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Effects of Temperature Variation on Concrete Surface Electrical Resistivity

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Abstract

Electrical resistivity is an important property of concrete, related to the risk of rebar corrosion. Studies related to the maintenance and reinforced concrete structures service life have established resistivity as a parameter of durability and quality. Resistivity is a property that is influenced not only by materials characteristics, but also by environment conditions. The influence of temperature on concrete surface electrical resistivity measurements, and consequently, the risk of rebar corrosion are not well known and need further studies. The aim of this paper is to analyze resistivity variations caused by temperature and environmental changes. Three experimental stages were established. In the first stage, this study analyzed concrete surface electrical resistivity variations due to changes in water/cement ratio during the cure. In the second stage, surface electrical resistivity variations in concrete samples exposed to an external environment were evaluated, part of the specimens were maintained wet (saturated) and part were dry (unsaturated) and assessments were made at different times of the day. In the third stage, the research analyzed temperature and its effects in concrete surface electrical resistivity. The results show that a decrease in water/cement ratio from 0,65 to 0,45, increased by approximately two times concrete surface electrical resistivity values. They also show that resistivity values increase approximately two times from day 3 to day 28 for both water cement ratio. Analyzing each of the series used in this study, surface electrical resistivity values of the wet (saturated) sample were lower than those of the dry (unsaturated) sample. Lastly, the most important result of this article is that concrete surface electrical resistivity values varied inversely to the temperature. The increase of environment temperature by 1ºC resulted in a 1.23% reduction in the surface electrical resistivity of concrete.

Keywords: Concrete; Surface electrical resistivity; Temperature; Wenner Method

INTRODUCTION

Electrical resistivity is related to concrete structure service life since it is associated with the transport of aggressive agents through the material (Polder, 2001). Concrete electrical resistivity is also seen as one of the most important parameters to evaluate steel corrosion inside concrete (Hornbostel *et. al*, 2013). The main idea of most electrical resistivity tests is to quantify the conductive properties of concrete microstructure. Structures with thin pore networks and lower connectivity have low permeability, while porous structures with greater pore connectivity have high permeability and, consequently, lower durability (Layssi *et. al*, 2015).

Some conditions are known to affect concrete electrical resistivity and it can be pointed out that the most significant of them are temperature and moisture content (Helene, 1993; Gowers and Millard, 1999). Other studies refer to different factors that affect concrete electrical resistivities, such as saturation and pore quantity analysis (Polder and Peelen, 2002), water/cement ratio

(Santos, 2006), total pore volume (Hossain and Lachemi, 2004), replacement of coarse aggregate by recyclable aggregate (Singh and Singh, 2016), carbonation (Chi *et. al*, 2002; Morshed *et. al*, 2015), the influence of steel bars (Nguyen, 2017; Garzon, 2014; Chen *et. al*, 2014), geometric size, probe spacing, replacement levels of silica fume and metakaolin (Ghosh and Tran, 2015), among others.

Specifically related to temperature, one study used Arrhenius relation to explain the effects of temperature on concrete electrical resistivity values (Liu and Presuel-Moreno, 2014). In this study, 200 specimens and 54 different types of concrete mixtures were analyzed. The authors concluded that the decrease of concrete resistivity with increasing temperature is more significant on concrete with higher resistivity values than on concrete with lower resistivity values.

Another article studied five different concrete mixtures in temperature cycles within a chamber, ranging from + 24ºC to -24ºC, at a rate of 1ºC/h (Tomlinson *et. al*, 2017). Researchers concluded that, in all mixtures, resistivity changed with temperature and followed the Arrhenius relation at temperatures above the phase transition temperature. It was possible to verify in the study that, the lower the temperature, the higher the electrical resistivity of concrete, and the higher the temperature, the lower the electrical resistivity. Another study (Spragg, 2013) also concluded that resistivity measurements followed an Arrhenius relation, with different conduction activation energies.

Other research analyzed the variation of temperature from -10°C to 23.3°C and concluded that resistivity decreases rapidly as the temperature increases up to 0°C, and as temperature increases further, the rate of decrease in the resistivity slows down (Dehghanpour and Yilmaz, 2020). Another study varied temperature from -5°C to -20°C and results showed that the increase of resistivity was significant as the freezing temperature decreased (Sang and Yang, 2020).

