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Electrical resistivity of unsaturated concrete using different types of cement

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HIGHLIGHTS

- We performed electrical resistivity tests.
- We analyzed twelve different concrete samples.
- The electrical resistivity increases over time for all samples.
- The w/b ratios did not interfere significantly in results.
- Cements with additions show biggest resistivity values.

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ABSTRACT

This paper aims to contribute with durability studies by monitoring the unsaturated concrete resistivity over 2 years. Four types of cements commercially used in Brazil were investigated. Some statistical tests (ANOVA and Turkey's test) were performed to analyze the data. It was found that w/b ratios have no significant influence on the electrical resistivity values of the concrete for a same type of cement. However, the types of cement have a significant effect on resistivity. Cements with blast furnace slag and pozzolan additions have a higher resistivity. Trend lines to estimate the changes in resistivity over time were discovered.

1. Introduction

Several studies address the durability of reinforced concrete structures based on modeling the penetration of aggressive agents [1,2]. These aggressive agents enter through the pores network of concrete and affect initial properties of the material reducing the service life [3,4]. However, durability studies require long-term data validation [5].

Concrete is a typical porous material; just like other cement based materials, concrete properties have strong relationship with the pore structure, such as pore size distribution and connectivity [6]. Electrical resistivity is a good parameter to be used in modeling the penetration of aggressive agents in concrete. It is a property that indicates the ability of concrete to carry electrical charges within itself. Concrete resistivity can be monitored over time by a Non-Destructive Testing (NDT) through a relatively simple and inexpensive technique. Several studies [3,7] consider concrete resistivity as an important factor that indicates the permeability of concrete to aggressive agents such as chloride and carbon dioxide, as resistivity has a good relationship with the concrete microstructure [8,9].

Reinforcement corrosion is an electrochemical process. Therefore, the electrochemical properties of concrete, such as electrical resistivity, are able to produce information about this degradation process. Thus, the concrete resistivity has also been used as a parameter to evaluate the likelihood of corrosion in reinforced concrete structures [10].

Several studies investigate the properties related with concrete resistivity. Wei and Xiao [11] found a logarithmic relationship between hydration heat at 24 h and resistivity at 24 h. In another study, chemical shrinkage and autogenous shrinkage were linearly correlated with electrical resistivity after hydration for 24 h and 30 h respectively [12].

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Hossain [13] investigated correlations between porosity, chloride diffusivity and electrical resistivity in cement pastes. Other studies suggest methods for predicting the compressive strength of Portland cement paste based on electrical resistivity measurements [3,14]. Some studies have found the effect of temperature [15,16] and relative humidity [17] on the electrical resistivity of Portland cement pastes.

Further studies are needed to investigate the evolution of concrete resistivity over time and, consequently, the pore network behavior, especially regarding the inclusion of cements with additions and long term data. The use of various cement types with different additions (blast furnace slag, fly ash, besides cements resistant to sulfate, and others), with different chemical compositions and physical characteristics is very common. Thus, there is a need to understand the behavior of the concrete resistivity with these materials. The aim of this paper is to study the electrical resistivity, over a period of 2 years, of unsaturated concrete with some cement used in Brazil, easing the use of resistivity in durability studies.

2. Experimental program

2.1. Materials

Several types of concrete with different Brazilian cements were used in order to cover a broad range of conditions. Table 1 presents the proportions of concrete mixes.

Twelve different dosages of concretes were used, including four types of Brazilian Portland cements and three water/binder ratios (w/b = 0.4, 0.5 and 0.6). All other proportions were kept constant between the different dosages studied. No chemical additives were used on the concrete samples in order to not affect the electrical resistivity of the specimens. Therefore, only the influence of cement types was investigated.

All specimens were cubic (edges 25 cm). The selection of the specimen's size was based on Gowers and Millard [18] recommendations, which take into account the minimum required dimensions in order for the currents lines inside the concrete close themselves, therefore not causing changes on the resistivity values during the test. This verification was carried out in this study and it was confirmed that the size of the specimens used is large enough to be considered as a semi-infinite medium, therefore does not interfering on electrical resistivity measurements. Thus, it was observed that there is no need to apply a shape factor for the size of the specimens used.

A total of 48 samples (four samples of each concrete mixture) was cast. They were unmolded after 48 h of being cast and cured in saturated water conditions during 28 days in a moist chamber. After the curing period, samples were kept in unsaturated condition in laboratory environment (air dried, $T = 22 \pm 3$ °C, RH ± 65%).

