

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ABSTRACT
The present study aims to discuss the effect of air entrainment on the mechanical behavior and durability of molded concrete elements. The experiment was carried out using samples with 4 different masses (1500 kg/m3, 1700 kg/m3, 2000 kg/m3, and 2300 kg/m3) and 3 water/cement ratios (0.63-1:5, 0.50-1:4, 0.43-1:3) that were tested to determine compressive strength, water absorption, void index, and carbonation depth. The results showed significant decreases in performance and in the protection indicators of the armature (water absorption and carbonatation), confirming the need for additional mitigation for the structure (protective paints, stainless steel bars), under penalty of premature loss of durability over its lifetime.
Keywords: lightweight concrete and entrained air; concrete wall; compressive strength; capillarity; absorption.

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Avaliação comparativa do comportamento mecânico de concretos leves com ar incorporado

RESUMO

O presente estudo visa discutir o efeito dos incorporadores de ar no comportamento mecânico e de durabilidade de elementos de concreto moldados no local. O experimento foi desenvolvido com a confecção de amostras com 4 diferentes massas específicas (1500kg/m3, 1700kg/m3, 2000kg/m3 e 2300kg/m3) e 3 relações água/cimento (0,63 – 1:5, 0,50 – 1:4, 0,43 – 1:3), ensaiados para determinação da resistência à compressão, absorção de água, índice de vazios e profundidade de carbonatação. Os resultados obtidos apontaram quedas expressivas no comportamento e indicadores de proteção da armadura (absorção de água e carbonatação), o que confirma a necessidade de utilização de meios adicionais mitigadores para a estrutura (pinturas protetoras, barras inoxidáveis), sob pena da perda prematura da durabilidade ao longo da sua vida útil.

Palavras-chave: concreto leve e ar incorporado; parede de concreto; resistência à compressão; capilaridade; absorção.

Evaluación comparativa del comportamiento mecánico de concretos ligeros con aire incorporado

RESUMEN

En el presente estudio busca discutir o efectuar dos incorporadores de comportamiento no mecánico y durabilidad de elementos de hormigón moldeado no locales. El experimento fue desarrollado con un conjunto de muestras con 4 masas específicas diferentes (1500 kg / m3, 1700kg / m3, 2000kg / m3 y 2300kg / m3) y 3 relaciones agua / alimento (0,63 - 1: 5, 0,50 - 1: 4, 0,43 - 1: 3), pruebas para determinar la resistencia a la compresión, absorción de agua, velocidad de profundidad y profundidad de la carbonatación. Los resultados obtenidos no son expresivos, no se comportan como indicadores de protección de armadura (absorción de agua y carbonatación), o que confirme la necesidad de usar suavizantes de agua adicionales para la estructura (tintas de protección, barras de acero inoxidable) debido a la pérdida prematura. Da durabilidad a lo largo de su vida útil.

Palabras clave: concreto ligero y aire incorporado; pared de concreto; resistencia a la compresión; capilaridad; absorción.

1. INTRODUCTION

Concrete made from Portland cement is the most important structural material in civil construction today. As described by Helene and Andrade (2007), concrete can be considered one of the most interesting discoveries in the history of human development and quality of life, even being the most recent of structural building materials.
The use of concrete walls molded onsite has become an option frequently used in Brazil in order to achieve the social goal of reducing the housing deficit. In hot climates, it becomes necessary to discuss the thermal discomfort caused by the use of this type of material, which can be minimized with concrete having lower specific mass obtained with the incorporation of air entrainment additives. This technique, however, can lead to a decrease in both mechanical performance and in protection against the entry of water and aggressive agents into the structure.
It is noteworthy that these systems have been used in buildings around the country for about 30 years and, according to Corsini (2011), are divided basically into two types, depending on the

concrete adopted: normal density concrete walls and light concrete walls. To regulate systems of conventional concrete walls, ABNT NBR 16055 (2012) was published in 2012. For wall systems made from light foamed concrete, there are standards dating from 1992 (ABNT NBR 12645 and NBR 12646, 1992), which are currently under review, with important discussions taking place regarding the improvement in thermal performance and the loss of reinforcement protection provided by the concrete itself. In this context, the current study evaluated, through experimental development, concrete having different levels of specific mass and its consequences on the principal mechanical properties (resistance to compression) and cement qualities (water absorption, void index, carbonatation depth, etc.) to prevent water entering into the interior of the structure.

1.1 Light concrete

As shown by Rossignolo (2009), lightweight concrete is characterized by a reduction of the specific mass in relation to conventional concrete, as a consequence of the substitution of part of the solid materials with air. According to Romano, R. C. O. et al. (2015), they can be classified as concrete with light aggregates, cellular concrete, and non-fine concrete. According to NBR 8953 (2015), these concretes should be classified by specific mass according to Table 1.

Table 1. Classification of specific mass. Source: (NBR 8953, 2015).

Nomenclature	Dry specific mass (kg/m^3)
Light concrete (CL)	< 2000
Normal concrete (C)	2000 to 2800
Heavy or dense concrete (CD)	> 2800

The analysis of the specific mass obtained for groups of concrete shows a correlation with the inclusion of voids. The relationship between intentionally entrapped air content and specific mass is quite straightforward; an increase in the volume of air causes a reduction in the value of specific mass, while maintaining the same proportion of materials. The specific mass of the concretes is reduced through the inclusion of voids in its interior.

The lightweight concrete group, however, is broad and it is not adequate to simply classify it only by specific mass. Other qualities must also be taken into account. It is important to consider the production method, that is, what materials and processes are considered during preparation, such as mechanical resistance, workability, retraction, and fluency, among others.

1.2 Air entrainment additives

According to Du et al. (2005) and Whiting et al. (1999), air-entraining additives have the function of producing stable air bubbles evenly distributed throughout the concrete. According to Mehta and Monteiro (2014), the air-entraining additives are surfactants, usually consisting of wood resin salts, proteins and fatty acids, and some synthetic detergents. According to Kumaran et al. (2004), the air entrained by the additive takes the form of small bubbles having dimensions between 0.01 mm and 1.00 mm, spaced from 0.10 mm to 0.20 mm apart, that display elastic behavior.

According to Torres et al. (2014), the additive incorporated in the mixture promotes a reduction in the surface tension of the water. For Fujii et al. (2015) and Bauer (1994), it acts by involving the air bubbles already present and also involves the finest aggregate particles of the cement. The combination of the solid particles involved, and the air bubbles is more stable than the each is alone. Although it reduces the mechanical strength of the concrete, the incorporation of air improves workability, reduces exudation, and improves the behavior of the material during transportation, which can be done with less possibility of segregation.

2. EXPERIMENTAL DEVELOPMENT

The proportions used were determined by adapting the Ibracon dosing method (Helene and Terzian, 1992), using concrete samples with three cement:aggregate proportions: 1:3, 1:4, and 1:5, all having the same consistency (170 ± 30) mm, which required the use of three different water/cement ratios: 0.43, 0.50, and 0.63, respectively (Table 2). The mortar content (α%) of 0.65 was also fixed for all dosages, a percentage commonly adopted for the preparation of lightweight concretes.
For each of these dosages, samples were prepared with four levels of specific mass in the fresh state, obtained using polyfunctional additive Mira 93/Grace (density: 1.17 g/cm^3) and air entrainer SikaAer, (density: 1.01 g/cm^3, nature: liquid, base: synthetic resin, pH (23ºC) 10-12, solid content(%): 4-6) with proportions of 0.5% and 0.1% of the mass of the cement, respectively, totaling 12 test families. The increase in void content was obtained from increasing the mixing time of the concrete in the concrete mixer (between 3 and 15 minutes), since the amount of additive was kept constant.

Table 2. Groups and subgroups tested.

Group(1:m)	Subgroup	Approximate specific mass(kg/m^3)
A (1:5) w/c=0.63	1	2300
	2	2000
	3	1700
	4	1500
B (1:4) w/c=0.50	1	2300
	2	2000
	3	1700
	4	1500
C (1:3) w/c=0.43	1	2300
	2	2000
	3	1700
	4	1500

To carry out the study, 120 cylindrical (10 cm x20 cm) concrete specimens were molded for the tests to determine specific mass (fresh and hardened state), compressive strength (at 7 and 28 days), total and capillary absorption, and carbonatation depth, as shown in Table 3. All tests were performed according to their current standards, which are described in Table 4.

Table 3. Description of samples used per test.

Group	m	Subgroup	Specific mass	Rupture (7 and 28 days)	Absorption and dry sp. mass	Capillarity	Carbona-tation	**Total Specimens**
A	1:5	1	2300	**4**	2	3	1	10
		2	2000	**4**	2	3	1	10
		3	1700	**4**	2	3	1	10
		4	1400	**4**	2	3	1	10
B	1:4	1	2300	**4**	2	3	1	10
		2	2000	**4**	2	3	1	10
		3	1700	**4**	2	3	1	10

		4	1400	**4**	2	3	1	10
C	1:3	1	2300	**4**	2	3	1	10
		2	2000	**4**	2	3	1	10
		3	1700	**4**	2	3	1	10
		4	1400	**4**	2	3	1	10
Total Specimens			-	**48**	24	36	12	**120**

Table 4. Tests and Normative Parameters.

TESTS:	Normative Parameters	International Equivalents
Determination of specific mass	ABNT NBR 9778:2009	ASTM C231/C231M:2017 ASTM C29/C29M:2017
Compressive strength	ABNT NBR 5739:2007	ASTM C39/C39M:2018
Cement consumption	ABNT NBR 12655:2015	ASTM C1084:2010
Water absorption, void index, and specific mass	ABNT NBR 9778:2009	ASTM C29/C29M:2017
Capillary absorption	ABNT NBR 9779:2012	ASTM C1585:2013
Carbonatation depth	RILEM CPC-18, 1988	-----------

2.1 Laboratory production of concrete

For the production of the concretes in the laboratory, dry aggregates and pre-mixed large and small aggregates were used with type CP-V ARI cement, similar to type III of ASTM C150 (2017). Some of the principal characteristics of the aggregates used are described in Table 5.

Table 5. Description of physical characteristics of the aggregates used.

Aggregate Characteristics	Fine Aggregate	Coarse Aggregate
Fineness modulus	1.71	5.51
Maximum diameter (mm)	2.36	12.5
Dry specific mass (g/cm^3)	2.63	2.77
Apparent specific mass (g/cm^3)	2.73	2.72
Bulk density (kg/m^3)	1620	1470

Soon after the initial mixing of the materials, the polyfunctional additive and kneading water were added (reserving approximately 500ml of water from the concrete to add the air entrainer). After initial mixing of the concrete, its subsidence and specific mass were determined. Subsequently, the air entrainer was added along with the remainder of the water, as shown in Figure 1.
After completing production, the specific mass of the fresh concrete was measured until reaching the approximate values intended and initially stipulated.

Figure 1. Mixing of materials in concrete mixer. Without air entrainment additive (a) and with air entrainment additive (b).

3. RESULTS

After reaching the ages planned after molding and wet curing, samples were divided among the tests planned for the hardened concrete. Figure 2 displays a graph with the specific masses according to ABNT NBR 9778 (2009), with their respective equivalences (ASTM C231/C231M and ASTM C29/C29M, 2017), obtained from the fresh concretes for the different study groups evaluated.

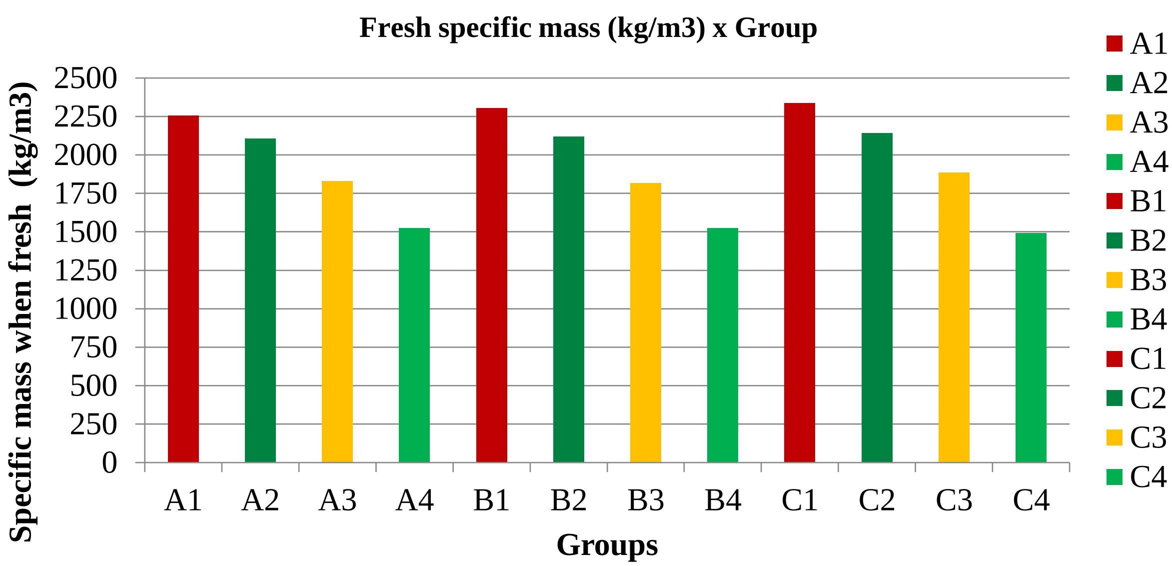

Figure 2. Specific mass x test groups

Fig. 3 shows the entrained air contents obtained from the fresh concrete for the different study groups evaluated.