Further studies are needed to understand the variation of concrete electrical resistivity at different temperatures, given that concrete surface electrical resistivity is a non-destructive test that can be used in the field, outside controlled laboratory environments. Because temperature can vary significantly in-field analysis, it is important to understand the influence of this parameter on the surface electrical resistivity of concrete, which is the purpose of this paper.

Therefore, because of the importance of temperature influence on concrete surface electrical resistivity, this paper aims to analyze resistivity variations caused by temperature and environmental changes. To accomplish this objective, three experimental stages were established, which are detailed below.

2 MATERIALS AND METHODS

2.1 Materials

Two distinct series were chosen, in which the only change was the water/cement ratio. Water/cement ratios of 0.65 for "Series 1" and 0.45 for "Series 2" were established. The cement used on both series was Brazilian Portland Cement, classified as "CP V-ARI" (properties are presented in Table I). Fine quartz sand aggregate with the specific mass of 2.58g/cm³ and limestone gravel aggregate with 2.67g/cm³ were used. The mixture of each series is shown in Table II.

Table I: Cement properties

Specific gravity (g/cm³)		3,10
Fineness	Sieve residue #200 (%)	0,34
	Sieve residue #325 (%)	2,27
	Specific surface (cm²/g)	4742
Setting time	Start (min)	102
	End (min)	157
Compressive Strength (MPa)	1 day	29,6
	3 days	43,0
	7 days	47,8
	28 days	57,4

Table II: Mixture proportion of concrete

	Series 1	**Series 2**
Concrete dosage	**Consumption**	**Consumption**
Cement CP V - ARI (kg/m³)	382	382
Quartz Sand (kg/m³)	764	764
Limestone Gravel (kg/m³)	955	955
Water (l/m³)	248	172
Water/cement ratio	**0,65**	**0,45**

Specimens molding procedures followed the recommendations of Brazilian Standard NBR 5738:2015. The mixture was made in an electric mixer and molded in cylindrical metal molds with 100mm diameter and 200mm height. The demolding was performed 24 hours after molding and all specimens were cured submerged in potable water.

2.2 Methodology

Surface electrical resistivity assessments of this study were performed by the Wenner method. The equipment used with this method has four electrodes, equidistant (50mm) and aligned, which are positioned in contact with concrete. An alternating current passes the external electrodes and the potential difference between the internal electrodes is assessed (Letícia Pérez, 2015). The equipment used in this study was Proceq Resipod 50mm and the original configuration was used (correction factor = 1,0).
Procedures of measuring surface electrical resistivity were based on an international standard (AASHTO, 2017) and eight measurements were made in each sample. After each measurement, the sample was rotated 90 degrees and the following measurement was recorded, until the eighth.

Three experimental stages were established. On Stage 1, 28 specimens were cast (14 specimens of each series), assessments were made on days 3, 7, 14 and 28, after the date of molding. On stage 2, 6 specimens from each series used in the first stage were selected. These specimens were placed out of the laboratory, subject to environmental variations such as temperature, humidity, solar incidence, rain and wind. Three specimens from each series were kept saturated (submerged in a box full of water) and the other three dry specimens were placed outside the box. The surface electrical resistivity measurements were obtained during the first 48 hours, the first measurement occurred at 15:25 hours (time = 0) and the temperature and humidity control was performed with a hygrometer.

On Stage 3, additional 20 specimens of series 1 (water/cement ratio 0.65) were cast. After 28 days of submerged cure, the samples were removed from the water and submitted to the ultrasound test. From the 20 specimens, 12 specimens with the nearest ultrasonic pulse velocity values were selected. These specimens were kept submerged in water for an additional 11 months. After 12 months from the molding date, the 12 specimens were submitted to different temperatures (5ºC, 10ºC, 22ºC, 40ºC and 55ºC) with an exposure period of 4 hours, enough to keep the temperatures uniform throughout the mass of the specimens as shown on Figure 1.

