







New Insights of Effect of Chloride Ions on Surface Electrical Resistivity of Concrete

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Abstract: Corrosion is one of the main problems of degradation of buildings. In the marine environment, corrosion is mainly caused by chloride ions. The electrical resistivity of the concrete is one of the main factors that influence the initiation period and the propagation velocity of the reinforcement corrosion. Several studies have been carried out on the electrical resistivity of concrete as a qualitative parameter of the corrosion probability of steel reinforcement. Factors that influence electrical resistivity include the ratio of water/cement, temperature, concrete age, and carbonation, among others. However, there is still no consensus regarding the influence of chloride ions on the electrical resistivity of the concrete. In this context, a study is presented on the effect of chloride on the superficial electrical resistivity of the concrete, in which concrete samples with 0%, 3%, and 5% chloride ions addition were molded, which were submitted to the surface electrical resistivity test until two years of age. The specimens remained immersed in water during the test period, and the same concentrations of chloride ions were added to the samples. The results show that the higher chloride ions concentration induced lower superficial electrical resistivity in concrete, contributing to the reinforcement corrosion process.

Keywords: concrete; surface electrical resistivity; chloride; corrosion.

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1. Introduction

Considering the immense variety of applications in the construction industry, the reinforced concrete structures end up subject to different environmental exposure conditions under the action of aggressive external agents [1,2].

The main problem of degradation of structures located in marine atmosphere zones is the corrosion of the reinforcing steel, whose process begins when the chloride ions entering the concrete reach critical concentration content in the reinforcement region [1,3–7].

In marine environments, it is not uncommon for buildings to present early degradation well before the project's useful life [8]. The corrosion rate in the marine atmosphere can be 30 to 40 times higher than in a rural atmosphere [9], given the presence of chloride ions.

The degradation of reinforced concrete structures related to the corrosion of the reinforcement causes cracks and chipping of the concrete covering, loss of the steel cross-section, and reduction of the adhesion with the concrete, reducing the physical and mechanical resistance of the structure, which can even lead to the collapse of the structure [1,9].

The corrosion of the reinforcement in concrete structures generates extremely high economic losses for the maintenance and recovery of the structures [10]. The costs of maintenance, repair, and recovery of structures are, on average, 125 times higher than the expenses with protective measures that could be taken in the project, aiming to guarantee the structure's durability and minimum design lifetime [1].

In countries such as Japan, the United States, Australia, and Canada, expenditures intended only to recover bridges and viaducts with premature deterioration problems represent 0.01 to 0.1% of GDP (Gross Domestic Product). In 2013, the United States had a total cost for recovering reinforced concrete structures equivalent to 6.2% of GDP [11].

The electrical resistivity of concrete plays a very important role in the corrosive process of reinforcement since electrical resistivity is one of the main factors that influence the initiation period and the propagation speed of the corrosion of the material [12].

Several studies point to a strong correlation between resistivity and periods of initiation (resistance to penetration by aggressive agents and de-passivation of the reinforcement) and corrosion propagation (corrosion rate) [6,9,13–19].

The electrical resistivity is also associated with the quality and characteristics of the concrete and the materials that make up the mixture [20,21]. It is also directly related to the permeability and porosity characteristics of the concrete [1,6,9,22].

Higher permeability and porosity result in an easier penetration of chloride ions, favoring a greater ionic flux in the interior and, consequently a reduction in the electrical resistivity of the concrete, which will reduce the period of initiation of corrosion and provide a greater speed of propagation of this degradation process [23].

The corrosion of the reinforcement of concrete structures is an electrochemical process; for this reason, the electrical resistivity of the concrete and the availability of oxygen will control the corrosion rate [9,23,24], but there must be moisture inside the concrete for the chemical reactions of this degradation mechanism to occur [9,25,26]. Several studies correlate the measures of surface electrical resistivity of concrete and the reinforcement's corrosion probability as a method of evaluating and monitoring the performance and durability of reinforced concrete structures [13].

The presence of chloride ions in the concrete, one of the main causes of corrosion in the reinforcement of structures, brings much discussion regarding its influence on the electrical resistivity of the concrete [13,27].

According to Cascudo (1997), the concentration of chloride ions inside the concrete's pores increases the electrolyte's electrical conductivity [28].

Morris *et al.* (2002) [16] and Lencioni (2011) [13] presented results in which the addition of sodium chloride to the concrete did not significantly influence the values of surface electrical resistivity.