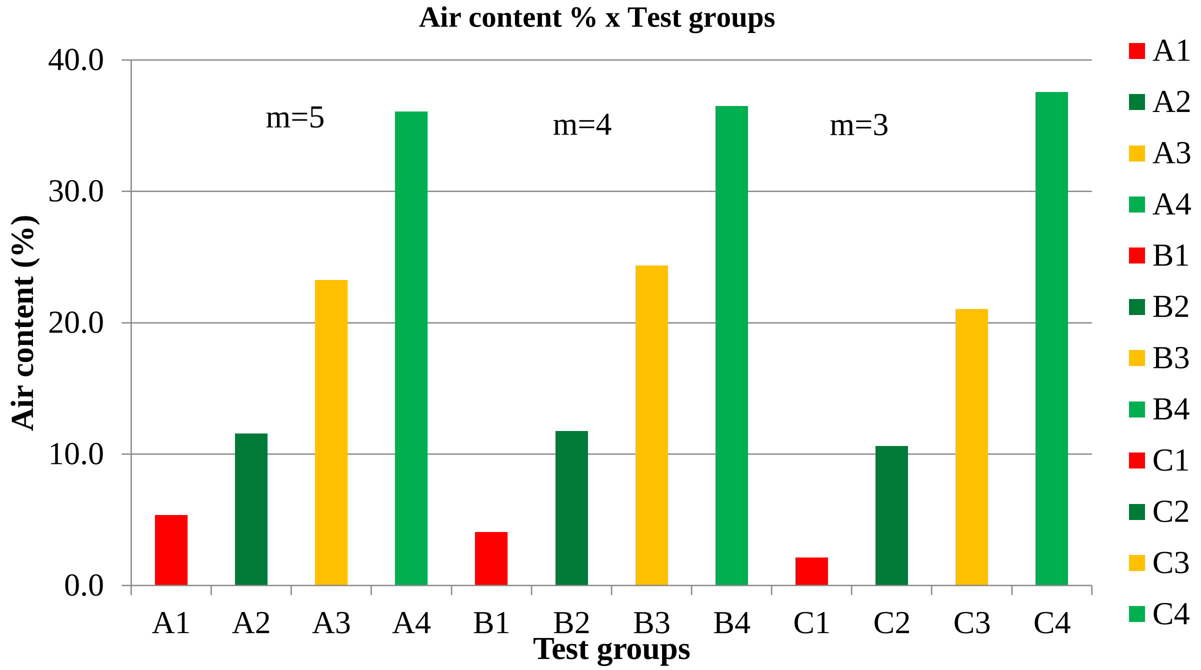

Figure 3. Air content x groups

3.1 Relationship between specific mass in the fresh state and compressive strength

Table 6 presents the results found from the compressive strength tests at 7 days and 28 days according to ABNT NBR 5739 (2007), equivalent to ASTM C39/C39M (2018), compared to the specific mass initially defined. For each concrete family, two cylindrical specimens were used, and the highest value found for the tested pair was considered to be representative of the sample.

Table 6. Results of compressive strength tests

Group	Specific mass (kg/m^3)	Compressive Strength (MPa)	
		7 days	28 days
A (1:5) w/c = 0.63	2300	32.6	40.8
	2000	18.4	23.3
	1700	7.7	9.8
	1500	1.8	2.1
B (1:4) w/c = 0.50	2300	43.2	54.6
	2000	20.7	29.2
	1700	7.6	11.0
	1500	1.1	1.8
C (1:3) w/c = 0.43	2300	50.0	65.4
	2000	22.1	28.7
	1700	14.7	18.0
	1500	1.6	2.2

Figures 8, 9, and 10 were generated from the compressive strength test data (Table 4) and the analysis of the influence of the water content of the concrete (Table 3). The water/cement ratio and the compressive strength for each specific mass group was evaluated.

The correlation between the water/cement ratio and strength, a determining factor in the study of concretes and verified by the Abrams model, is clearly observed for concrete of the conventional

class (specific masses of 2300 kg/m³ and 2000 kg/m³). For the concrete of the lightweight class contemplated in the study (specific masses of 1700 kg/m³ and 1500 kg/m³), the w/c ratio alone is not the only determining parameter of compressive strength behavior.
Once the air-entrainment additive was added to the blend, an improvement in the cohesion of the materials was visually observed, but there were no variations in the subsidence values of the concretes with specific masses of 2300, 2000, and 1700 kg/m^3. Concretes with specific mass of 1500 kg/m^3 showed small increases in subsidence values, varying between 190 mm and 210 mm.
According to ABNT NBR 12655 (2015), equivalent to ASTM C1084 (2010), cement consumption of concrete having a lower specific mass is, in general, lower than for those of higher mass, as expected by Romano, et al. (2017), due to the inclusion of the air-entrainment additives, for similar consistency levels. In addition, for a larger "m" value, smaller cement consumption took place. The curves obtained for cement consumption for each specific mass is shown in Figure 4.

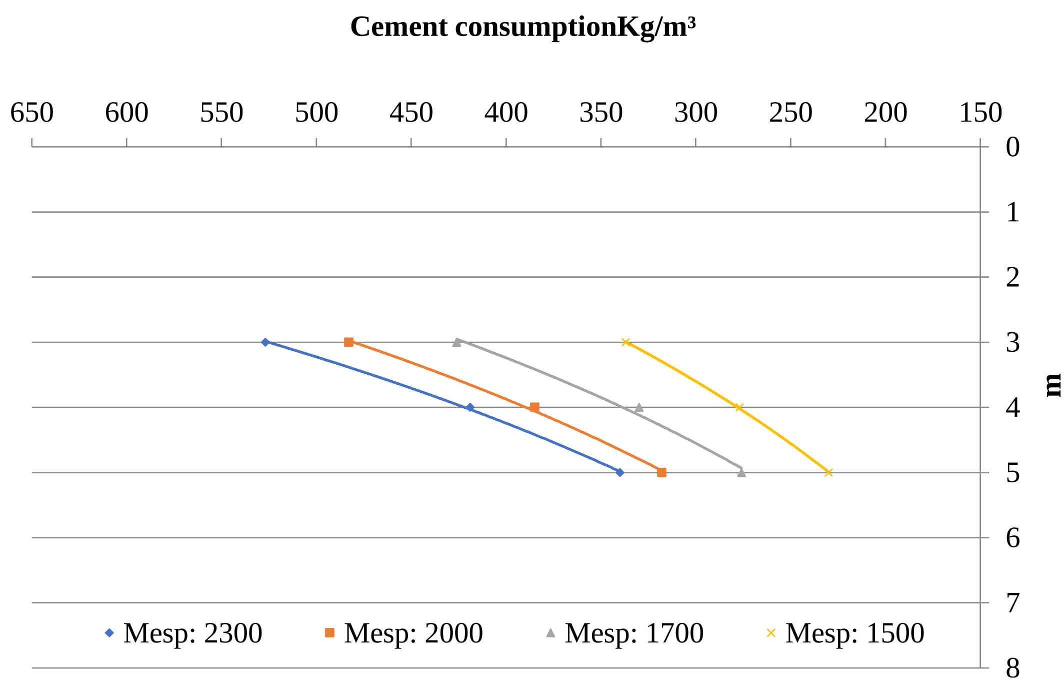

Figure 4. Cement consumption by specific mass

3.2 Relation between specific mass in the fresh state, water absorption, void index, and dry specific mass.

The dry specific mass values obtained from the hardened concrete test showed variations from the initial values and those stipulated for the specific mass bands of the study. This is due to the different losses of water to which the concretes are submitted once the hardening process begins.
The values obtained from the void index tests corroborate the idea that concrete with lower specific mass has a higher void index. It also presents higher values of water absorption. A visualization of these three properties is shown in Figure 5.

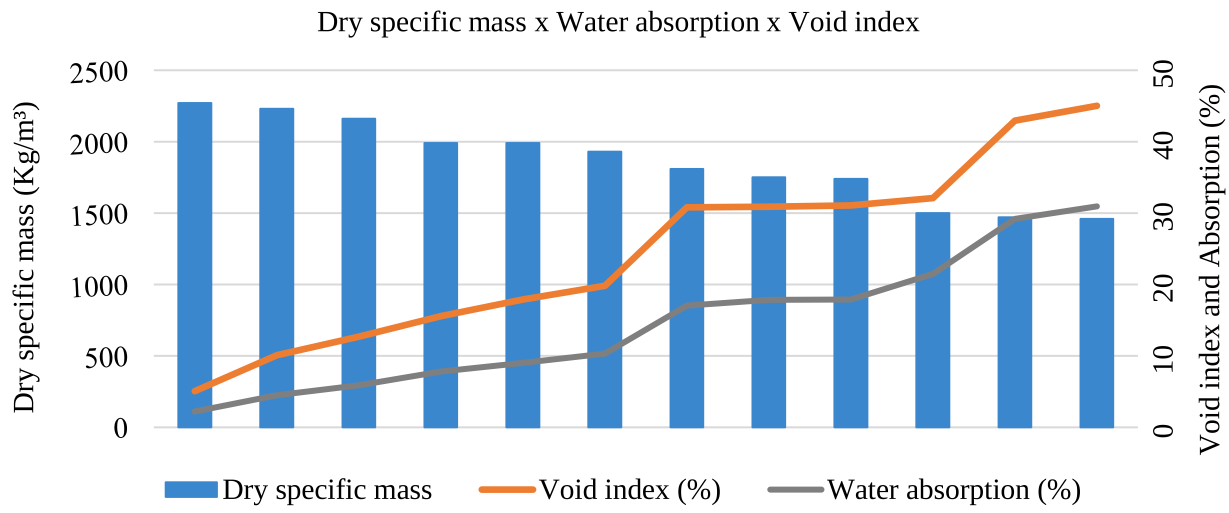

Figure 5. Relationship between dry specific mass, void index, and water absorption

Figure 6 shows the relationship between the specific mass and the void index for the samples, according to NBR 9778 (2009), with equivalent international standard ASTM C29/C29M (2017).

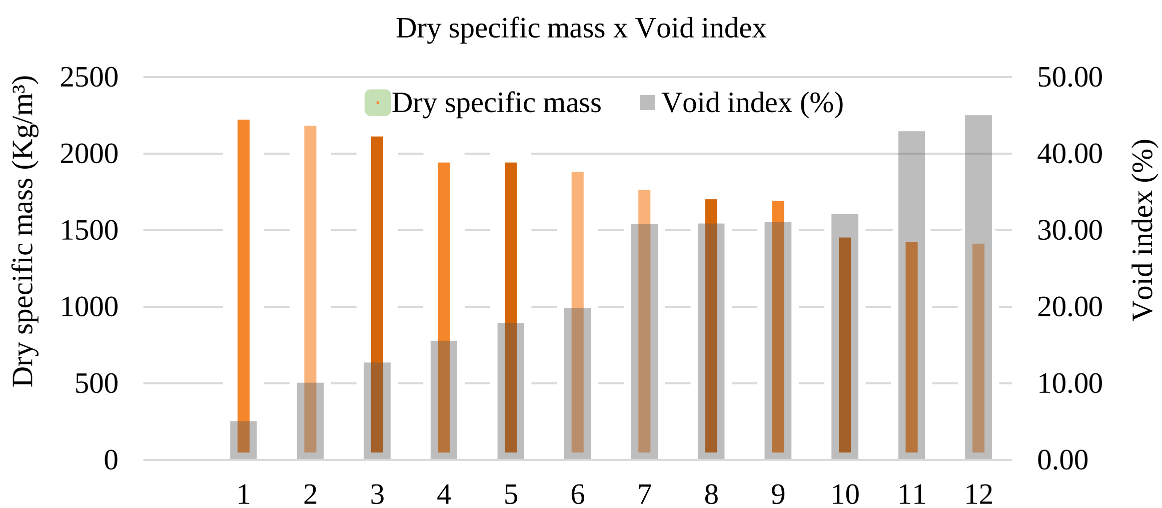

Figure 6. Relationship between specific mass and void index.

3.3 Relationship between specific mass in the fresh state and capillary absorption

The study also sought to evaluate the capillary absorption rates of the concretes prepared, in order to verify the the effect of their properties on capillarity. To achieve this, the 12 concrete dosages used in the study were tested according to standard ABNT NBR 9779 (2012), equivalent to ASTM C1585 (2013).

In the specific case of capillary absorption, the relationship observed to have the greatest influence was still the specific mass of the concrete (obtained through the entrainment of air), but in addition, the water/cement ratio was much more influential than in the absorption, void index, and specific dry mass tests.

Figure 7 shows the graph of specific mass and capillary absorption for the 12 dosages, sorted into descending order of specific mass.

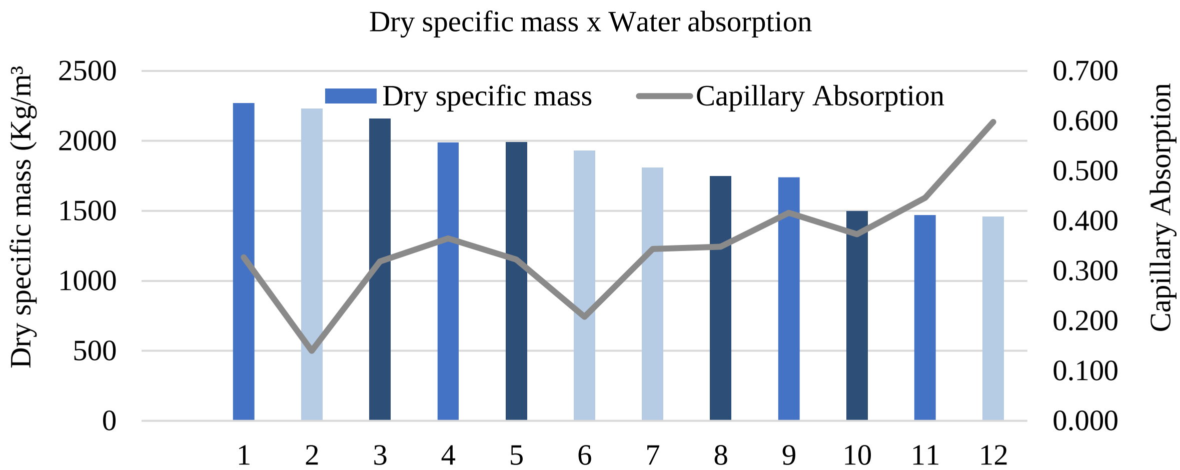

Figure 7 – Relationship between specific mass and capillary absorption

It can also be observed that, for concretes without the use of the air entrainment additive, the capillary absorption followed variation in the water/cement ratio quite closely. For the other concretes, there were variations in the results. It is still possible, however, to visualize the tendency of the absorption curve to grow as the values of specific mass decrease. It can be said that the w/c ratio influences but is not the only source of influence on the absorption behavior.