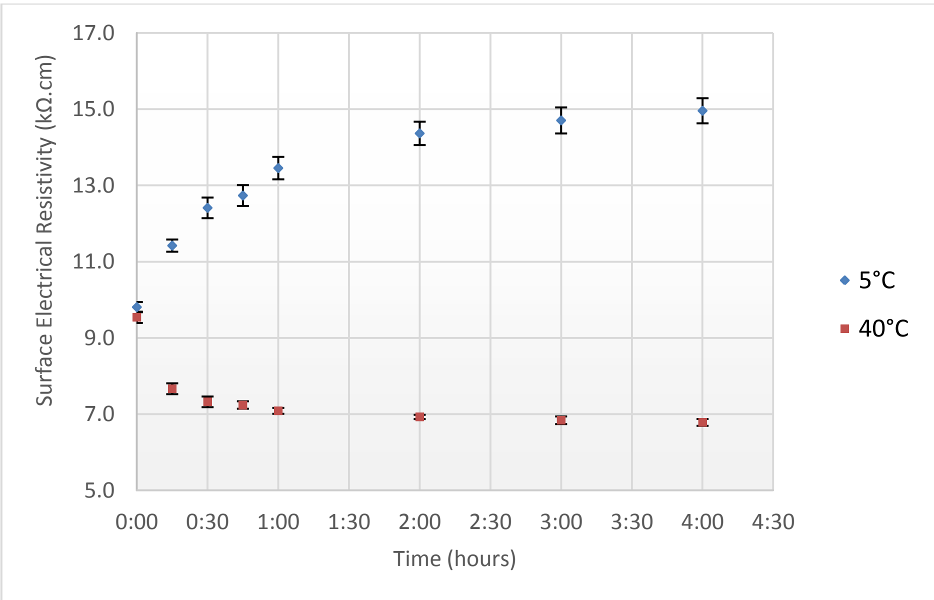

Figure 1: Variation of surface electrical resistivity over time, during four hours exposed for the same tamperature.

3 RESULTS AND DISCUSSIONS

The results of the Stage 1 are presented in Figure 2. A growth in resistivity values over the 28 days of cure was observed for both studied series. The increase in surface electrical resistivity observed between days 28 and 3 of the molding date was approximately 99% for both series. Series 2, with lower water/cement ratio (0.45), showed higher surface electrical resistivity values than series 1, with higher water/cement ratio (0.65). This result was verified at all assessed ages.

Throughout the curing period, samples of series 2 presented higher surface electrical resistivity than samples of series 1 in an average proportion of 107%. This behavior was expected, since, as verified by other researchers (Santos, 2006), the water increase in the mixture is related to the quantity of pores and their interconnections. The higher the amount of water in the mixture, the higher the porosity, which results in lower values of surface electrical resistivity.

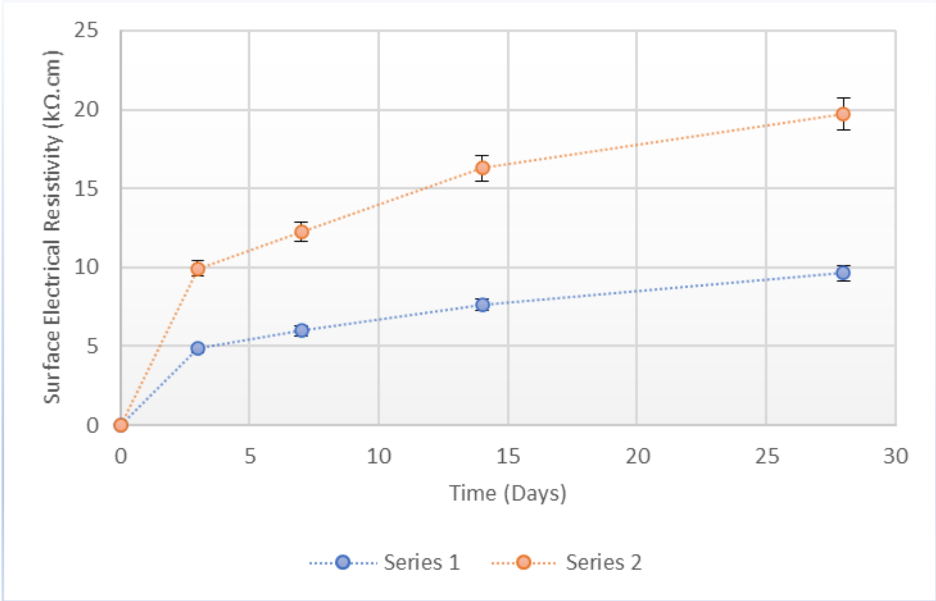

Figure 2 :Variation of surface electrical resistivity over time for series 1 and 2.