Yu *et al.* (2017) affirm that the chloride content directly affects the electrical resistivity of the concrete due to the increase in conductive ions, just as there is an increase in the ease of the concrete to absorb moisture, contributing even more to the conductivity, resulting in a significant reduction in resistivity [17]. Xiang *et al.* (2018) observed that the higher the chloride

content and the water saturation content of the concrete pores, the lower the electrical resistivity [29].

According to Pyo *et al.* (2017), in their study on the effect of chloride ions on electrical resistivity and compressive strength of ultra-high-performance concrete, observed that in common samples containing steel fibers, the higher the chloride concentration contents, the greater the values of electrical resistivity and that the phenomenon was reversed in samples without steel fibers [30].

Therefore, it is necessary to intensify studies on the degree of influence of chloride ions in the measurements of the surface electrical resistivity of concrete. For this reason, this research was developed to contribute to the knowledge about the influence of chloride ions on the measures of surface electrical resistivity of concrete, where the behaviors of this phenomenon were investigated in different levels of concentration of chloride ions added to the concrete mass.

2. Materials and Methods

To investigate the degree of influence of chloride ions on the surface electrical resistivity of concrete, cylindrical concrete specimens (100 x 200 mm) were molded with 0%, 3%, and 5% of chloride addition concerning the cement mass, and that were dissolved in the mixing water of the concrete, with a trace in the mass of 1:2:3 and water/cement (w/c) ratio of 0.5, for all samples. Each variation of the samples was subjected to tests to determine the surface electrical resistivity, the compressive strength, the water absorption by capillarity, the water absorption by immersion, and the determination of the voids index.

The aggregates used to mold the specimens were tested to determine their characteristics. The manufacturer provided the physical-chemical characteristics of the cement used in this study. To better understand the experimental program accomplished in this research, Figure 1 presents a flowchart containing the steps and tests carried out in the present study.

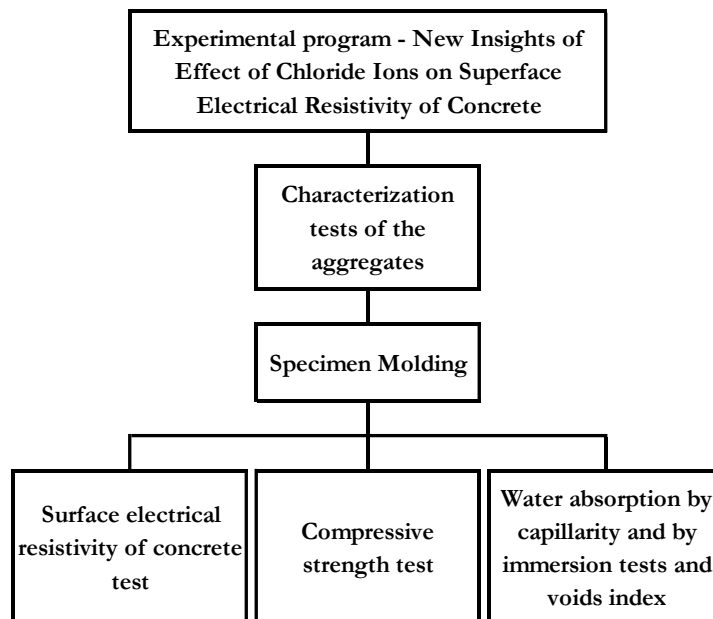


Figure 1. A flowchart of the experimental program was developed for the present study.

The characterization of the aggregates and the cement used, the molding methodology, and the tests carried out are described in specific subtitles, presented below.

2.1. Fine and coarse aggregates.

The aggregates used for the molding of cylindrical specimens were subjected to characterization tests following technical standards.

The tests carried out with small and large aggregates and the respective technical standards used are described in Table 1.

Table 1. Characterization tests of the aggregates and the respective methodologies established in the technical standards.

Aggregate	Test	Method / Technical norm
Fine aggregates	Determination of the granulometric composition - Maximum Diameter of the Aggregate and Fineness module	ASTM C136 / C136M - 14 [31] and ASTM C33 / C33M - 18 [32]
	Determination of water absorption	ASTM C128 - 15 [33]
	Determination of specific and apparent density	ASTM C128 - 15 [33]
	Determination of unit weight	ASTM C29 / C29M - 17a [34]
	Fine material passing through the 75 µm sieve per wash	ASTM C117 - 17 [35]
Coarse aggregates	Determination of the granulometric composition - Maximum Diameter of the Aggregate and Fineness module	ASTM C136 / C136M - 14 [31] and ASTM C33 / C33M - 18 [32]
	Determination of specific and apparent density and water absorption	ASTM C127 - 15 [36]
	Determination of unit weight	ASTM C29 / C29M - 17a [34]

The results obtained in the characterization tests of the fine and coarse aggregates used in the samples are shown in Table 2.