3.4 Relation between dry specific mass and compressive strength

Figures 8, 9, and 10 show the relationship between the specific mass values of the concretes in the dry state and their respective compressive strengths, demonstrating the strong correlation between the properties.

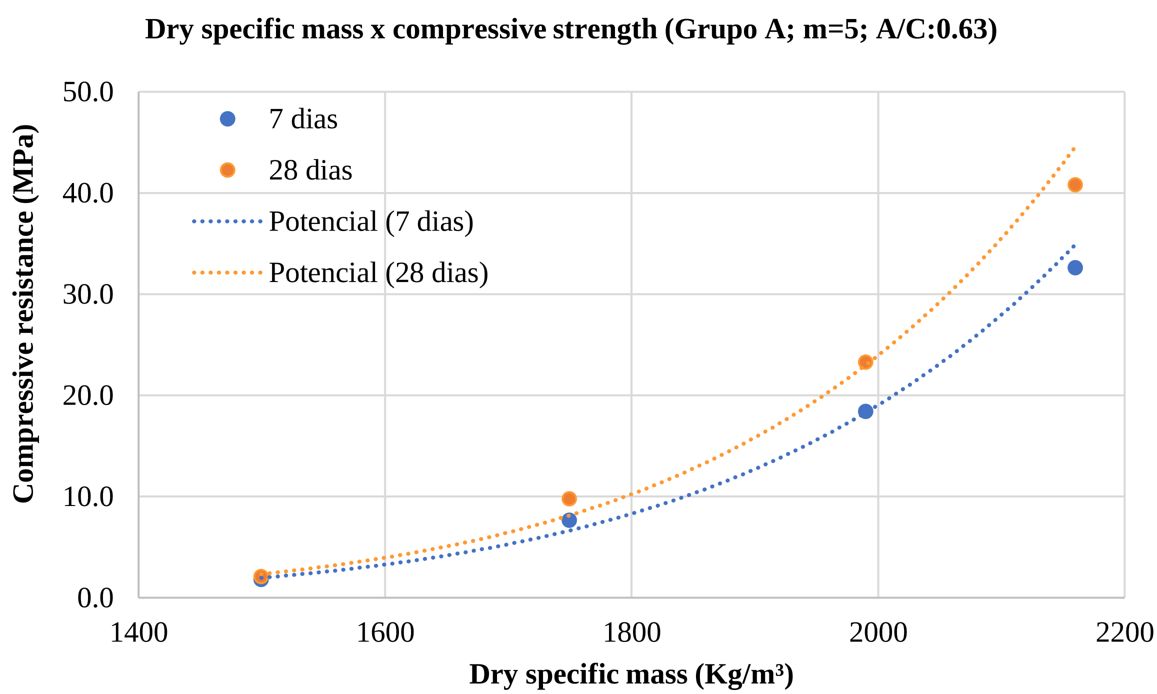

Figure 8. Compressive strength and specific mass - m=5

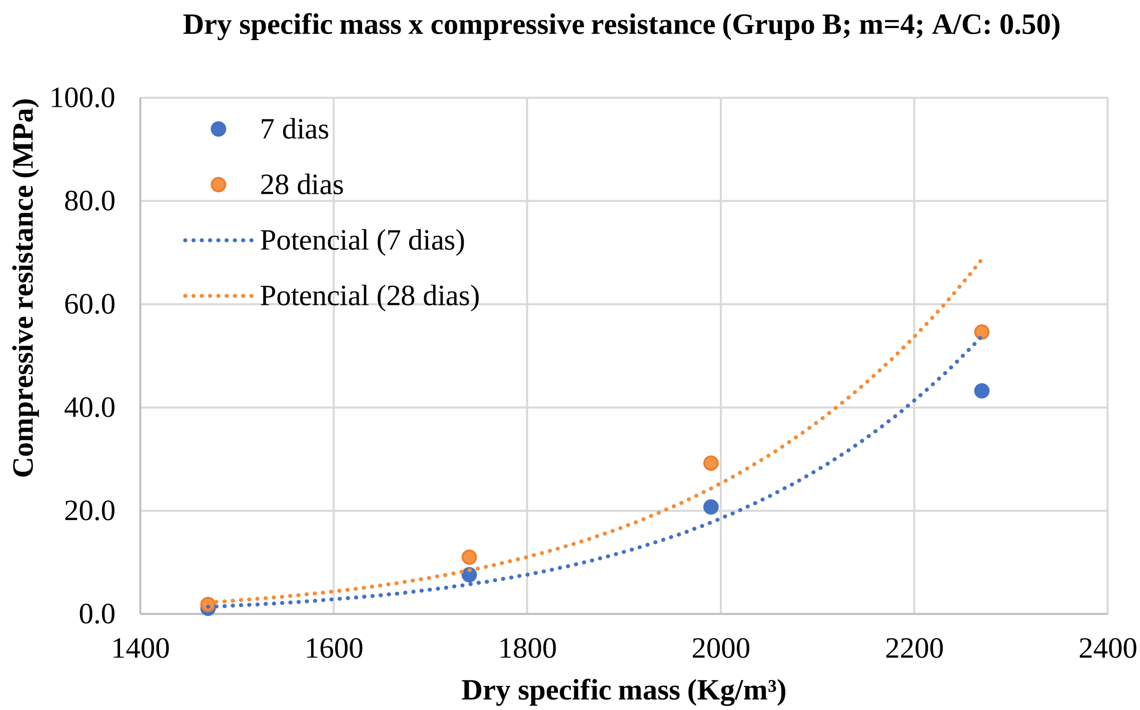

Figure 9. Compressive strength and specific mass - m=4

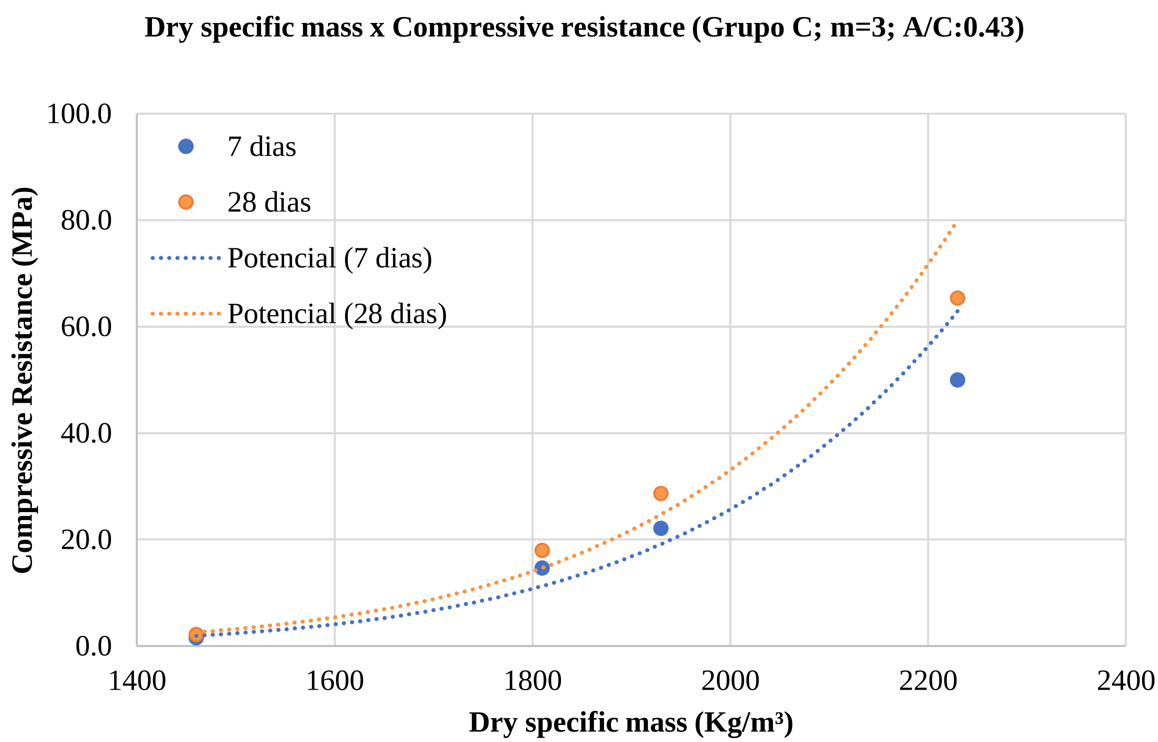

Figure 10. Compressive strength and specific mass - m=3

The results show that higher values of compressive strength were found for higher densities. An increase in voids within the concrete causes both lower specific mass and a reduction in mechanical strength. According to NBR 12646 (1992), compressive strength values for of cellular concrete must meet a minimum value of 2.5 MPa.

It was verified that, for the same concrete, the increase of the entrainment of air provoked a reduction in the specific mass, and consequent reduction in the mechanical resistance. This behavior was influenced principally by two properties: the increase of the voids in the concretes and the water/cement ratio used.
It was observed that the concretes with specific mass near 1500 kg/m^3, that is, those with more air entrainment, had compressive strength performance determined almost completely by the quantity of voids, taking into account the water/cement ratio adopted.
The results found agree with those obtained by Teixeira Filho (1992), where one of the observed results was the distinction of the influence of the water/cement ratio when different specific mass classes were observed. For concrete with specific mass of 1100 kg/m^3 and 1300 kg/m^3, increasing the water/cement ratio from 0.5 to 0.6 resulted in an increase in strength. For concrete classes with specific mass of 1700 kg/m^3 and 1900 kg/m^3, the same increase in the water/cement ratio, from 0.5 to 0.6, resulted in lower values of compressive strength.
In this study it is also observed that, for example, for dosages with specific masses of 1500 kg/m^3, a water/cement ratio of 0.63 had higher axial compressive strength than for a water/cement ratio of 0.50. For the results obtained, it is possible to consider that the changes in the influence of w/c ration on the axial compressive strength are justified by the reduction of specific mass and increase in voids in the concrete (Teixeira Filho, 1992).
In addition, it was observed that concrete with a specific mass of 1900 kg/m^3 has interesting mechanical properties, with values of compressive strength in the range of 20 MPa, combined with the possible benefits of air entrainment, such as reduced consumption, lower weight, and improvements in thermal and acoustic comfort compared to conventional concrete.
In the case of capillary phenomena, the evaluated concretes showed an increase in capillary absorption as specific mass decreased.
It is known that the permeability of concrete is a crucial factor for its durability. The more permeable the concrete, the more susceptible to the deleterious actions of agents present in the environment. Thus, special attention must be given when using concretes that have high void indices and high capillarity, as is the case in the present study.

3.5 Relationship between specific mass in the fresh state and carbonatation depth.

In order to evaluate the concretes studied from the point of view of carbonatation, 12 specimens were separated to be used in the evaluation. Because the previous test was non-destructive, it was possible to evaluate these concretes submitted to the atmospheric action of the laboratory environment, where they remained for a period of 110 days of exposure.
To perform the test, the procedure described in Rilem (1988) was used, and the 10x20 cm test specimens were sectioned at 1/3 of their length.
After sectioning, the specimens were sprayed with a solution of phenolphthalein (2%) for pH identification. A transition zone occurs along the advance of the carbonatation front, having pH below 9 and tending to be colorless in the presence of the solution. The zone with pH higher than 9 tends to be violet in color.
In this way, it was possible to identify the carbonatation front formed by observation, as shown in Figures 10 and 11.

Figure 10. Measurement of carbonation depth for concrete with specific mass of 1500 kg/m^3

Figure 11. Measurement of carbonation depth for concrete with specific mass of 1700 kg/m^3

Table 5. Average carbonatation depth values

Group	W/C	1:m	Subgroup	Specific mass (kg/m^3)	Carbonatation depth (mm)
A	0.63	1:5	1	2300	0.97
			2	2000	1.87
			3	1700	3.54
			4	1500	18.75
B	0.50	1:4	1	2300	0
			2	2000	1.27
			3	1700	1.59
			4	1500	18.92
C	0.43	1:3	1	2300	0
			2	2000	0.84
			3	1700	1.6
			4	1500	10.68

It was found that the lightweight concretes have a carbonation front that is much more advanced than that of the conventional concretes. Even those concrete with a reduced water/cement ratio, such as group C (w/c: 0.5), presented significant carbonation depths for the lower specific masses (1500 and 1700 kg/m^3) over the 110 days of the test.

4. CONCLUSION

The current study evaluated the repercussions of a reduction in specific mass of concrete on its mechanical properties and durability. The interest in using concrete with an air entrainment additive has grown, especially for walls poured in place, that usually are repeated. This solution stands out for its tendency to improve thermal behavior, when compared to concrete of normal density, which is indispensable in regions of high temperatures, such as in the Brazilian northeast. Associated with this is a marked reduction in cement consumption insofar as the concrete density is reduced, despite the possible cost due to the inclusion of the air-entraining additives. However, it is essential that these benefits are weighed against the possible compromise in durability, due to the greater ease of entry for aggressive agents, especially chloride ions and carbon dioxide.

The tests demonstrated the strong influence that the reduction of the concrete's specific mass had on its mechanical behavior, in particular, its durability. Reducing the specific mass also provoked significant increases in water absorption (3% to 30%), void index (5% to 50%), capillary absorption (0.2 g/cm^2 to 0.6 g/cm^2) and carbonatation depth (0 mm to 18.9 mm).