Results of the Stage 2 are presented in Figure 3 and the corresponding temperatures and times are presented in Figure 4. The influence of the saturation conditions of the specimens was important for both series in all measurements performed during the 48 hours of testing. In each series, the surface electrical resistivity values of the wet (saturated) samples were always lower than those of the dry samples. This can be explained by the moisture content of each sample, dry samples have lower moisture content than saturated ones, and because of that, electric current flows easier on saturated samples, which is represented in a lower resistivity.

Figure 4 shows that the temperature variations occurred discretely and cannot explain the changes obtained on surface electrical resistivity values. This happened because the specimens were outside of the laboratory with several other factors that were not controlled, like wind, moisture content and ambient humidity. This experiment was important to establish guidelines to Stage 3.

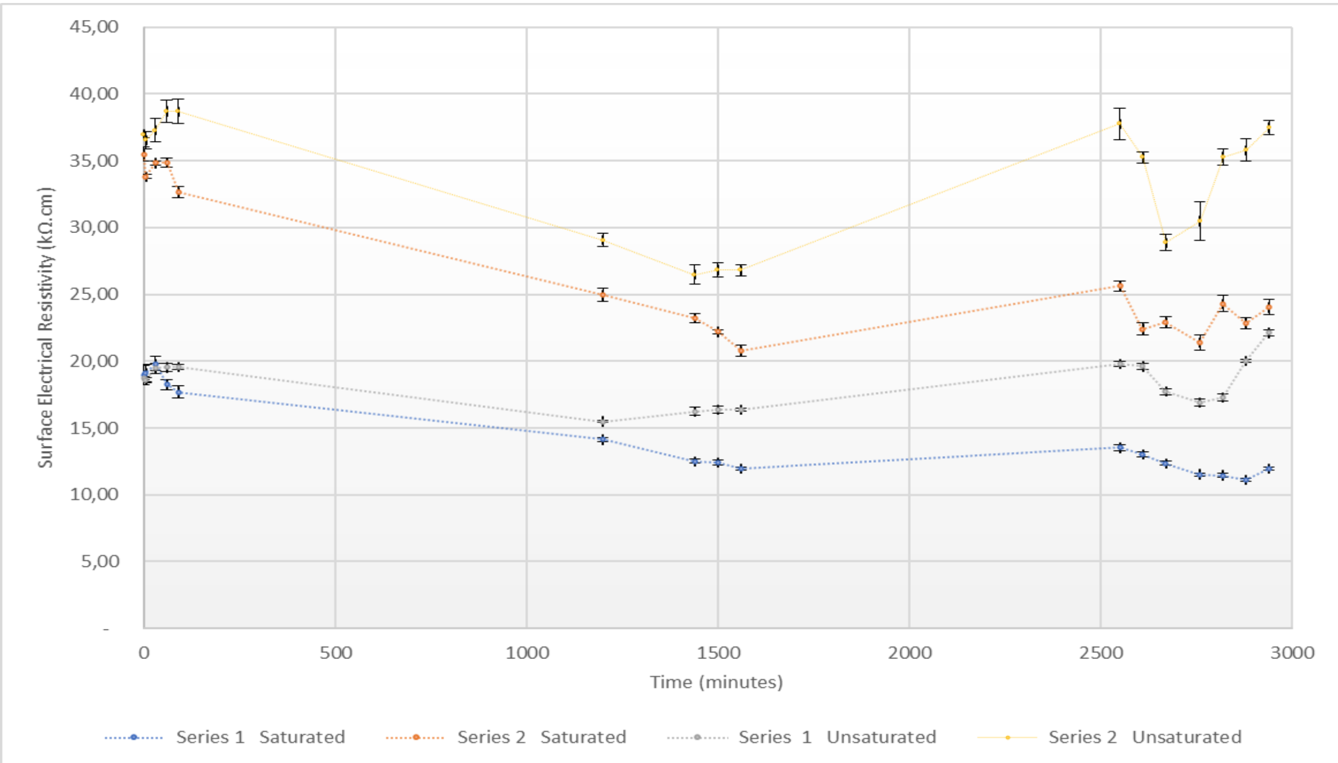

Figure 3: Variation of surface electrical resistivity during the exposure time.