Table 2. Characteristics of the aggregates.

Property	Fine aggregate	Coarse aggregate
Fineness module	2.45	6.79
Maximum Diameter of the Aggregate (mm)	2.36	19
Apparent density (g/cm ³)	2.15	2.69
Specific density - saturated dry surface (g/cm ³)	2.24	2.70
Specific density (g/cm ³)	2.36	2.72
Unit weight (g/cm ³)	1.50	1.52
Water absorption (%)	2.7	0.45
Powdery material (%)	1.9	0.6

2.2. Portland cement.

The Portland cement used for molding the specimens was CP V-ARI, specified according to Brazilian technical standards [37], and it has a low content of additions and high initial strength.

The physical-chemical characteristics of Portland cement CP V-ARI used in the molding of the samples are presented in Table 3.

Table 3. Physico-chemical and mining characteristics of Portland cement type CP V-ARI.

Property	Data	Property
Compressive strength - 7 days (MPa)	42.99	SiO ₂ (%)
Compressive strength - 28 days (MPa)	50.45	Fe ₂ O ₃ (%)
Specific density (g/cm ³)	3.13	Al ₂ O ₃ (%)
Sieve residue of 32µm (%)	5.55	MgO (%)
Sieve residue of 45µm (%)	0.85	CaO (%)
Sieve residue of 75 µm (%)	0.00	SO ₃ (%)
Setting time (min)	183	K ₂ O (%)
Soundness time (min)	248	Na ₂ O (%)

2.3. *Samples molding.*

The specimens were prepared using a fixed trace in the mass of dry materials of 1:2:3 (cement: sand: gravel) and a water/cement ratio of 0.5, with three different concentrations of chloride ions: 0%, 3 % and 5% addition of chloride ions in cement mass, which were dissolved in the mixture water.

During the molding of the samples, the fresh concrete was also submitted to the slump test, according to ASTM C 143-15a [38]. Table 4 presents the dosage of dry materials, the addition of chlorides and water, the results of the slump tests, and the identification of each sample studied. Table 4 also shows the effect of the superplasticizer caused by the addition of chloride ions to the mixture [39]; that is, the higher the addition content, the greater the slump test result.

Table 4. Sample dosage (1: 2: 3 - a / c: 0.5) and slump test.

Specification	Sample identification		
	A	B	C
Addition of chloride ions in cement mass	0%	3%	5%
Cement (kg/m ³)	361.03	358.04	356.08
Fine aggregate (kg/m ³)	722.05	716.08	712.16
Coarse Aggregate (kg/m ³)	1083.08	1074.12	1068.24
Water (kg/m ³)	180.51	179.02	178.04
Slump test (mm)	50	68	86

All the specimens were molded in a cylindrical form of 100 x 200 mm. Table 5 presents all the tests performed, the methodologies used (technical standards), and the ages corresponding to each test.

Table 5. Description of the tests performed, the methodologies used, and the ages corresponding to each test.

Test	Method / Technical norm	Age of test (days)
Surface Electrical Resistivity	UNE 83988-2 [40]	1, 3, 7, 14, 21, 28, 35, 42,49, 56, 63, 91, 365 and 730
Compressive Strength	ASTM C39 / C39M - 18 [41]	1, 3, 7, 28 e 63
Water absorption by capillarity	ABNT NBR 9779 (2012) [42] and ASTM C1585 – 13[43]	28
Water absorption by immersion and the void index	ABNT NBR 9778 (2005) [44] and ASTM C642-13 [45]	28

After molding, the specimens were covered with a plastic tarpaulin for a period of 24 hours to avoid evaporation of water from the surface of the samples. After the first 24 hours, the specimens were subjected to submerging curing in water and maintained under this condition throughout the research period. They were then removed from immersion to perform the tests.

The water used to cure each sample variation contained the same concentration of chloride ions in the water added to the concrete mixture to prevent the loss of chlorides by ionic diffusion, thus preventing this transport phenomenon from interfering with or altering measurements of surface electrical resistivity.

2.4. *Surface electrical resistivity test.*

The tests to determine the surface electrical resistivity of the concrete were performed using the four-point method, also known as the Wenner method [46], which is accomplished on the surface of the structure or specimen. It is the best known and used for tests to determine

electrical resistivity [13]. This method was developed to measure the electrical resistivity of the soil [47], and later, the adaptation of its application to concrete was studied [46,48].