These results point to the need to adopt measures of surface protection for the concrete when used in regions with an aggressive environment, in order to reap the benefits (especially financial and economic) of the technique, without compromising the concrete's durability. It is also necessary to assess the need for maintenance in order to ensure adequate performance behavior over the years.

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Influence of sugar cane bagasse ash inclusion on compacting, CBR and unconfined compressive strength of a subgrade granular material

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ABSTRACT

The aim of the present work was study the influence of sugar cane bagasse ash (SCBA) as a partial substitution of Compound Portland Cement (CPC) in order to enhance the properties of a granular sand soil. AASHTO standard compaction test, unconfined compressive strength test, and CBR test were made, has been compared the behavior of natural soil in study and mix with percentages of 3%, 5% and 7% of CPC as a control percentage, being carried out partial substitutions of CPC by SCBA in 0%, 25%, 50% and 100% percentages with respect to dry soil weight. The results showed enhances in the compacting, CBR and unconfined compressive strength features, reducing up to 25% the consumption of PCC.
Keywords: sugar cane bagasse ash; compaction, CBR; soil; subgrade.

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Influencia de la inclusión de ceniza de bagazo de caña de azúcar sobre la compactación, CBR y Resistencia a la compresión simple de un material granular tipo subrasante.

RESUMEN

El objetivo del presente trabajo fue estudiar la influencia de la ceniza de bagazo de caña de azúcar (CBCA) como sustituto parcial del Cemento Portland Compuesto (CPC) para mejorar las propiedades de un suelo granular arenoso. Se llevaron a cabo ensayos de compactación AASHTO estándar, resistencia a la compresión simple y CBR, comparándose el comportamiento del suelo natural en estudio y mezclado con porcentajes de 3%, 5% y 7% de cemento portland como porcentajes de control, realizándose sustituciones parciales del mismo por CBCA en porcentajes de 0%, 25%, 50% y 100% con respecto al peso del suelo en estado seco. Los resultados mostraron mejoras en el suelo en las características de compactación, resistencia a la compresión y CBR, reduciéndose hasta un 25% el consumo del CPC.
Palabras clave: ceniza de bagazo de caña de azúcar; compactación; CBR; suelos; subrasante.

Influência da inclusão de cinzas do bagaço de cana-de-açúcar sobre compactação, CBR e resistência à compressão não confinada de um material granulado de sub-esmagamento.

RESUMO

O objetivo do presente trabalho foi estudar a influência da cinza de bagaço de cana-de-açúcar (CBCA) como uma substituição parcial do Cimento Portland Composto (CPC), a fim de melhorar as propriedades de um solo de areia granular. O teste de compactação padrão AASHTO, a resistência à compressão não confinada e a CBR foram feitas, foi comparado o comportamento do solo natural em estudo e mistura com porcentagens de 3%, 5% e 7% de PCC como porcentagem de controle, sendo realizadas substituições parciais de CPC por CBCA em porcentagens de 0%, 25%, 50% e 100% em relação ao peso do solo seco. Os resultados mostram aprimoramentos nos recursos de compactação, CBR e resistência à compressão não confinada, reduzindo até 25% o consumo de CPC.
Palavras chave: Cenoura de bagaço de cana de açúcar; compactação; CBR; solo; subtração.

1. INTRODUCTION

On roads infrastructure works, the soils located on the projection zone are the main materials used for embankments construction, therefore, its performance is important to a suitable service life on any functional structure. These soils when being used in engineering must fulfill established quality requirements on international codes, and if they do not fulfill these requirements then they must be improved, mainly on volumetric stability and strength characteristics. (Fernández Loaiza, 1982; Jofre et al.,2008; Juárez & Inzunza, 2011).

The improvement of soils are related with compaction process and addition of stabilizer agents and both have a direct influence on the quality control of conformed layers, strength soil structures, economy and contributions to sustainability (Rico-Rodriguez & Del Castillo, 2006).

Further, the addition of agents that act by physicochemical principles has been one of the most techniques employed in treatment of soils, materials like lime, portland cement, asphalt, fly ash, blast-furnace slag, rice husk ash among other, have been subject to research and analysis due their influence on soils of different classifications (Behak & Perez Nuñez, 2008; Cristelo, Glendinning, Miranda, & Oliveira, 2012; Sargent, Hughes, Rouainia, & Glendinning, 2012; S. Correia & Graca Rasteiro, 2016) because have been observed increases on the durability and strength due to the pysicochemical process occured on blend; furthermore, poozolanic materials it has been used for reducing the comsumption of portland cement, lime and asphalt due to the high energetic required, and genetarion of CO_2 during its proccess.

Nowadays SCBA is one of the most researched supplementary material as a replacement of portland cement in concrete and mortar mixes (Moraes et al., 2015), SCBA is a recent alternative in soil improvement both in physical characteristics as confinement, density and volumetric stability, as well as chemical characteristics due to chemical reactions of the stabilization agent (lime or cement) with water and in exceptional cases with the constitutive of soil (mainly clay), where its use as construction material contributes to solving problems of generation and disposal of agro industrial wastes, that only in Mexico their 57 sugar factory in harvest period 2016-2017 ground 53,308,643 tons of cane of the 777,078 hectares harvest, obtaining 15,222,471 tons of bagasse (CONADESUCA, 2017) that once burned becomes ash whose final disposition is not determinate. Several studies have reported that the combustion of bagasse ash in boilers produce a sub product called sugar cane bagasse ash (SCBA), having higher contents of silica and alumina as main oxides, that in appropriate conditions have a reaction with calcium hydroxide producing a pozzolanic activity (Cordeiro & Kurtis, 2017). This activity is function of particle size, amorphous material contents (silicoaluminates), calcium hydroxide present and optimum water content, saying some researchers, the ash that is not consuming during the reaction can be used as a filler material, filling the voids present in compound material (Sing, Singh, & Rai, 2000; Cordeiro, Toledo Filho, Tavares, & Fairbairn, 2008; Cordeiro, Toledo, & Fairbairn, 2009; Morales, Villar Cociña, Frias, Santos, & Savastano, 2009; Arenas Piedrahita et al., 2016; Joshaghani & Amin, 2017;) and where on a dynamicly compacted soil it would offer an alternative to increas its stability due to filler effect of voids on compacting soil and a possible pozzolanic reaction to late ages.

The aim of the present work is determinate the influence of partials substitution of CPC for SCBA on compacting properties, compressive strength and CBR of a sand granular soil, in order to improve its mechanical characteristics and to be used in pavement structural layer, taking advantage materials of agro industrial waste and reduce the percentages of cement employed in soil stabilization, that despite being small percentages of addition, generated an environmental and economic impact due to growing construction of roads over the world.

1. EXPERIMENTAL PROCEDURE

1.1 Materials

The materials used in this study were portland cement, classified type III or CPC 30R as is established in standards (ASTM C150, 2017; NMX C414, 2004, respectively) which density = 3.11 g/cm^3. Sugar cane bagasse ash obtained from sugar factory "Mahuixtlan" in Coatepec, Veracruz Mexico. The SCBA was obtained from one boiler where the combustion temperature was around to 700 ºC. The ash collected was cooled and grinding to 1500 rpm for 1 hour, getting the material passing the sieve No 200. The density of SCBA was 2.1 g/cm^3.

The grinding process was used to decrease the particle size under 75 microns in order to increase the specific surface area, which is related to the increase of pozzolanic reactivity of SCBA as several authors have described (Cordeiro G. C., Toledo Filho, Tavares, & Rego Fairbairn, 2009; Cordeiro & Kurtis, 2017).
The soil used in this study was obtained from material bank el Castillo in Xalapa, Veracruz Mexico. The sampling, identification, conditioning of samples and test it was carried out as is established in the procedures to analyses and assessment of embankments conformation (ASTM D 2217, 1998; ASTM D 421, 2007; ASTM D 2216, 2010; ASTM D 698, 2012; ASTM D 4318, 2017).

1.2 Materials characterization.

Chemical composition of SCBA was obtained by x ray fluorescence analysis (XRF), the ash phases was determinate by x ray diffraction (XRD), morphology and surface characteristics were observed by scanning electron microscopy (SEM), particle size distribution (PSD) was obtained as well by laser diffraction granulometric analyze, in order to know the average size of ash particles.

1.3 Soil mixing design

In the mixing design three percentages of portland cement were used according to the material classification, in this case for granular materials as sand used in this study the addition percentages must be less of 10% in order to do not have cracking due to high stiffening, as are established in several technical prescriptions (Jofre et al., 2008; Juarez Gutierrez & Inzunza Ortiz, 2011). The percentages used were 3%, 5% y 7% with respect to dry soil weigh. The partial substitution on each percentage mentioned 0%, 25%, 50% y 100%, having 12 mixes in total.

1.4 Compacting characteristics.

Compaction is a mechanical process that improves the strength characteristics of materials which constitute structural sections in roads, for it, the impact energy is transferred by unitary volume of soil, obtaining a compaction curve which shows the dry unit weight and water content parameters of material. For this work, the ratio between dry unit weight and water content were determinate on each mix, in order to analyze the variation due to the additions and as data for making the specimens soil-cement. The tests were carried out following the procedure to granular materials using molds 944 cm^3, and dynamic compacting with rammer 2.5 kg weight and 30.48 cm height of drop (ASTM D558, 2011).

1.5 CBR test

CBR is penetration strength test that compares support capacity of material in the study to crushed stone well graduate as a reference (100% CBR). For it, the load is applied through one piston with strain of 1.3 mm per minute recovering loads from 0.64 mm to 7.62 mm; In this work the CBR test was determinate on each mix in study, for it, three specimens for mix was dynamically compacted to optimum water content followed by to place surcharge weights and place it in immersion period for 24 h simulating the critical conditions followed of test on the loading machine to deformation velocity described (ASTM D1883, 2016).

1.6 Unconfined compressive strength

For assessment compressive strength of mixes, soil-cement and soil-cement-SCBA specimens were made to 100% compacting degree. These specimens were prepared as established the procedure for soil stabilized with cement (ASTM D558, 2011), using the values of compacting characteristics obtained previously. Dimension of specimens was 101.6 mm diameter and 116.4 mm high, with a high-diameter ratio of 1.15.

Samples were extracted of the mold by mechanical extractor and curing in water during 7 days. The specimens tests were made following the procedure compressive strength on soil-cement specimens (ASTM D1633, 2017), for it, previously to test, they were submerged in water for a period of 4 h in order to obtain the critical conditions followed by the test in an automatically loading machine.

2. RESULTS AND DISCUSSION

2.1 Physicochemical characterization of materials.

Table 1 shows the characterization results of soil in study. This table shows the geotechnical parameters, it can observe that the predominate material is sand with 89.5% passing sieve No 4 and 20.7% passing sieve No 200, according to plasticity results there is not interval between liquid limit and plastic limit, concluding that fine material present in sample is not plastics, that means that it has a material with granular characteristics with specific gravity 2.0, according to unified soil classification system it is SM silty sand (ASTM D 2487, 2011). The compacting characteristics show that the optimal water content to produce a dry unit weigh of 1311 kg/m^3 was 21.7%, and CBR value was 24% with 0 % expansion, satisfy the characteristics to use in subgrade layer as the Mexican rules established (Rico Rodríguez, Orozco y Orozco, Telles Gutierrez, & Perez García, 1990)

Table 1. Geotechnical characteristics of granular soil in study.

Properties	Results
Natural Humidity (%)	22.38
Pass sieve 3” (%)	100
Pass sieve No 4 (%)	89.50
Pass sieve No 200 (%)	20.70
Liquid limit (%)	31.2
Plastic limit (%)	N/P
Plastic index (%)	N/P
Maximum dry density (kg/m^3)	1311
Optimal humidity (%)	21.7
Density	2.0
CBR (%)	24.5
Expansion (%)	0

Table 2 shows chemical composition of SCBA, it can be observed that sum of main oxides (SiO_2+Al_2O_3+Fe_2O_3) were 73.069%, being up to 70% the minimum, as established the pozzolanic standard, furthermore it has loss of ignition 1.5% having classification of class N (ASTM C 618, 2017).

These results has been contrasted with different researchers that have used SCBA as supplementary material to portland cement, having consistency with them (Frias, Villar, & Savastano, 2011; Ganesan, Rajagopal, & Thangavel, 2007).

Table 2. Chemical composition of sugar cane bagasse ash in study.

Compound	Concentration
SiO_2	62.66
Al_2O_3	5.20
Fe_2O_3	5.19
TiO_2	0.64
CaO	4.87
MgO	2.19
SO_3	0.30
K_2O	13.93
Na_2O	0.56
P_2O_5	3.36
Density (g/cm^3)	2.1
Loss ignition (%)	1.5

Figure 1 shows phases present in SCBA by diffraction patron, it can be observed amorphous particles presents in halo localized between 10 – 40º, 2θ region, it is observed that on SCBA the main compounds are tridymite, kyanite, potassium oxide, iron oxide and silicon-aluminum oxide as crystalline materials. Similar diffractograms has been obtained of several authors, coinciding to mark off the region describing before (Jagadesh, Ramachandramurthy, Murugesan, & Sarayu, 2015; Torres Rivas, Gaitan Arevalo, Espinoza Perez, & Escalante Garcia, 2014).