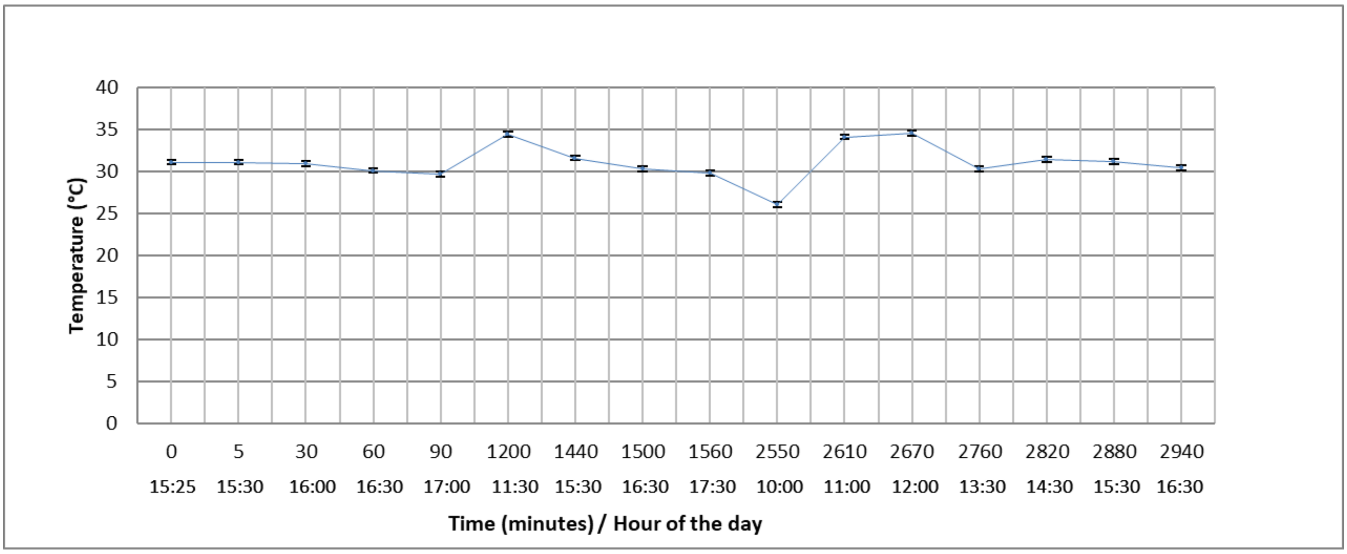

Figure 4: Temperature variation during the test.

Stage 3 results are presented in Figure 5. The surface electrical resistivity values of the 12 chosen specimens varied inversely to the temperature. When submitted to a temperature of 5ºC for four hours, the specimens presented the maximum resistivity value, being the minimum value reached after exposure to 55ºC. These results also were observed in several other studies (Polder, 2001; Liu and Presuel-Moreno, 2014; Tomlinson *et. al*, 2017; Spragg, 2013; Dehghanpour and Yilmaz, 2020; Sang and Yang, 2020).

The temperature variation can cause significant changes in concrete surface resistivity values. In this research, the increase of 50ºC in temperature resulted in a reduction of almost 62% in the average resistivity values of specimens. It can be said that the elevation of ambient temperature in 1ºC resulted in a 1.23% reduction in surface electrical resistivity of the studied concrete. By analyzing the results shown in the study mentioned above (Dehghanpour and Yilmaz, 2020), it is possible to inform that a comparable reduction was found, when considering the variation of temperature from 5°C to 23.3°C in that study.