The four-point method uses four surface contacts equally spaced. The contact points are positioned on the surface of the concrete element. Then, a small alternating electric current (I) is applied between the contact electrodes of the extremities, being measured by the device, the resulting potential difference (V) between the internal contact electrodes [15,17]. The electrical resistivity tests of the present study were carried out with the use of portable equipment, with the capacity to measure resistivity values between 1 to 1000 kΩ.cm (± 0.2 kΩ.cm or ± 1%), applying a current of 200 μA at a frequency of 40 Hz, with a fixed spacing between the electrodes of 5.0 cm. Figure 2 shows the scheme of the surface electrical resistivity test of concrete by the Wenner method.

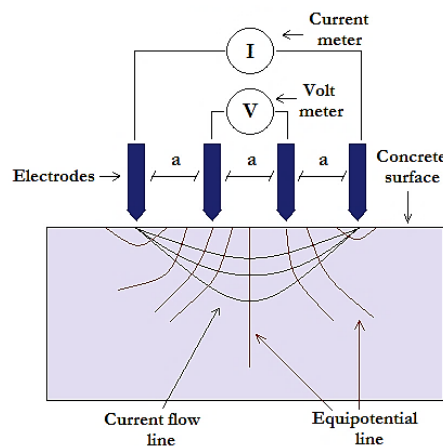


Figure 2. Scheme based on the Wenner test.

The superficial electrical resistivity determined by the four-point test is obtained by Equation 1 [49] as a function of the distance between the electrodes (a), which in the present case was 5.0 cm (where: ρ = electrical resistivity (kΩ.cm), a = distance between the electrodes (cm); ΔV = potential difference (V); I = electric current (A)).

$$\rho = 2 \cdot \pi \cdot a \cdot \frac{\Delta V}{I} \quad (1)$$

A correction coefficient of 0.377 was applied to the values obtained as a function of the geometric shape of the specimens and the spacing between the electrodes, as proposed by the Spanish standard of the Asociación Española de Normalización Y Certificación, UNE 83988 - 2 (2014) [40], which aims to eliminate the difference in results depending on the geometric shape of the concrete elements. Table 6 presents the correction coefficients for different dimensions of cylindrical specimens as a function of the spacing of the electrodes.

Table 6. Correction coefficients for different dimensions of cylindrical specimens as a function of the spacing of the electrodes [40].

Dimensions of cylindrical specimens (mm)	a = 3.5 cm	a = 5.0 cm
150 x 300	0.714	0.606
100 x 200	0.384	0.377
75 x 150	0.384	-

a: spacing between the electrodes.

2.5. Compressive strength test.

The methodology established by the technical standard of ASTM C39 / C39M - 18 [41] was used for the compressive strength test. A mechanical press with a hydraulic servo with a

load cell of 2.000 kN was used. Figure 3 presents an image of the compressive strength test in progress.



Figure 3. Compressive strength test in progress.

For each variation of samples, two specimens per age were used, obtaining the compressive strength value from the average of the results obtained.

2.6. Water absorption tests by capillarity, water absorption test by immersion, and determination of the voids index.

Each of the studied variations was subjected to capillarity water absorption tests provided for in the technical standard of ABNT NBR 9779 (2012) [42] and ASTM C1585 - 13 [43] and immersion water absorption tests and determination of voids index, according to the methodology of the technical standard of ABNT NBR 9778 (2005) [44] and ASTM C642-13 [45]. A set of 3 samples from each variation studied was used for each test.

These tests started when the specimens completed 28 days of age. The samples were dried in an oven at a constant temperature of $(105 \pm 5) ^\circ\text{C}$ until the mass consistency. After drying, the specimens were cooled to a temperature of $(23 \pm 2) ^\circ\text{C}$, then determining the masses of the dried samples.

To obtain the absorption of water by capillarity, following the cooling, the set of samples dried in an oven was placed in a container with a constant water level of $(5 \pm 1) \text{ mm}$. The mass of the specimens was determined at 3, 6, 24, 48, and 72 h after the contact with the water slide began. The capillarity absorption values were calculated with the application of Equation 2 [42] (where: C = water absorption by capillarity (g/cm^2); A = mass of the sample remaining with one side in contact with the water for a certain period of time (g); B = mass of the sample dry in the stove (g); S = cross-sectional area of the sample (cm^2)), obtaining at the end the average value of the results.

$$C = \frac{A-B}{S} \quad (2)$$

For the immersion absorption test and determination of the void index (total porosity), after the drying and cooling process, the specimens were placed in a container with a water level corresponding to 1/3 of its volume immersed in the first 4 hours and 2/3 in the next 4 hours, then being fully submerged for the next 64 h, totaling 72 hours of testing. The mass of

the samples was determined with 24, 48, and 72 h of immersion in water; then, hydrostatic weighing was performed to obtain the mass of the saturated and submerged specimens.