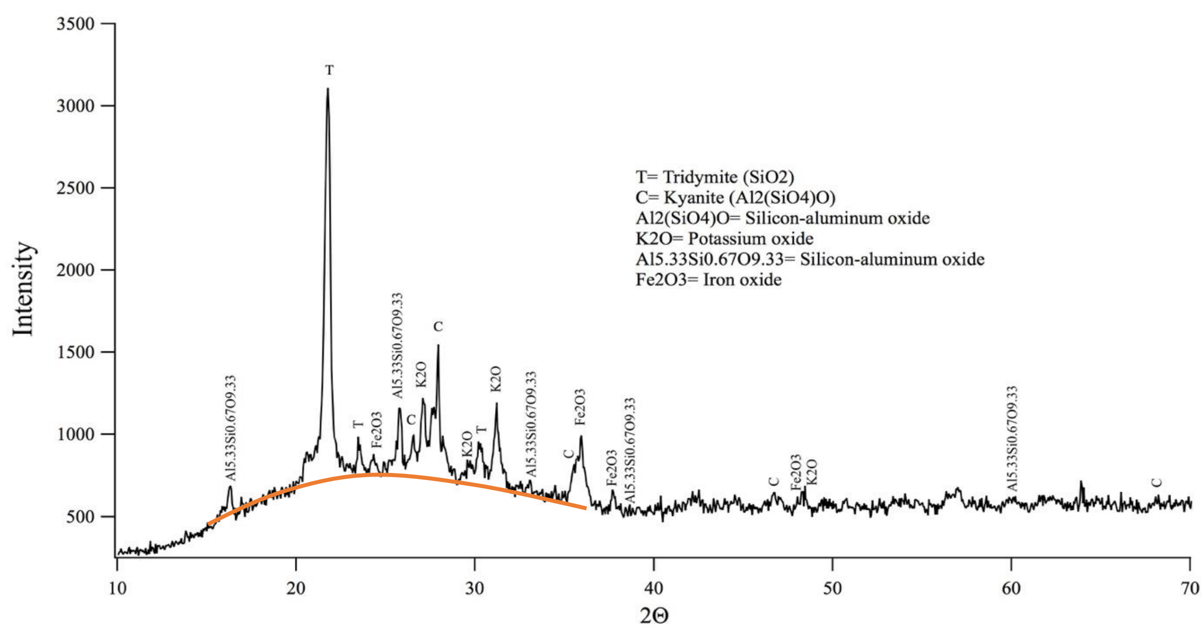

Figure 1. DRX results of sugar cane bagasse ash in study.

Figure 2 shows the SEM analysis on SCBA particles, it can be observed irregular and elongated shapes particles of tridymite (SiO_2) mix, and porous particles of ash also is observed to 500x, the several sizes can be observed taking as reference 50 μm scale on micrograph. On the other hand, at 800x is observed tridymite particles with grains of less size between 20 μm y 40 μm. The morphology found is associate to process and temperature of burned of bagasse as it has been reported by several researchers. Additionally, the same figure shows particle size distribution of SCBA particles, observing a uniform size distribution, namely, the SCBA is compound to particles from 10 μm until 200 μm, having an average size 86.62 μm according to laser diffraction granulometric analysis. The appropriate symmetry of the ash reflect the uniform distribution of SCBA. The morphology and composition is according to several microphotographs obtained from other researcher. (Alavez Ramirez, Montes Garcia, Martinez Reyes, Altamirano Juarez, & Gochi Ponce, 2012; Jimenez Quero, Leon Martinez, Montes Garcia, Gaona Tiburcio, & Chacon Nava, 2013)

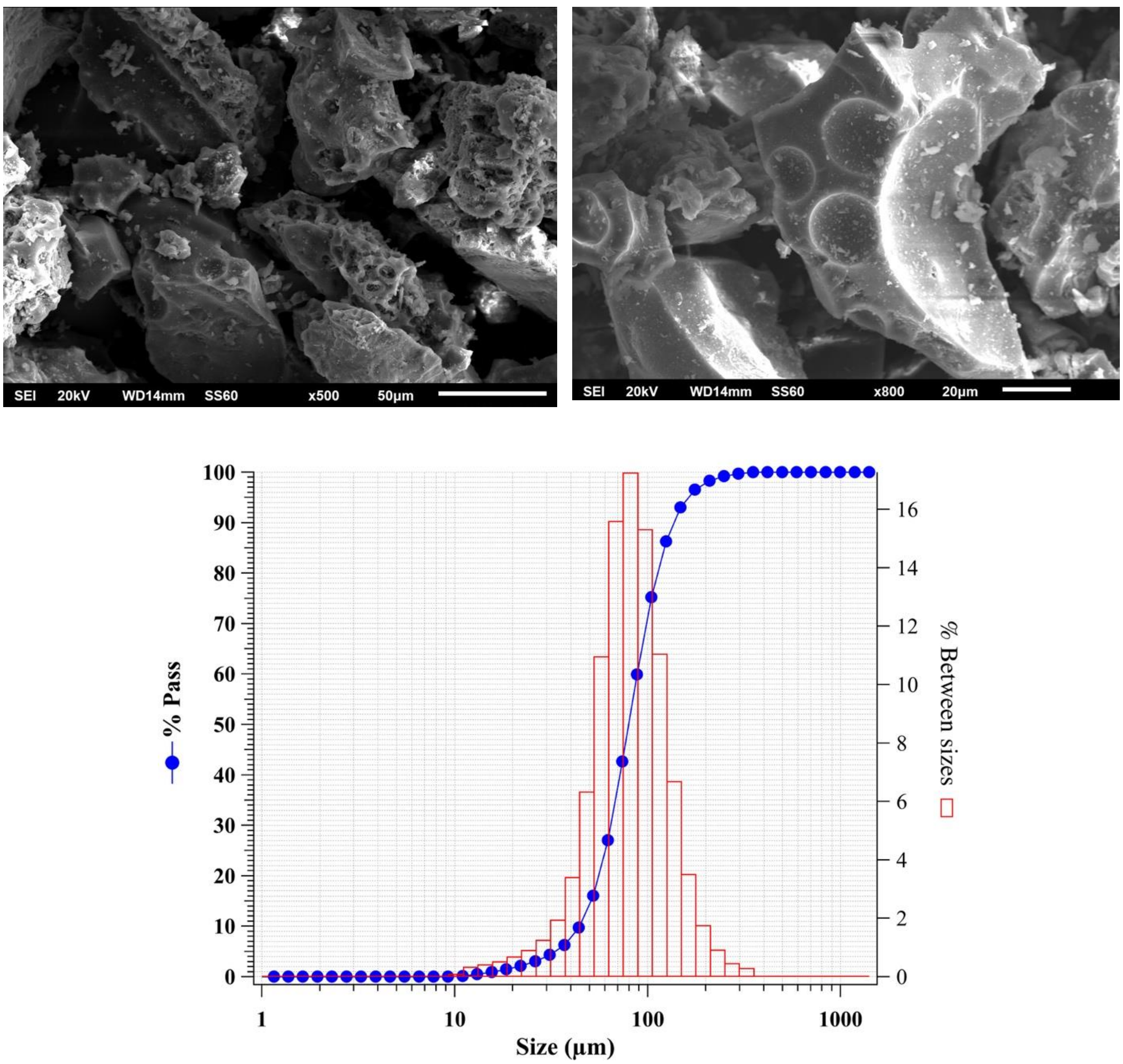

Figure 2 SEM microphotographs and particle size distribution curves of SCBA.

2.2 Characteristics compaction effects

Figure 3 shows the effect on dry unit weigh (DUW) as consequence of CPC and SCBA addition in 3%, 5%, and 7% as well as the effect of combination CPC-SCBA on the same percentages (3%, 5%, 7%) but 75%CPC – 25%SCBA and 50%CPC-50%SCBA blended. It can be observed when the CPC is added the DUW does not present significate variations, it have values of -0.84% with 3% addition, 0.07% with 5% and don't present variation in 7% addition, because the DUW value was 1311 kg/m^3, this results are according with prescription in literature (imcyc, 2017), where is established that on soil stabilized with cement, except in exceptional cases, DUW and water content does not present wide variety of values with respect to soil without cement, being a rewarding characteristic on soil stabilization, since the effect of cement will be the improved durability and strength.

The soils with combinations 75%CPC-25%SCBA present the highest increments in DUW, when 3% was added of combination CPC-SCBA having to increase of 2.8% reach 1348 kg/m^3; The soils of 5% with combination 75%CPC-25%SCBA present increasing on DUW of 1.22% and soil of 7% with 75%CPC-25%SCBA combination the DUW was 1345 kg/m^3 representing 2.6 % of increase. The increase is associated with three mechanims: 1) A greater compaction due to suitable particle distribution and size of SCBA, 2) Due to tension for water suction inside of pores, producing an adherence phenomena between particles due to negative press or capillary forces called apparent cohesion (Suarez, 2009) , 3) A probably poozolanic reaction of $Ca(OH)_2$ by hydration of CPC with amorphous components of SCBA to early ages due to change of kinetics reaction produced for ash presence (Cordeiro & Kurtis, 2017). The soils with combination 50% CPC – 50% SCBA, in 3% increased their DUW 2.6%, this is associate to the good compaction process due to SCBA characteristics, in 5% addition with combination 50%CPC- 50% SCBA the DUW decreasing 1.6%, and in 7% showed 3.66% being the least DUW in all soil blended studied, this decreasing is associate to the less compaction energy to reach its DUW, as it has been demonstrated in sand materials free of clay the permeability is high enough to do not develop pressures inside during compaction process, and at low water contents the capillary forces are development, obstructing the arrangement of soil particles, having inefficient compaction but not permanent, and if the water content is increasing those forces disappear and the process becomes efficiently again (Rico-Rodriguez & Del Castillo, 2006). Of the above, is observed the inefficient compaction on 50% SCBA combination due to capillary forces, but if the SCBA content is increase to 100% the water content required as a consequence of absorption causes the disappearance forces becomes it in efficiently process, impacting on lower cost constructions as several works have demonstrated (Muntohar & Hantoro, 2016).

The soil with 100% SCBA show increase in DUW as well, getting values of 1.3% in 3% addition, 0.4% in 5% addition and on 7% of additions was observed a decrease of 0.6%, these performances on DUW in SCBA addition without cement are associate to efficiently compaction process and filler effect due to uniform particle distribution of SCBA, which is corroborated in CBR test.

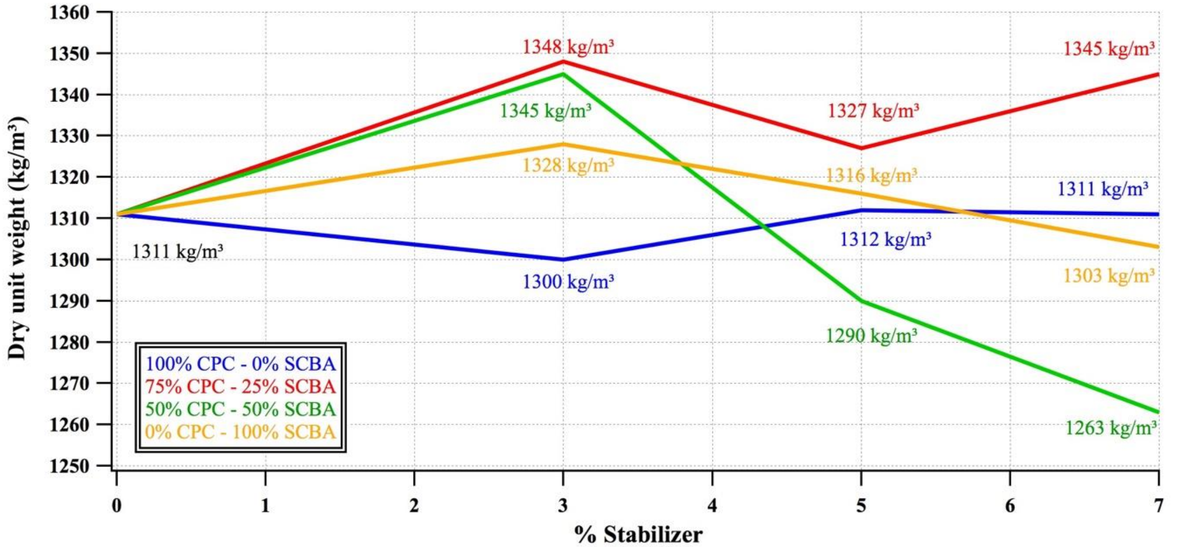

Figure 3 Effects of partial substitution of CPC for SCBA on dry unit weight of soil in study.

With respect to water contents Figure 4 shows the influence of CPC additions and the substitution to SCBA. In general water contents on mixes with SCBA increased as a consequence of high water absorption from particles, observing 2% of increase in 50% substitution which was associate to reduction of DUW because this had water content to generate the capillary force and the compacting process was not successful as is observed on figure 3.
On mixes with substitutions of 25% and 100% the water content was found inside of range that allowed an adequate compaction process, the variability of results of water contents are similar to results reported in another research (Onyelowe, 2012)

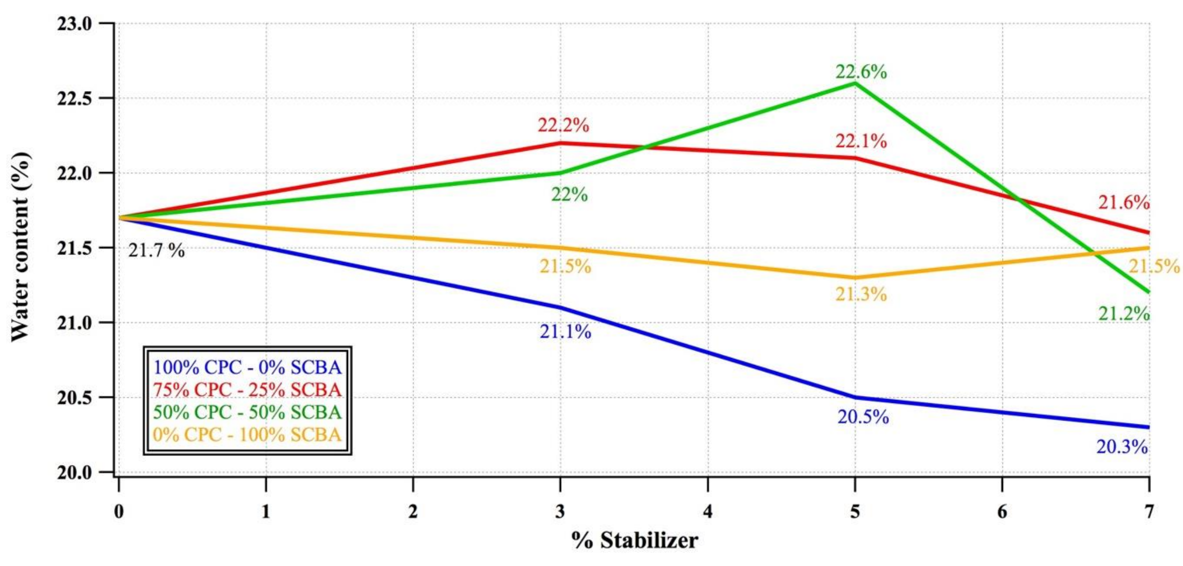

Figure 4 Effects of partial substitution of CPC for SCBA on water content of soil in study.