Four types of cement commercially available in Brazil were used. These cements have different compositions due the presence or absence of minerals additions. The following Brazilian Standards govern the specification of the cements used in this paper: (a) CPII Filler-modified Portland cement with calcareous filler – ground limestone [19]; (b) CPIII Portland cement with blast furnace slag and Sulfate-Resistant [20,21]; (c) CPIV Portland cement with pozzolan addition [22]; (d) CPV High Early Strength Portland cement [23].

Table 1
Concrete mix proportions.

Code	Brazilian Portland cement type	Cement (kg)	Sand (kg)	Gravel (kg)	Water (kg)	w/b ratio
IIF04	CPIIF-32	360	504	756	144	0.4
IIF05	CPIIF-32	360	504	756	180	0.5
IIF06	CPIIF-32	360	504	756	216	0.6
IIISR04	CPIIIRS-40	360	504	756	144	0.4
IIISR05	CPIIIRS-40	360	504	756	180	0.5
IIISR06	CPIIIRS-40	360	504	756	216	0.6
IV04	CPIV-32	360	504	756	144	0.4
IV05	CPIV-32	360	504	756	180	0.5
IV06	CPIV-32	360	504	756	216	0.6
V04	CPV-ARI	360	504	756	144	0.4
V05	CPV-ARI	360	504	756	180	0.5
V06	CPV-ARI	360	504	756	216	0.6

Table 2
Chemical properties (% by mass).

Properties	CPII	CPIII	CPIV	CPV
Clinker + Calcium sulfates	90	35	45	95
Blast furnace slag	–	60	–	–
Pozzolan	–	–	50	–
Limestone filler	10	5	5	5
Magnesium oxide (MgO)	6.5	–	6.5	6.5
Sulfur trioxide (SO_3)	4.0	4.0	4.0	–
Loss on ignition	6.5	4.5	4.5	4.5
Insoluble residue	2.5	1.5	–	1.0
Carbon dioxide (CO_2)	5.0	3.0	3.0	3.0

Table 3
Physical and mechanical properties.

Properties	CPII	CPIII	CPIV	CPV
Sieve 75 μm residue (%)	12	8	8	6
Specific area (m^2/kg)	260	–	–	300
Start setting time (h)	1	1	1	1
Final setting time (h)	10	12	12	10
Expandability in hot (mm)	5	5	5	5
Expandability in cold (mm)	5	5	5	5
Compressive strength – 3 days (MPa)	10	12	10	24
Compressive strength – 7 days (MPa)	20	23	20	34
Compressive strength – 28 days (MPa)	32	40	32	–

Tables 2 and 3 show the chemical, physical and mechanical specifications for these cements.

2.2. Procedures

Regarding the techniques for determining the electrical resistivity of concrete, the four-point method (Wenner's method) can be applied both in the laboratory and on the field. This technique allows to obtain the resistivity by a commercially available equipment. The measurements are obtained by the contact of four equidistant electrodes on concrete surface. An electric current crosses the concrete through the pair of external electrodes, and the resulting voltage is measured between the inner electrodes [18].

The four-point method of resistivity testing was performed in this study. A commercial equipment (distance between electrodes = 0.05 m) was used and the equipment calibration was always checked before tests.

Test conditions are described as follows: the four-point method of resistivity testing was performed by measuring on the faces of the cubic specimens. First test was performed on concrete at 28 days – on dry surface condition – after the curing period. Then, new resistivity measurements were performed in unsaturated conditions every 30 days until 730 days (2 years), also on dry surface condition. Monthly resistivity data were used for investigating the resistivity evolution over time for different concrete samples. Also, statistical tests (one way ANOVA, Turkey test) were performed in order to evaluate the data.

Porosity test in sample of around 1 cm^3 was performed by mercury intrusion on samples with 91 days old and w/b ratio equal to 0.6 (IIF06, IIISR06, IV06 and V06). A commercial equipment (AutoPore IV 9520 model, Shimadzu, Japan) was used for the test.

3. Results

3.1. Electrical resistivity – influence of cements types and w/b ratio

Figs. 1–3 show the results of resistivity tests of unsaturated concrete specimens for w/b equal to 0.4, 0.5 and 0.6, respectively.

According to Figs. 1–3, resistivity increases over time for all samples due to cement hydration and to the progressive hardening of concrete. This means that there is a tendency to reduce the interconnected pore network of the concrete over time, contributing to reduce the conductivity of the concrete, in agreement with other studies [24,25]. Other studies [26] have also noted an inverse relationship between capillary porosity and relative resistivity on cement pastes, in accordance with the results of this paper.

Concrete resistivity is also strongly affected by the type of cement (Figs. 1–3). The four cements used in this paper are