The immersion absorption of each specimen was calculated by Equation 3, and the void index will be determined by Equation 4 [44] (where: A: immersion absorption (%); Msat: mass of the saturated sample (g); Ms: mass of the sample dry in the stove (g); Iv: voids index (%); Mi: mass of saturated and submerged sample (g)), obtaining the average of the results found at the end.

$$A = \frac{M_{sat} - M_s}{M_s} \times 100 \quad (3)$$

$$I_V = \frac{M_{sat} - M_s}{M_{sat} - M_i} \times 100 \quad (4)$$

3. Results and Discussion

The results obtained through the tests of superficial electrical resistivity, compressive strength, water absorption by capillarity, water absorption by immersion, and the voids index are presented in this item.

The electrical resistivity values were also correlated with the results of the other tests to complement the analysis of the influence of chloride ions on the surface electrical resistivity and its relation to the quality of the concrete. The analysis of the data obtained by the present study is also presented in this item.

3.1. Results of the surface electrical resistivity test.

The measurements of the surface electrical resistivity of the specimens with the addition of 0%, 3%, and 5% chloride, concerning the cement mass, performed using the Wenner method, are shown in the graph in Figure 4. All values were measured with the specimens under the saturated surface dry condition (ssd).

The results presented in Figure 4 correspond to the average value of each of the measurements, where three measurements were taken in each sample variation; each one constituted a set of 6 specimens.

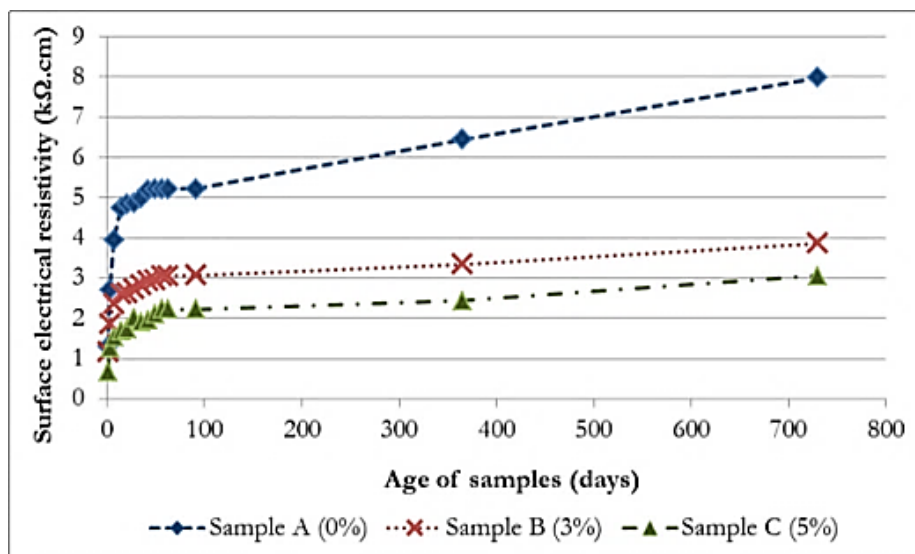


Figure 4. Results of superficial electrical resistivity tests about the age of the specimens with 0, 3, and 5% of the addition of chloride ions in cement mass (Samples A, B, and C, respectively).

As shown in Figure 4, the results show a strong influence of chloride ions on the surface electrical resistivity values. The samples without the addition of chloride ions (A) showed higher values of electrical resistivity than the specimens with 3% (B) and 5% (C) addition of chloride in all ages.

The higher the levels of addition of chloride ions, the lower the values of surface electrical resistivity. This demonstrates an inverse relationship between electrical resistivity and the content of chloride ions inside the concrete. Figure 5 shows the high correlation between the electrical resistivity values concerning the chloride ions content in the studied samples.

Thus, it can be seen that greater availability of chloride ions within the pores of concrete increases the flow of electrical current and decreases surface electrical resistivity, as also concluded by Yu *et al.* (2017) [17].

However, in the tests carried out with only 01 days of the age of the concrete, the result regarding the specimens with 0% chloride addition was very close to those with 3% addition, observing a greater difference only concerning the samples with 5%, that is, in the first hours after molding, the effect of chloride under electrical resistivity was more significant for the highest addition content. Still, even so, samples without addition had the highest value.