2.3 Effects on compressive strength

Figure 5 shows the behavior of compressive strength with the three different additions of CPC and SCBA as well as 75%CPC-25%CBCA and 50%CPC-50%CBCA, being this percentage 3%, 5% y 7% with respect to dry soil. It can be observed that soil with CPC addition increase compressive strength according to cement content is increased, observing strengths of 9.89 kg/cm^2, 12.78 kg/cm^2 y 30.85 kg/cm^2, in additions of 3%, 5% y 7% respectively, being soil with 7% of CPC highest strength, however the blended with combination 75%CPC-25%CBCA presented best performance in additions of 3% and 5%, having values 10.29 kg/cm^2 and de 14.25 kg/cm^2, which was highest that the soil with CPC; The soil 7% and 75%CPC-25%CBCA combination had 29.19 kg/cm^2 strength, 1.66 kg/cm^2 less that soil-CPC. The blend with combination 50%CPC-50%CBCA presented in 3% have 5.44 kg/cm^2 strength, 5% have 13.26 kg/cm^2 and 7% have 19.69 kg/cm^2 strength, observing the strength linear increase as function of increase of cement in 3%, 5% y 7%, this is showed in figure 5, on the other hand, soils with 100% SCBA, presented compressive strength smaller that the soil in study, with 2.26 kg/cm^2 in 3%, and 1.5 kg/cm^2 in 5% of SCBA respectively, and is observed a very smaller strength on 7% addition having a linear decrease as respect the SCBA content, Thus when the SCBA content increase without some quantity of CPC the compressive strength decreasing. In soils stabilized with portland cement the compressive strength is function of portland cement addition and specific energy give to soil per volume unit, if there are not cement contents the strength is some units per square meter and when the content of cement is increased is possible to reach the highest strength due to hydration products network, but the consumption quantity of cement will be of ton because the construction of roads is in km. Of above in agreement with the results of strength the blended 75%CPC-25%CBCA, can reduce until 25% consumption of CPC with similar strength, doing efficiently the compaction process to use SCBA as were discusses in 3.2 apart besides taking advantage of the use an agro-industrial waste whose storage generate a pollution problem.

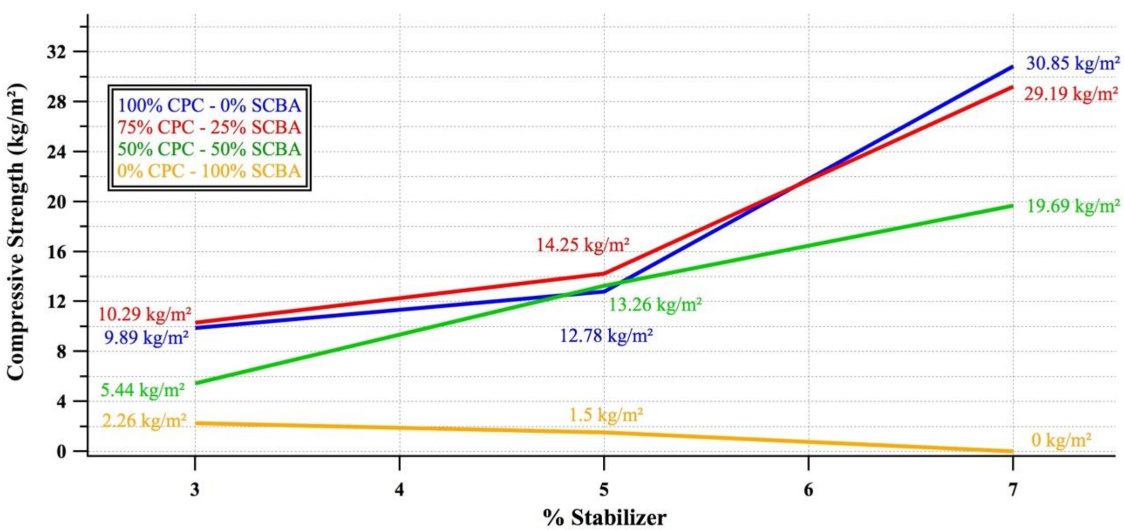

Figure 5 Effects of partial substitution of CPC for SCBA on compressive strength of soil in study.

2.4 Effects on CBR

Figure 6 shows CBR behavior of different mixes tested. It can be observed that the behavior is similar to compressive strength, the soil with 100% CPC showed increases more than three times respect to natural soil that was 24.5%; The soil with 3% of CPC showed 92.50% of CBR, 110% to soil with 5% and 208% in soil with 7%. On the other hand, the soil of 3%, 5% and 7% with

75%CPC-25%SCBA presented an excellent behavior on CBR test with values of 95% in 3%, 107% in 5%, this values are similarly to 3% and 5% only with CPC, while the soil of 7% and the 75%CPC-25%CBCA combination was 137% CBR being below 71% with respect to soil with CPC but above 112% with respect to soil without additions. This increases of CBR are associate to hydration process reaction and the compaction energy on the soil. The soils with additions in 75%CPC-25%SCBA combination, the increase of CBR values is associate to hydration process plus kinetics reaction between $Ca(OH)_2$ and amorphous silica presented in SCBA that change from first hours of mix as has been reported in some researchers (Cordeiro & Kurtis, 2017), besides the filler effect of SCBA particles that did not reaction, comparing this conjectures with several researches as Basha et. al, in this work the residual soil stabilization with CPC and rice husk ash (RHA) was assessment, found the maximum CBR with 4% CPC – 5%RHA combination, showed a change in microstructure observed through SEM and DRX techniques due to pozzolanic reaction. (Basha, Hashim, Mahmud, & Muntohar, 2005)In another study stabilization on soil type CH was assessment with additions of CPC and RHA, where was demonstrated that optimal addition was 10% RHA – 6% CPC obtained the highest increase in CBR and strength.
On the other hand, 50%CPC-50%CBCA combination in 3% was 142% CBR associated this performance to hydration reaction, one initial puzzolanic reaction and a very important filler effect on pores, this performance was decreasing when the 50%CPC-50%CBCA combinations contents was increasing, so that in 5% the CBR was 83% and in 7% was 70%, this is associated to discussion of part 3.2 referenced to compacting process on the blended.

All CBR values with CPC, CPC-SCBA additions satisfy requirements for this material can be used to subgrade on roads in agreement with manual of quality of SCT Mexico which establish 40% of CBR, and on soils with 100% can be used on base layer, or above the blend of CPC-SCBA are workable on subgrade and base layers being a substantial saving and ecological support on roads construction (Rico Rodriguez, Orozco y Orozco, Telles Gutierrez, & Perez Garcia, 1990).

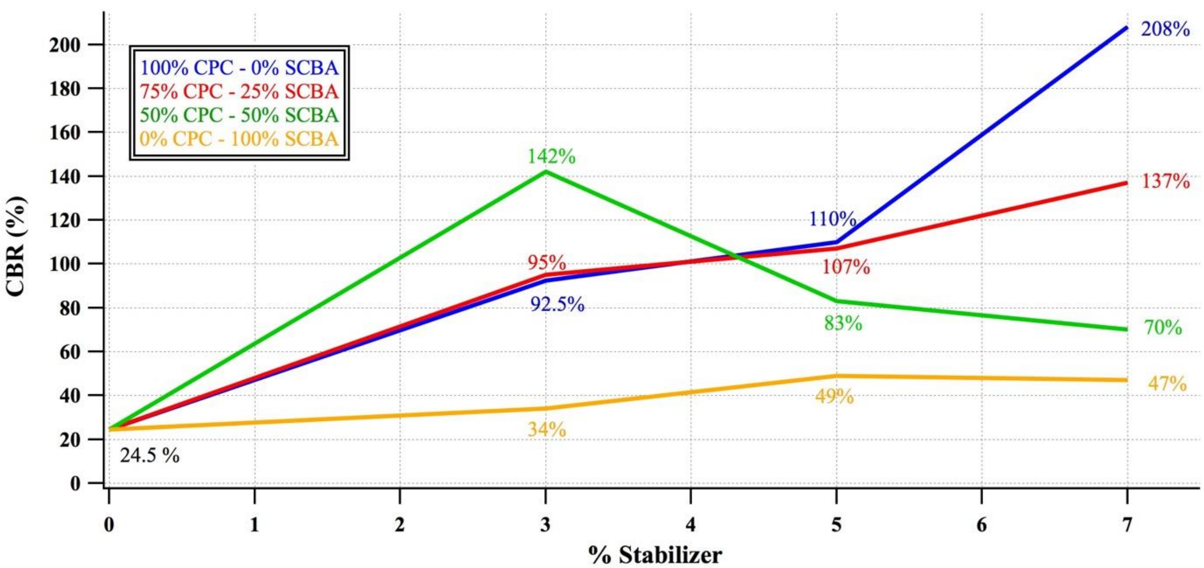

Figure 6. Effects of partial substitution of CPC for SCBA on CBR of soil in study.

For the soils with only SCBA additions in 3%, 5%, and 7% it was observed that the values increase with respect to the reference. From 24% CBR to 34% of CBR with 3% of SCBA, 49% with 5% and 47% with 7%. This result complements the discussion in part 3.2, which suggest the compaction process increase mechanical strength of soils, and although this project has one soil and one compaction mechanics the results changed from one case to another, because the condition of sample, and the SCBA added to soil in 25% substitution of CPC on CBR characteristics is a alternative technique, environmental and economic for embankments conformation.

3. CONCLUSIONS

The partial substitution of PCC for SCBA in the percentages studied and according to results obtained in the experimental tests, the following conclusions can be drawn:

- The 25% partial substitution of PCC for SCBA it can be established as an optimal percentage on a granular sand soil, due to an excellent performance on the compacting, compressive strength and CBR, having a similar behavior to soil with 100% cement, this leads to viable use of SCBA as a partial substitution for the improvement soil mechanical properties on the construction of roads layers.
- The mix with partial substitution of fifty percent of PCC for SCBA, shows an improvement on soil properties, highlighting the compressive strength and CBR test, where the results show a significate improvement with respect to soil without additions, reaching CBR values that satisfy the specification even to base layer.
- The use of SCBA as unique material on granular soil improvement shows increase strength of soil on confined conditions, such as CBR test, achieve as the case of 5% and 7% CBR values that satisfy the specification to base material.

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Selection of constructive systems using BIM and multicriteria decision-making method

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ABSTRACT
This study aimed to identify whether the use of a BIM platform software associated with the AHP decision-making method can assist in the decision-making process during the design phase of projects. Three construction systems were analyzed: Load-bearing masonry, *Light Steel Framing* and *Light Wood Framing*. BIM modeling enabled scenario simulations and facilitated the extraction of data, which, in turn, assisted experts in the selection of the most appropriate constructive system, considering the established criteria. The originality of this research lies on the consideration of several factors relevant to constructive system choice. The limitation lies in modeling only the walls of the analyzed constructive systems, and not of the complete building.
Keywords: constructive systems; building information modeling; BIM; AHP.

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Seleção de sistemas construtivos utilizando BIM e método de tomada de decisão multicritério

RESUMO

O objetivo deste estudo é identificar se o uso de um software de plataforma BIM associado ao método AHP de tomada de decisão, pode auxiliar no processo decisório, durante a fase de concepção de projetos. Três sistemas construtivos são analisados: Alvenaria Estrutural, *Light Steel Framing* e *Light Wood Framing*. A modelagem em BIM possibilitou simulações de cenários e facilitou a extração de dados, que, por sua vez, auxiliaram os especialistas na seleção do sistema construtivo mais adequado, considerando os critérios estabelecidos. A originalidade dessa pesquisa está em considerar vários fatores relevantes à escolha do sistema construtivo, e sua limitação está na modelagem somente das paredes dos sistemas construtivos analisados, e não da edificação completa.

Palavras-chave: sistemas construtivos; modelagem da informação da construção; BIM; AHP.

Selección de sistemas constructivos utilizando BIM y método de toma de decisión multicriterio

RESUMEN

El objetivo de este estudio es identificar si el uso de un software de plataforma BIM asociado al método AHP de toma de decisión, puede auxiliar en el proceso decisorio durante la fase de concepción de proyectos. Se analizan tres sistemas constructivos: Albañilería estructural, *Light Steel Framing* y *Light Wood Framing*. El modelado en BIM posibilitó simulaciones de escenarios y facilitó la extracción de datos, que a su vez ayudaron a los especialistas en la selección del sistema constructivo más adecuado, considerando los criterios establecidos. La originalidad de esta investigación está en considerar varios factores relevantes a la elección del sistema constructivo, y su limitación está en el modelado solamente de las paredes de los sistemas constructivos analizados, y no de la edificación completa.

Palabras clave: sistemas constructivos; modelado de la información de la construcción; BIM; AHP.

1. INTRODUCTION

Traditionally, designers in the construction industry have chosen constructive systems in two ways: based on known characteristics or selecting systems that were used in previous projects (Jalaei et al., 2015).

