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Influence of cement type in reinforcement corrosion of mortars under action of chlorides

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HIGHLIGHTS

- ▶ Increasing the curing period has improved the cement performance.
- ▶ Water–cement ratio presented itself as the most important factor to increase the durability, followed by the cement type.
- ▶ The CPIII-40 cement had the best performance with respect to corrosion by chloride ions to both water–cement ratios studied.
- ▶ To increase the durability in structures the cement to be used must be specified according to environmental conditions.

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ABSTRACT

In addition to the technological and environmental factors, the corrosion caused by chloride ions is strongly influenced by the type of cement used in concrete; however, currently, cement is manufactured and specified without taking into account its resistance to the action of aggressive agents. Given this context, a study on the protective capacity of some types of cement (CPII-Z-32, CPIII-40 and CPIV-32) was conducted regarding the reinforcement structure under the action of chloride ions. The specimen molded with CPIII-40 cement clearly showed high resistance to corrosion caused by chloride ions, high compressive strength, and low capillary absorption.

1. Introduction

Concrete represents the most suited building material to structures, surpassing alternatives, also viable, such as steel and wood [1]. For a long time, it was believed that the durability of this material was limitless; however, during the decades of 1980 and 1990, the initial perception on durability was changed with the advent of pathological manifestations that caused significant and frequent damage to structures [2].

Reinforcement corrosion, one of the main causes of deterioration of reinforced concrete structures, can be defined as an electrochemical process that causes the degradation (oxidation) of concrete steel [3]. In advanced stages, it can compromise safety of the structure and may lead to the collapse of the affected concrete structures [4].

The literature on durability of reinforced concrete structures has considered corrosion initiated by chloride ions as the most severe attack and the leading cause of premature corrosion in reinforced concrete structures [5–11].

Various technological aspects of concrete (water/cement ratio; particle size distribution; chemical composition) contribute to reducing voids and increasing the compactness of concrete, thus reducing the transport of aggressive agents to the structure interior.

It is widely recognized that the corrosion of steel in concrete induced by chloride ions can lead to a rapid deterioration of reinforced concrete structures. This type of corrosion is influenced by several factors, such as pH, concentration of tricalcium aluminate (C_3A) in cement, water/cement ratio, cement content, and concrete cover. The presence of a critical concentration of chloride ions in contact with the reinforcement will cause its depassivation, paving the way to the corrosion process, which, after corrosion initiation, will contribute to the loss of the structure mechanical performance.

The current Brazilian standard NBR ABNT 6118:2007 (Project of concrete structures) has followed the international tendency, since it has specified levels of environmental aggressiveness; such detailing seeks, however, to ensure durability only through defini-

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tion of maximum water/cement ratio (w/c), minimum coatings, and minimum compressive strength, not taking into consideration the type of cement used and the minimum service life the structure should reach [12].

The partial replacement of cement for products such as blast furnace slag and pozzolanic materials leads to the beneficial effects of reinforced concrete structures [13,14], especially when it comes to protection against chloride-induced corrosion of steel reinforcement [15,16]. The reduction in the diffusivity/permeability is a major purpose of using these products, particularly for chloride ion transportation [13,17,18]; besides increasing the resistivity of the concrete [19]. In previous work, it was noted that the reinforcement corrosion initiated by chloride ions depends fundamentally on the chemical composition of the cement used for the manufacture of mortars and concretes [11,20–23].

Due to this it is necessary to study the influence of type of cement used for making mortar and concrete taking into consideration the particularities of the cements produced.

In view of the aforementioned, the present work aims to compare the protective capacity of some types of cement in Northeastern Brazil, CPII-Z-32 (Portland Composite Cement with Pozzolans), CPIII-40 (Portland Blast furnace Cement), and CPIV-32 (Portland Pozzolanic Cement), as the reinforcement corrosion under the action of chloride ions, which primarily depends on the chemical composition of this material. The results presented here are part of a dissertation by Pereira [24] and will be useful for the concrete technologists to specify correctly the type of cement to be used on structures placed in potentially aggressive environments due to the presence of chloride ions.

2. Materials and methods

2.1. Experimental plan

A full factorial design was carried out in order to investigate concomitantly the effects of multiple variables and their interactions in a response variable.

Thus, the independent or explanatory variables (type of cement, water/cement ratio and curing period) are called factors, while the three types of cement used (CPII-Z-32, CPIII-40 and CPIV-32), the two water/cement ratios (0.4 and 0.7), and two curing periods (7–28 days) are the corresponding levels to each factor (Table 1).