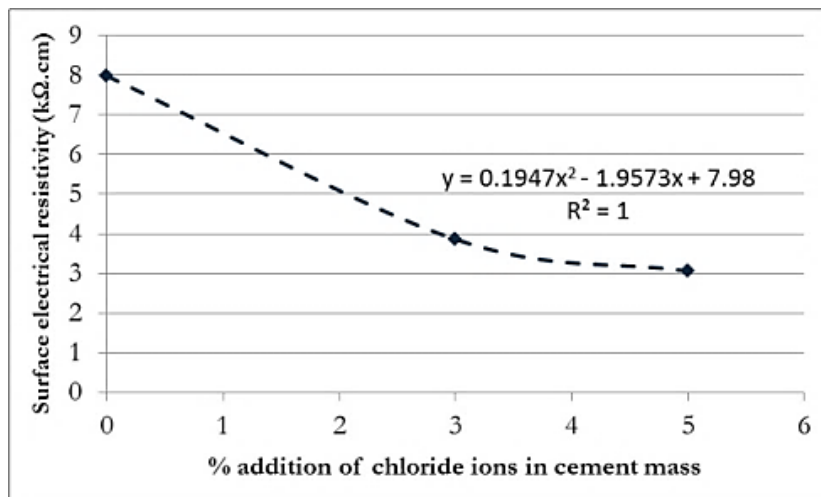


Figure 5. Values of surface electrical resistivity versus chloride ions addition content.

Figure 6 shows the values of surface electrical resistivity that were measured at one day of age.

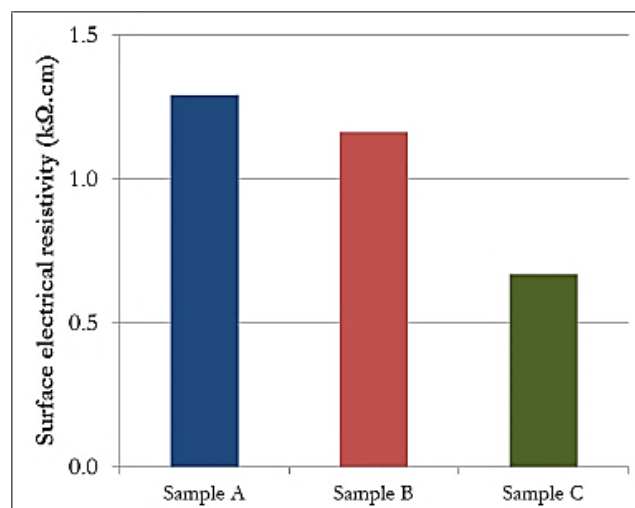


Figure 6. Values of superficial electrical resistivity at one day of age.

As samples with only one day of age were still in the initial phase of the cement hydration process, the values tended to be significantly lower, suffering a gradual increase with advancing age [50]. This may explain why the result obtained from samples without addition was close to those with a 3% addition of chloride, and a greater difference was only observed with a higher concentration of chloride, that is, for samples with a 5% addition.

As the hydration process of the mixture cement progressed with the advancing age of the specimens, there was a significant increase in the values of surface electrical resistivity, mainly up to the first fourteen days of age, as shown in Figure 4. After the first fourteen days, the measurement values show a less significant increase, according to the aging of the concrete samples. From ninety-one days of age, the samples tended to stabilize the electrical resistivity values. However, the concrete sample without adding chloride ions showed the greatest increase between ninety-one and seven hundred and thirty days of age, as shown in Figure 4.

The behavior of surface electrical resistivity undergoes an increase in electrical resistivity values with advancing age due to the progress in hydrating the cement that makes up the mixture [26,27,51]. Furthermore, to the extent that cement hydration tends to stabilize, electrical resistivity also reaches levels that tend to stabilize after a certain period [13].

Comparing the results obtained between samples with 3% and 5% addition of chloride ions, specimens containing 3% chloride ions obtained higher values of surface electrical resistivity than samples with 5% addition; for all measured ages, the samples without chloride addition had the highest values of surface electrical resistivity concerning the others. The higher the chloride addition content to the concrete, the greater the effect of reducing the surface electrical resistivity of the concrete.

Similar results were also observed in studies carried out by other authors, such as Lecieux *et al.* (2015) [52] and Yu *et al.* (2017) [17]. According to Cascudo (1997) [28], the concentration of chloride ions inside the pores of the concrete increases the electrical conductivity of the electrolyte.

Broomfield and Millard (2002) [53] affirm that the type of ion present in the aqueous solution of the concrete pores is responsible for interfering with the flow of electrical current.

Therefore, the chloride ions, which have high mobility, intensify the ionic current, reducing the electrical resistivity of the concrete and increasing the corrosion rate.