In Brazil, according to Molina and Calil Junior (2010), despite the technological advances achieved in this sector, the same construction system is still used since colonial times, which is the masonry system, essentially handmade, based on stacking blocks.

It is known that this practice of civil construction is favored to the detriment of alternative construction systems. This is due to pre-established standards and institutions, existing infrastructure investments, consolidated technical knowledge, and also due to the large number of agents (owners, designers, contractors and suppliers) in the industry supply chain who have always worked with these input materials and techniques (Mahapatra et al., 2012).

However, for Jadid and Badrah (2012), a high demand for materials has arisen due to the expansion of the construction industry worldwide. Therefore, arises an emerging need for research on new input materials.
According to Mahapatra et al., (2012) many countries are looking for more efficient alternatives to be in accordance with environmental sustainability protocols. Finland, for example, has submitted plans to use resources and inputs that meet the energy efficiency target set in 2010. These rules would be applied for any construction in the country, starting in 2017. According to the authors, a "code for sustainable homes" has set standards for all new buildings in the UK since 2008.
In Brazil, the main building system used in building construction is masonry. However, the environmental impacts of this practice cannot be ignored, mainly due to the amount of waste generated at construction sites. The problems are not restricted only to environmental issues, but also to the low productivity and quality of the projects, when compared to other countries with more industrialized construction systems, characterized by high productivity and process control (Molina and Calil Júnior, 2010; Mello, 2007).
Therefore, it is evident that identifying other construction systems that may be more adequate for day-to-day operation in the Brazilian scenario is crucial. For instance, systems presenting lower environmental impact and systems which could facilitate the future maintenance of buildings.
Based on this problem, the Building Information Modeling (BIM) platform software can be used as a resource during the design of the architectural projects.
BIM, according to Succar (2008, p.5) "is a set of technologies, processes and policies that allow various stakeholders to design, build and operate a facility in a collaborative way." In the BIM model, components, inputs and materials can be inserted, allowing the creation of an accessible database, which acts as a support for the selection of inputs and components for a project (Jalaei and Jrade, 2014).
In this way, this article aims to identify whether the integration of BIM in architectural projects can aid in decision making, during the project design phase, in order to optimize the selection of components for a construction. To achieve this objective, the article uses the Autodesk software Revit® (2015 version) for BIM, and the decision-making method Analytic Hierarchy Process (AHP). In an approach inspired by Marcos (2015), the innovative proposal presented by this article is the integration of BIM and AHP and the use of not only a criterion of selection for a constructive system, but also several criteria considered relevant and highlighted in the literature.
The research analyzes three constructive systems: Structural Masonry, Light Steel Framing (LSF) and Light Wood Framing (LWF). The constructive options, more specifically, the walls of each system, are analyzed, compared and their alternatives evaluated.

2. BIBLIOGRAPHICAL REVIEW

2.1 Construction systems

The increase in competitiveness among construction companies is growing throughout Brazil. This competition requires business strategies that allow a greater use of resources and rationalization of processes (Milan, 2011). In this context, Marcos and Yoskhioka (2015) point out that a possible alternative towards rationalization and industrialization of civil construction processes is the use of new constructive technologies.
The reasons for such a significant use of masonry in the country refer to: non-qualified workforce[1], cheap and available throughout the country; familiarity with the raw material, which consists of ceramic or concrete blocks, which is also easily accessible and used in various works, and finally,

[1] In this paper, the terms "non-qualified workforce" or "unskilled labor" are intended to mean "the ones whose level of education is restricted to the incomplete secondary education (incomplete high school), because in Brazil the high school category also includes technical courses that could qualify, even in a limited way, professionals for the civil construction" (Fochezatto and Ghinis, 2011, p.654).

the cultural aspect: Brazilians value the construction in masonry, as it ensures comfort both in winter and summer (Ferreira, 2014).

However, it can be seen that this constructive process, based on structural masonry, is still essentially artisanal, and presents significant flaws such as low productivity and high waste of material resources (Santiago and Araújo, 2008). Mello (2007) further emphasizes that this construction system provides unsatisfactory quality and productivity, unwillingness for modifications, employment of low-skilled workers and consequent high turnover.

In addition to the aforementioned characteristics, sector studies of SEBRAE (2008) show that there is a small share of formal employment in the total number of workers employed in the construction sector, which favors high turnover rates.

Based on this reality, the civil construction sector in Brazil has been looking for alternatives, in order for constructive systems to become more effective and less environmentally harmful. Prefabricated building systems, such as Light Steel Framing (LSF) and Light Wood Framing (LWF) are an alternative to traditional systems, since control of planning and design within the industry contributes to avoid material waste and slow production processes (Vivan, 2011).

According to Ferreira (2014), industrialization in the civil construction sector provides several advantages. Among them, one could highlight faster completion of the project, elimination of indirect costs that are difficult to account, higher quality of final product, replacement of part of the workforce by equipment, process traceability, cleaner and more organized construction site.

The LWF system is composed of structural wood components, covered by panels such as: OSB boards, and cement boards, which act as bracing elements, and gypsum board. The LWF consists of an industrialized, fast-running construction system. According to Molina and Calil junior (2010), Cardoso (2015) and Kobunbun 2014 the industrial environment allows for several activities to be carried out simultaneously resulting in shorter delivery times and lower costs.

Another advantage related to works with the LWF system is that the raw material is renewable. However, not all wood can be used for this processing. According to DATec 020-A (2015) the wood used for LWF must be properly treated. Said wood must present good quality (without defects) and with considerable dimensions to be industrialized in the design of structural panels.

According to data from the Brazilian National Forestry Information System (SNIF, 2017), lumber, i.e. sawn wood used for construction, has been increasingly used in recent years, with a growth of 48% from 2013 to 2014.

Because it is considered a new constructive method in Brazil, there are only a few suppliers and manufacturers of specific products such as cement boards, waterproof membrane, etc., which adds costs to building (Cardoso, 2015). Another important factor is the issue of skilled labor. Kokubun (2014) emphasizes that skilled labor is essential for this type of constructive system, for operations of panel manufacturing and structure assembly and disassembly. This labor force, in turn, becomes less available, given the need to train these employees and bring these professionals from the timber industry.

Besides these aspects that must be considered, the system suffers with cultural barriers. Wood is still considered a poor-quality material and many are afraid that it's use will involve deforestation, says Cardoso (2015). For Dias (2005), the main problem related to the cultural barrier is the lack of knowledge and technological development in the area.

The LSF system has similar characteristics to the LWF. The main difference is in the use of raw material, which in this case is steel and not wood. The Light Steel Framing pieces are galvanized, cold formed, designed to withstand building loads and work together with other industrialized subsystems (Sousa and Martins, 2009).

Being an industrialized system, it demands more qualified workforce, as well as the LWF. (Ferreira, 2014).

The LSF is a more expensive construction system in terms of raw material: galvanized steel (Ferreira, 2014). However, direct and indirect costs may be lower compared to reduced construction time and the absence of common losses in conventional construction.
According to Gomes et al. (2013), this system presents a time reduction of 1/3 in construction periods when compared to the conventional construction methods in masonry. Therefore, the system is more used when the construction time factor is more important than the costs.
It should be emphasized that the choice of construction systems should take into account environmental, economic and social aspects. According to Jadid and Badrah (2012), the choice of an input material, and consequently a constructive system, is related to several criteria which include, but are not limited to:

- Durable, with low maintenance requirements;
- Produced with natural and renewable resources;
- Affordable and available from local manufacturers;
- Material does not affect indoor air quality and is environmentally friendly;
- Material contains no toxic compounds;
- Material is adaptable for redistribution of the internal spaces to attend a specific service;
- Costs.

This information must be available for selection of the constructive system most appropriate to that situation. For this purpose, it is essential to create a database in which this information is available during the design phase of the project. This can be created in partnership with suppliers and designers who already work in the area and who can inform about the aspects listed above (Jadid and Badrah, 2012).

2.2 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) developed by Saaty (1990), is based on three fundamental principles: the decomposition of the structure, the comparison of the judgments and hierarchical priorities composition. The decomposition of the decision problem facilitates the construction of hierarchies of criteria to determine the importance of each criterion. These criteria, defined by experts, are analyzed and compared, two by two, independently. For this purpose, concrete data of subjective alternatives or judgments can be considered.
Once the hierarchy is structured, the alternatives are systematically evaluated by means of comparison, two by two, according to each of the criteria and a numerical scale is assigned to each pair of *n* alternatives (Table 1). These numerical scales are used for comparisons of pairs between the alternatives according to their impact on an element placed at a higher level of the hierarchy (Saaty, 1990).

Table 1. Saaty rating scale.

Intensity of importance	Definition
1	Equal importance
3	Weak importance of one over another
5	Essential or strong importance
7	Very strong
9	Extreme importance
2, 4, 6, 8	Intermediate values between the two adjacent judgments

Source: Adapted from Saaty (1990).

The sequence of the method calculations can be found in detail in Saaty (1990). This method further allows for the ranking obtained by calculating the consistency index.

Among the advantages of AHP are the ease of use and ease of adjustment of its hierarchical structure to deal with problems of different dimensions (Velasquez and Hester, 2013).

2.3 Building Information Modeling (BIM)

According to Eastman et al. (2014), BIM is a modeling technology and an associated set of processes for producing, communicating and analyzing construction models, including information related to design, simulation and operation through the use of different integrated tools.

During project design, BIM can support project detailing, providing specific information on the structure of the project, the execution processes and even on the choice of the most appropriate building system (Jalaei and Jrade, 2014).

According to Jalaei et al. (2015), the great advantage of using BIM for selection of constructive systems is its function of information integration and interoperability. BIM allows to include detailed descriptions of a single building or set of buildings may be important to make accurate analyzes of the project.

In addition, several studies have assessed the integration of BIM with environmental sustainability in Brazil. Oliveira et al. (2015), for example, highlights BIM as a resource that allows for a lifecycle approach (LCA) of the building, enabling analysis during the design phase of the project; Marinho (2014) highlights BIM as a tool to help optimize, for example, energy, water and materials use in integrated analyzes. Carvalho and Scheer (2015) demonstrate the characteristic of BIM in the anticipation of problems and prevention of project inefficiency. For them, prevention of mistakes that are often noticed only at the construction site can lead to a reduction in the costs of construction and the expense of materials, providing gains in work quality and resource savings, favoring sustainability of the buildings.

2.4 Related Papers

To better understand the practical problem and to examine the potential of the topic under study, a search was carried out to identify recent and related works published in the last five years. The search was carried out in the reference databases - ScienceDirect and CAPES Journals.

Several papers related to this topic were identified. Papers that came closest to the analysis of constructive systems using BIM and / or the decision-making tool were the four described below.

Marcos and Yoshioka (2015) wrote about how they used BIM as a tool to assist managers in the choice of inputs with the least environmental impact, comparing two construction systems: masonry and light steel frame. Its focus was specific on environmental impact.

The research of Jadid and Badrah (2012) created a decision-making method for material selection during the design phase of an architectural project. This paper focused on multicriteria method within the architectural projects.

The research of Jalaei et al. (2015) brought together the two subjects, the BIM platform software (Revit) and the decision-making method. The authors created a plug-in within BIM to assist in choosing inputs that would provide a lower environmental impact, analyzing more specifically the material life cycle. Again, this paper addresses environmental aspects.

For Jobim et al. (2006), the choice of construction systems is not only characterized from a technical or professional view but must take into account the context in which the project is inserted, user requirements, available resources, physical conditions, environmental conditions and aspects relating to cost improvement.

The novelty of this paper lies in the proposition to analyze not only a relevant factor for the construction system choice, but also some of the main factors, such as the environmental aspect related to the inputs, the financial cost and operational factors, such as availability of labor and materials.

In this way, this subject, besides being relevant and researched by other authors, is fundamental, as it enables the unfolding of the new constructive systems and helps to expand the incorporation of BIM in the production chain of civil construction in Brazil.

3. METHOD

The purpose of this study is to identify whether the use of a BIM tool associated with a multicriteria decision-making method can aid decision. It is considered that this integration may generate an instrument to assist in the most appropriate choice of construction system, according to user requirements, based not only on a relevant criterion but also on the environmental, economic and operational factors of the systems.

The proposal of the article is based on the *concept of design science* which, according to Dresch, Lacerda and Antunes Júnior (2015, p.57) "is the science that seeks to consolidate knowledge about the design and development of solutions to improve existing systems, solve problems or create new artifacts that contribute to a better human performance, whether in the society, or in organizations."

Thus, Lukka's method (2003), which divides the study into seven main steps, was used to develop this research. The steps are as follows: (1) to identify a practical and relevant problem; (2) to examine research potential together with the target industry; (3) to obtain theoretical and practical knowledge of the area; (4) to propose an innovative solution and develop a construction that solves the identified problem; (5) to implement and test the solution through a case; (6) to evaluate the applicability of the solution; and (7) to identify and analyze the theoretical contributions.

Steps 1 through 4 are presented in the first part of this article. In the sequence it will be described how steps 5 to 7 were developed.

In the step defined as "to implement and test a solution", a case study was carried out to present the use of BIM platform software with the AHP method. The BIM platform software chosen for this study was the software Revit® (2015 version) that according to Suermann (2009) is the most used software in the world (67.08%).

The AHP method allows formal structure of problems, provides simplicity for comparing pairs of problems and also allows to check the consistency of the assigned weights (Leite and Freitas, 2012).

For implementation of the AHP method, experts from the Federal University of Paraná (UFPR) and the private sector were invited, contributing with their direct experience in construction systems, through their *expertise* of the subject. The sample was non-probabilistic for convenience, i.e., experts were selected based on previous contact with the researchers and on the fact that they had an interest in participating in the research. The experts are:

- A and D - UFPR researchers;
- B, C and E - representatives of the corporate environment that work directly with the three construction systems in the state of Paraná.