In order to achieve the proposed objectives, capillary water absorption tests, compressive strength and accelerated corrosion, which are treated as dependent or response variables, were performed (Table 2). The water absorption test was carried out, since the penetration of water influences directly on the durability of reinforced concrete structure exposed to chloride contaminated environment. The compressive strength test is of significant importance, since other properties of concrete and mortar are directly related to this parameter. To corrosive process evaluation, an accelerated corrosion test was conducted, and the technique of corrosion electrochemical potential was used.

Test specimens were molded using the three types of cement chosen to be analyzed (CPII-Z-32, CPIII-40 and CPIV-32); two water/cement ratios with significant variation (0.4 and 0.7) to evaluate the performance of cements in different microstructural conditions, and two curing periods usually applied (7–28 days) [25,26]. The features were defined by the determination index of mortar normal consistency test in accordance with the procedures presented by the Brazilian standard NBR ABNT 7215:1997 [25]. Table 3 shows the definition of the series used in the study.

Table 1
Factors (explanatory variables) and the corresponding levels to each factor.

Factors	Levels
Type of Portland cement	CPII-Z-32
	CPIII-40
	CPIV-32
Water/cement ratio	0.7
	0.4
Curing period	7 days
	28 days

Table 2
Dependent variables and the corresponding levels to each factor.

Dependent variables	
Corrosion evaluation	Corrosion potential (ecorr)
Mortar properties evaluation	Capillary absorption
	Compressive strength

2.2. Materials

The physical and chemical properties of the three cements used are shown in Table 4. Table 4 also shows the limits specified by the Brazilian standards of the cement used. CPII Z-32 and CPIV 32 had pozzolanic material in their composition, also called natural pozzolan from volcanic rock, in levels of 12–43%, respectively. There was a percentage of 67% of blast furnace slag in the composition of CPIII-40.

The steel reinforcement used in prismatic specimens for electrochemical measurements of corrosion potential was the CA-60 class (reinforcing steel with flow resistance characteristic of 600 MPa) with 5 mm diameter.

2.3. Test procedures

The additional tests (water absorption, compressive strength) were performed aiming the understanding and interpretation of the accelerated corrosion test.

2.3.1. Capillary water absorption

The molding of specimens for water absorption test was carried out according to the Brazilian Standard NBR ABNT 7215:1997 [25], molding, therefore, cylindrical mortar specimens of 50 mm diameter and 100 mm tall. After molding, all specimens had the superior surface protected with a glass plate and remained in a wet chamber (thermally insulated, climate-controlled environment, temperature 23 ± 2 °C, fitted with shelves for storing specimens and water sprinklers to keep the relative humidity ⩾95%) for a period of 24 h, then they were de-molded. Afterwards, the samples were kept in a wet chamber until the desired age (7 or 28 days). Before starting the testing, the specimens were dried in an oven at a temperature of (105 ± 5)°C until constant mass was obtained. After reaching constant mass, they were cooled down at a laboratory environment (relative humidity ⩾65% and temperature 23 ± 2 °C) for 24 h.

The methodology adopted in the experimental program was based on the Brazilian Standard ABNT NBR 9779:1995 [27]; to do so, three mortar cylindrical specimens were tested for each combination of independent variables. During the testing, the water level was kept constant, 5 ± 1 mm above the lower surface of the specimens.

The absorption was monitored for 72 h in accordance with the Brazilian Standard ABNT NBR 9779:1995 [27], from the weighing of specimens. It is noteworthy that, in addition to the measurements fixed by the standard after 3 h, 6 h, 24 h, 48 h, and 72 h; the weight evolution was also monitored after 30 min, 1 h, 2 h, 4 h, and 5 h, for it is during the early hours when the highest capillary absorption speed occurs.

2.3.2. Compressive strength

The principle of the procedure of molding and performance of testing in itself is described on the ABNT NBR 7215:1997 [25]. To determine the strength, four mortar test specimens were molded and conveniently capped with sulfur in order to represent each series in the research; the equipment used has a upload speed of 0,45 ± 0,15 MPa/s. All the test specimens were subject to the curing in a moist

Table 3
Determination of the series.

Series	Type of cement	w/c ratio	Curing period	Feature	Cement content (kg/m^3)
A1	CPII-Z-32	0.7	7	1:3.0	463
A2	CPII-Z-32	0.7	28	1:3.0	463
B1	CPII-Z-32	0.4	7	1:1.3	821
B2	CPII-Z-32	0.4	28	1:1.3	821
C1	CPIII-40	0.7	7	1:3.0	463
C2	CPIII-40	0.7	28	1:3.0	463
D1	CPIII-40	0.4	7	1:1.1	875
D2	CPIII-40	0.4	28	1:1.1	875
E1	CPIV-32	0.7	7	1:3.0	463
E2	CPIV-32	0.7	28	1:3.0	463
F1	CPIV-32	0.4	7	1:1.0	905
F2	CPIV-32	0.4	28	1:1.0	905