3.2. Results of the compressive strength tests.

The results of the compressive strength tests are shown in Figure 7. The values in Figure 7 correspond to the average results obtained in each test performed for each age analyzed.

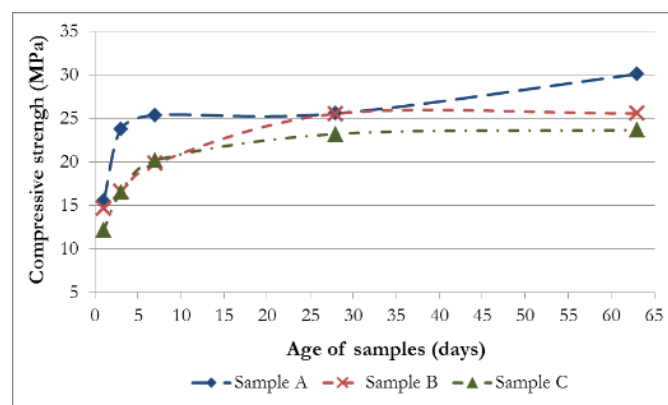


Figure 7. Results of resistance to compression strength until 63 days of age.

As shown in Figure 7, samples without adding chloride obtained the highest results, while those with 5% showed less resistance to compression at all ages. This demonstrates that the addition of chloride in the mixing water contributed to the decrease in the compressive strength of the concrete. This behavior was also observed by Pyo *et al.* (2017) [30]. The chloride levels added to the mixing water probably interfered with the microstructure of the concrete, causing a reduction in the resistance to the compression force [39,54]. Figure 8 correlates the results of surface electrical resistivity with the values obtained in the tests of the compressive strength, age, and sample variation.

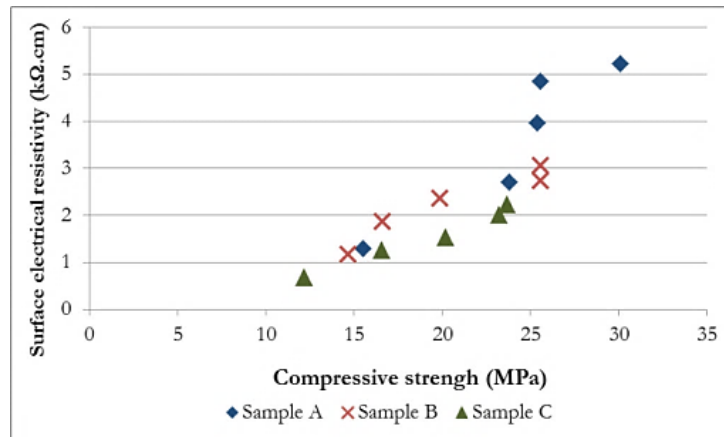


Figure 8. Values of surface electrical resistivity versus compressive strength.

The results presented in Figure 8 showed a good relationship between the superficial electrical resistivity and the resistance to simple compression. The higher the measured electrical resistivity values, the greater the results of the compressive strength tests. Medeiros-Junior (2014) [26] also studied the correlation between electrical resistivity and resistance to simple compression and found a good correlation between them.

The best correlation was obtained by the samples with 5% addition of chloride ions, obtaining a linear determination coefficient $R^2 = 0.975$ ($y = 0.1257x - 0.8749$), followed by samples with 3% ($R^2 = 0.913$; $y = 0.1419x - 0.6665$) and those without addition ($R^2 = 0.867$; $y = 0.2825x - 3.1994$). It can be concluded that the greater the addition of chloride ions, the lower the value of the surface electrical resistivity and the lower the result of the compressive strength.

3.3. Results of the water absorption tests by capillarity, water absorption test by immersion, and determination of the voids index.

The results of the water absorption tests by capillarity are shown in Figure 9, and the values found through the water absorption test by immersion and determination of the void index are shown in Table 7, respectively. The results presented correspond to the average values found in each tested specimen set.

Table 7 points out that the results of water absorption in the test performed with the immersion of the specimens in water were also greater the lower the content of chloride addition in the mixture. Samples with 5% chloride ions had the lowest water absorption in the immersion test, followed by 3% and 0% addition, respectively.

The void index obtained for each sample variation corroborates the result presented; that is, the higher the void index found, the greater the water absorption by immersion and capillarity.