The experts consulted evaluated the constructive systems through forms designed according to the structure of the AHP method. To aid in this part of the research, a questionnaire elaborated using *Google Forms* (Available at https://goo.gl/forms/GWo7viiJft30i1LG2).

To attribute weight to each established criterion, the experts used their professional experience and also an elaborated document, with the information found in literature regarding each constructive system used in Brazil. This information was presented in the bibliographic review of this article.

In order to weigh the criteria and formulate a ranking of alternatives, the software *SuperDecisions* was used (from the Creative Decisions Foundation, version 2.0.6).

An architectural design was chosen for the case study implementation. Among the identified projects, a house with 42m² from a social housing program was selected. It was modeled on the software® Revit three times. A first time using structural masonry construction, a second time using Light Steel Framing and a third time using walls in Light Wood Framing.
Information was inserted in each of the projects with the purpose of creating a database within the system. This information, presented in Table 2, was collected in different data sources and was based on the criteria presented by Jadid and Badrah (2012).
For research delimitation, the system was compared referring only to the area of wall with coating, not considering foundation, frames, electrical and hydraulic installations and neither roofs.
This information was manually entered into Revit, which allows storing specific data for each component. According to Marcos and Yoshioka (2015), the great advantage of using a unified tool such as Revit is that once a unified database is used for all information content, modifications in a particular document (for example, a floor plan of the architectural project), propagate themselves to the other documents involved automatically, thus guaranteeing the agility in the updates, modifications and reliability in access to information.
Figure 1 shows a schematic of the Revit information process. First the element (in this case, a wall) is drawn, then materials are applied and finishes relative to that wall and finally the information regarding the construction system as a whole. In this case, the value of incorporated CO_2 of each wall, the cost of each raw material, the execution time and the specification of the workforce.

Table 2. Source of Information for elaboration of the database in Revit software

Information	**Extraction source**
Energy incorporated by each material (CO_2)	Literature (Caparelli, Crippa and Boieng, 2016) and based on data extracted from Simapro Software
Production time	Literature (Cardoso,2015; Molina and Calil Júnior, 2010; Ferreira 2015)/corporate environment
Manufacturing cost	SINAPI/PR* nov. de 2016/literature (Cardoso, 2015) and corporate environment
Availability of labor	Literature (Ferreira, 2015 and Kokubun 2014)/ corporate environment
Availability of raw material (suppliers)	Literature (Ferreira, 2015)/ corporate environment

* Brazilian Nacional System for Research of Costs and Index in the Construction Industry (SINAPI), state of Paraná.

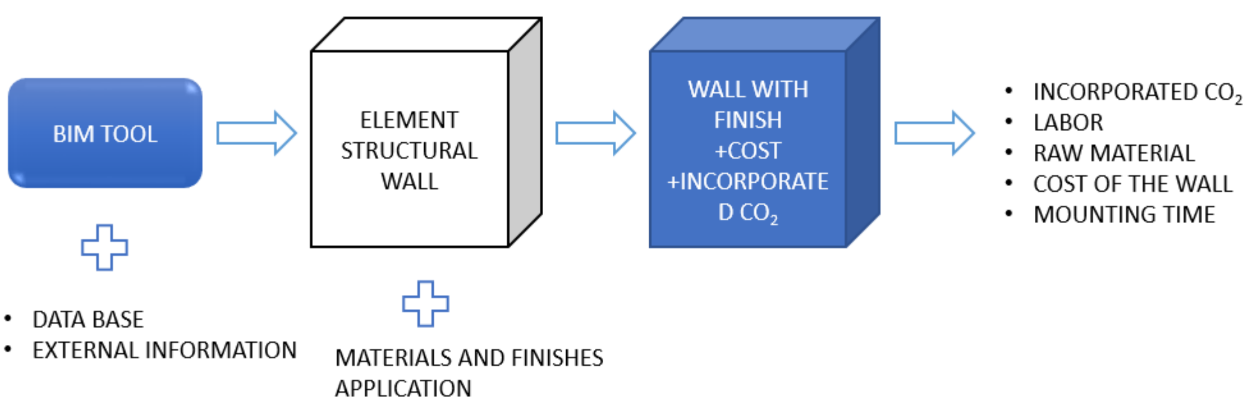

Figure 1. Revit information process schema. Adapted from Marcos and Yoshioka (2015).

In the next step, applicability evaluation, the experts were asked about the relevance of the BIM platform software to support the decision during the architectural project design.
Finally, in the "identification and analysis of the theoretical contributions" step, the authors aimed to reflect on the contribution made in comparison to similar recent studies.

4. DATA RESULTS AND ANALYSIS

4.1 Deployment and tests for the solution

The chosen residence is a 42 m² house, consisting of two bedrooms, living room, kitchen and bathroom. It was also considered that the housing scenario would be the region of Curitiba, in the state of Paraná.
Using Revit, the residence was modeled in the three constructive systems (structural masonry, LSF and LWF). The LSF and LWF systems were modeled from the plug-ins *Timber Framing* (from Autodesk) and *Metal Framing Wall* + of AGACAD (version 1.0.0.6), respectively. The use of plug-ins makes modeling faster, which allows the designer to model the project only once. The plug-ins allow conversion of any type of wall into a wall of LSF or LWF almost instantly, which increases productivity in the modeling process. The *plug-ins* also make possible to make changes in the new frame, according to the designer's preferences, since the types of profiles as well as their dimensions, the distances between the uprights and the details of the openings and connections can be changed.
The data highlighted in Table 2 were added to the parameters of the modeled walls.
Then, using Revit documentation resource, which is one of the advantages of BIM software, the list of materials with the values for the walls of the three construction systems was automatically obtained (Table 3).

Table 3. Comparative between the three constructive systems

	Structural masonry	**LSF**	**LWF**
Incorporated CO_2/m^2 of wall (kg)	50,3	159	36,9
Cost/m^2 of wall (R$)	247,63	295,99	182,32
Total of incorporated CO_2 (kg)	4.842,88	15.308,46	3.552,72
Total cost (R$)	23.841,82	28.498,08	17.553,77
Runtime	12 day	1/2 day	1/2 day
Skilled labor force	no	yes	yes

In the next step, the AHP method was used to help structuring the problem of choosing a constructive system. In this way, the criteria were first identified in the literature (Figure 2).

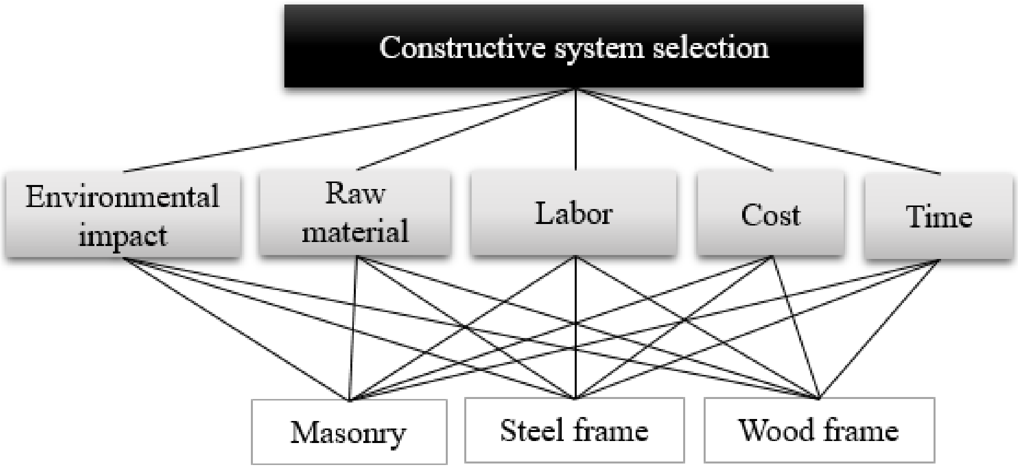

Figure 2. Hierarchy of criteria and alternatives of the case study, for use of the AHP method.

Subsequently, from the hierarchical structure of this case study and the data obtained through Revit, the abovementioned experts evaluated the constructive systems, following the structure of the AHP method, using the scale presented in Table 1. The expert evaluations were implemented in the software *SuperDecisions*. Thus, the weights stipulated by the experts for each criterion can be visualized in Table 4.

It can be seen from Table 4 that the weights indicated by the experts for each criterion of constructive system selection were very discrepant, i.e., there was no consensus among them. For experts A and B, for example, the weight of choice was the environmental impact. While for experts C, D and E, the most striking criterion is the financial value of work.

Table 4. Weights stipulated by the experts for each analyzed criterion (in percentage)

Criteria	Expert				
	A	B	C	D	E
Environmental impact	54,67	53,66	12,56	9,68	3,11
Availability of raw material	23,73	23,63	20,52	17,03	5,45
Availability of labor	2,91	13,61	11,81	17,24	11,31
Cost	7	5,66	37,32	42,5	52,49
Time	11,69	3,44	17,79	13,55	27,64

This analysis proves in fact that the choice of constructive system depends on the interests of each user / constructor. According to Jobim et al. (2006), the analysis of alternatives for constructive systems and materials available, regardless of whether the technology is considered innovative, should be analyzed under different criteria and in particular meet certain performance requirements, such as performance standard 15.575 (ABNT - Brazilian Association of Technical Standards, 2013).

From the stipulated weights for each criterion it was possible, with the help of the software *SuperDecisions*, to identify which building system is most suitable for each expert. The percentage preference for the construction system (ranking) is shown in Table 4.

It can be seen from Table 5 that the most appropriate constructive system in the evaluation of experts is *Light Wood Framing*.

The experts were consulted to analyze the integration of BIM with the MCDM method. As they also know the construction systems, because they work in the field of civil construction, they also contributed to create the preference ranking of construction systems.
This option was the most promising especially for the advantages that the system presents when compared to structural masonry in matters of: time, cost and environmental impact and with respect to the system Light Steel Framing, in matters of: cost, raw material and environmental impact.
It is noteworthy that the scenario elaborated took into consideration the construction of this house in the region of Curitiba in the state of Paraná, where companies are known to work with the three construction systems. It is also worth noting that the proposal of the article is to show the established scenarios and not which system is the most appropriate, since considering other factors, a system can be more promising in some situations and not so much in others.

Table 5. Percentage of systems preference obtained by the AHP method

Constructive systems	Experts				
	A	B	C	D	E
Masonry	12,1	35,37	8,27	4,63	**52,14**
LSF	17,95	14,16	17,91	18,51	24,67
LWF	**69,95**	**50,47**	**73,82**	**76,86**	**23,19**

4.2 Evaluation of the solution applicability

In order to evaluate the applicability of the proposed solution, the experts were asked about the relevance of the information extracted from Revit to choose the most appropriate construction system. On a scale of 1 to 5, in which 1 means nothing relevant and 5 very relevant, the average score of the experts was 3.2, i.e., in general they consider that the use of a BIM platform software contributes to the choice of construction system.
They also described how they believe BIM can contribute to the use of new constructive systems, which could also contribute to address some social barriers.
Expert A considered that, from the moment a professional is aware of the BIM tool, it may be essential to assist in their work. However, he warns that misuse of such tool may represent only a misleading view of the actual state of a project.
Expert B reported that the use of BIM platform software during the design phase is extremely satisfactory and stressed that this can help users choose more sustainable buildings.
Expert C, in agreement with expert B, considered the tool satisfactory for the comparative process, provided the extracted sources are reliable. Expert D also pointed out that BIM helps ensure that the same project will be edited, modifying construction systems in an easy and simple way allowing for efficient comparison between systems and a more reliable choice for the most appropriate option.
The expert also understood that BIM allows for greater detailing of a project which makes processes more accurate and with less waste of raw material and manpower.

4.3 Identification and analysis of theoretical contributions

Based on the case study and the evaluation carried out with the experts, it is believed that the use of BIM, as in this case, Revit and the AHP method have contributed in a promising way to assist in the choice of constructive method, since through this integration it was possible to compare criteria and have a better view from the BIM modeling, the 3D design, as well as easily extract quantitative data.
It is also considered that comparing is the way for more users to know other constructive systems and to implant them in their constructions.

As BIM incorporates a data library for information storage, said library can be used by managers during the design process of projects, contributing to the choice of the most appropriate building system. In addition, the information added can be updated depending on the project by the suppliers of inputs and contractors themselves. For example, LWF inputs are still being tested and physical tests and other inputs are being developed. In this situation, the input supplier could pass this information on to the project offices to show the new information and inputs, in order to update the data and present the novelties with respect to that construction system. Another advantage is the tool's practicality in modeling several different constructive systems in an easy and fast way, this being one of the resources to assist in the choice, which, together with the automatic obtaining of project documentation, can make project design a faster/efficient.

5. FINAL CONSIDERATIONS

The present work proposed the use of the BIM platform software associated to the AHP method to help choosing the most suitable constructive system during the design phase of architectural projects. The approach given by this research took into consideration the analysis of three constructive systems: Structural masonry, *Light Steel Framing* and *Light Wood Framing*.

The process of choosing the construction system took into account the main advantages of the use of each system, analyzing the following criteria: availability of labor and raw material; cost related to construction; time of project execution and environmental impact throughout the life cycle. The proposed method (using BIM platform software associated with the AHP method) showed that modeling a project with BIM allowed simulations of scenarios, i.e., it allowed the simulation of 3 buildings using different construction systems (wood frame, steel frame and masonry) within the same project. In addition, it facilitated data extraction, which, in turn, has been useful to help the experts choose the most appropriate constructive system considering the weighted analysis criteria and also the ranking that the AHP method suggested.

The presented method allows the designer to support a database to choose and weigh their preferences (or their client's) in relation to the criteria they find essential for the project. The academic contributions of this study include the use of BIM platform software and the AHP method together to choose the most suitable construction system for each project.

For future research, it would be interesting to apply the proposal in a real case study with the participation of end users and also presenting the theoretical reflection on the benefits brought by the association of BIM and AHP, also considering other criteria.

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