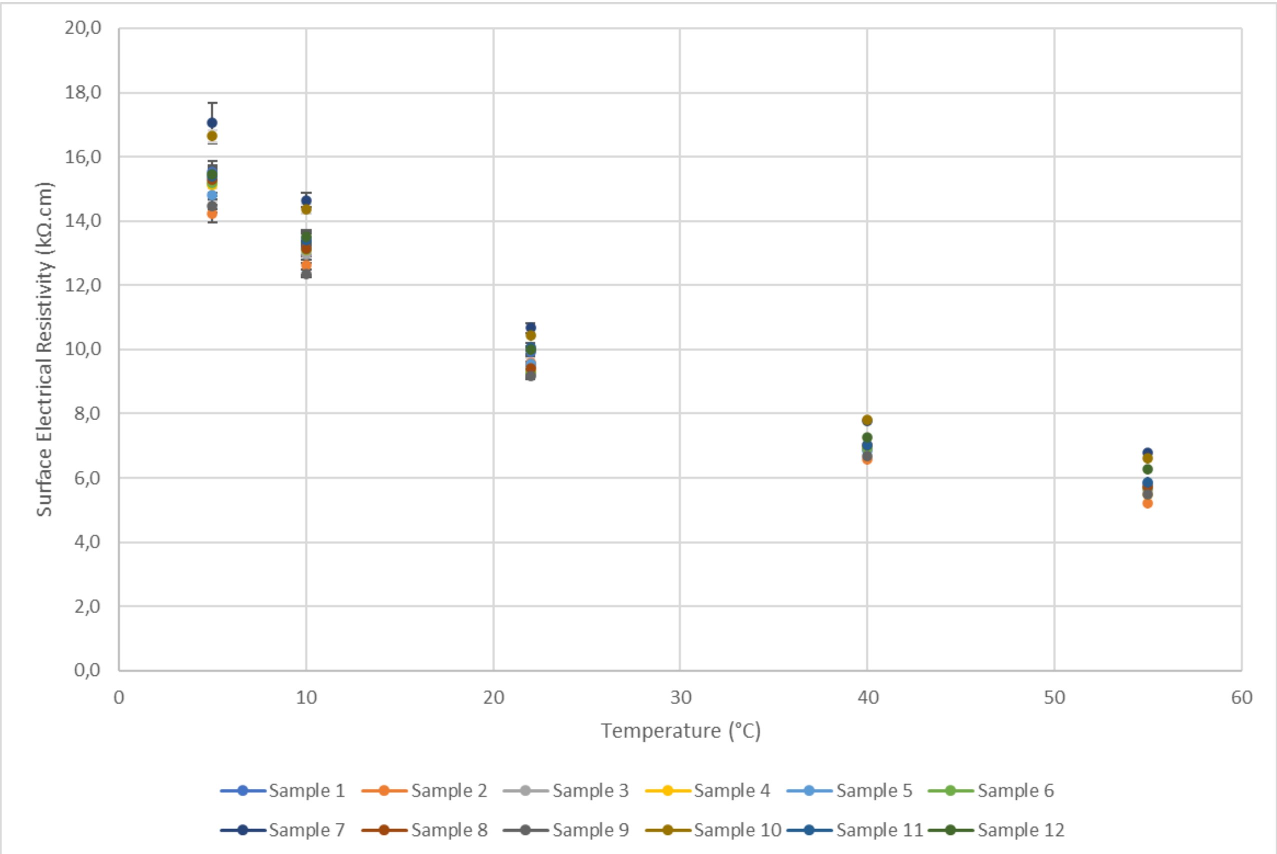

Figure 5: Variation of surface electrical resistivity as a function of temperature.

This variation can be attributed to the changes caused by temperature in the ionic mobility of concrete. In a saturated condition, concrete behaves as a semiconductor material, in which the increase in temperature promotes a weakening of the electron bonds to the atomic structure, increasing their mobility which consequently reduces their resistivity (Young, 2009).

4 CONCLUSIONS

Considering the mixture used in this study and a water/cement ratio of 0.65 (series 1) and 0.45 (series 2), it was observed that the increase of surface electrical resistivity between days 3 and 28 after the molding date was approximately 99% for both series. This result can allow a prediction of the surface electrical resistivity of concrete for future ages, which is important in monitoring concrete durability and quality.

Results also indicated that the reduction of the water/cement ratio from 0.65 to 0.45 caused an increase of approximately two times in concrete surface electrical resistivity. This result is important to reassure that a lower water/cement ratio is an important characteristic of concrete durability.

The influence of sample saturation is also relevant in surface electrical resistivity parameters. Analyzing each of the series used in this study, surface electrical resistivity values of the wet (saturated) sample were lower than those of the dry (unsaturated) sample.

As for temperature, concrete surface electrical resistivity values varied inversely to it. The increase of 50ºC in temperature resulted in a reduction of almost 62% in the average resistivity values of specimens. It can be said that the elevation of the ambient temperature by 1ºC resulted in a 1.23% reduction in surface electrical resistivity values of the studied concrete. This result is also important, mostly for field analysis, because temperature variation can significantly influence surface electrical resistivity values during the inspection. Lastly, considering that it is extremely difficult to control all factors like wind, rain, temperature and moisture content in-field analysis, it is necessary to make evaluations in a structure where environmental factors are as similar as possible.

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