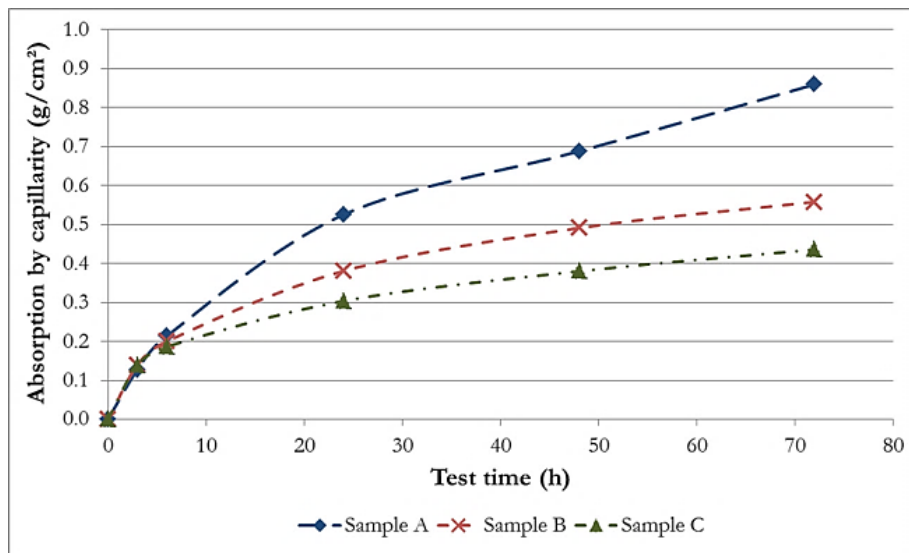


Figure 9. Results of the water absorption tests by capillarity up to 72 hours of exposure to the water slide.

Table 7. Average values of water absorption by immersion and of voids index.

Sample identification	Water absorption by immersion (%)	Voids index (%)
A	4.25	9.90
B	3.76	8.81
C	2.86	6.70

As can be seen in Figure 9 together with Table 7, the results of the sample without the addition of chloride obtained the highest results of water absorption, both by capillarity and by immersion, as well as the void index was also higher, while the lower results were from samples with 5% addition.

According to Yuan *et al.* (2009) [54], when chloride ions penetrate a structure, part of them is captured by the cement hydration products, forming salts and reducing the porosity of the concrete. Therefore, these results probably result from the capture of free chloride ions by cement hydration products forming salts, as stated by Yuan *et al.* (2009) [54], which reduces concrete porosity.

4. Conclusions

The results of the tests carried out on the samples up to two years of age (730 days) showed a strong correlation between the presence of chloride ions and the electrical resistivity measures.

Comparing the results obtained by the tests of superficial electrical resistivity in each variation of the studied sample (0%, 3%, and 5% of the addition of chloride ions in cement mass (g)), the higher the content of chloride ions added to the concrete, the lower was the result of the electrical resistivity of the concrete at all ages. This correlation was also found by Lecieux *et al.* (2015) [52], Yu *et al.* (2017) [17], and Xiang *et al.* (2018) [29].

Considering the results obtained by this research, it is also possible to extract the following conclusions:

The electrical resistivity values measured in samples with only one day of age showed very close results between the specimens with 0% chloride ions addition and those with 3% addition, with a greater difference concerning the samples with 5%, but still, samples without adding chloride ions had the highest value. In the first 24 hours of the concrete, the cement

hydration process is in its initial phase, and the electrical resistivity values tend to be significantly lower, with a gradual increase as hydration progresses;

The chloride ions exerted an influence on the surface electrical resistivity, reducing it, existing an inverse relationship between the values of the surface electrical resistivity and the concentration content of chloride ions inside the pores of the concrete;

A good correlation was found ($R^2 = 1$) between the concentration of chloride ions in concrete and the surface electrical resistivity of concrete, demonstrating that the higher the concentration of chloride ions, the greater the reduction in electrical resistivity;

The addition of chloride ions in the concrete mixture affected the concrete's strength, porosity, and permeability. The higher the content of chloride ion addition in cement mass, the lower the concrete's compressive strength and the lower the water absorption by capillarity and immersion, as well as the void index. The levels of chloride ions added to the mixing water may have interfered with the microstructure of the concrete, reducing its resistance to compression and porosity. According to Yuan *et al.* (2009) [54], when chloride ions penetrate a structure, part of them is captured by the cement hydration products, forming salts, reducing the porosity of the concrete;

A good relationship was found between the superficial electrical resistivity and the compressive strength in the reference samples (variation A) and those containing chloride ions (variations B and C). The best linear correlation was obtained by the specimens with 5% addition of chloride ions in cement mass, obtaining an $R^2 = 0.9752$, followed by the specimens with 3%, with $R^2 = 0.9134$, and those without the addition of chloride ions, where an $R^2 = 0.8675$ was obtained.

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Conflicts of Interest

The authors declare no conflict of interest.

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