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Assessment of the durability of grout submitted to accelerated carbonation test

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HIGHLIGHTS

- The advance of the carbonation front decreases with the higher compressive strength.
- Spacers must be used to assure the minimum steel cover recommended by the standards.
- The useful life of the grout is strongly related with its compressive strength.
- It's necessary to check the durability of structural mansory concerning carbonation.

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ABSTRACT

Durability and useful life of the structural concrete are related to the environmental conditions and degrading factors present in the environment. One of most concerning aggressive agents in the civil construction industry is carbon dioxide that penetrates into the pores of the concrete reacting with the interstitial hydrates reducing its pH, promoting depassivation of the steel armours inside the concrete, thus enabling to start the corrosion process. This paper produced grout proof-bodies, concretes with high fluidity used to fill the blocks in structural masonry, with different resistance to compression: 15 MPa, 20 MPa, 25 MPa. The specimens were submitted to a carbonation front in an accelerated chamber under controlled humidity, temperature and carbon dioxide. A numerical model was used aiming to estimate the forecast of the useful life by making a comparison of the values forecasted by the Brazilian and international performance rules. It was observed that the 15 MPa grout has a useful life forecast lower than that recommended by the standard, around 60% lower, while the 20 MPa and 25 MPa grout presented a satisfactory useful life. Hence, it was certified the importance of controlling the grout resistance and coverage in structural masonry works as a form to assure the desired durability to the structure.

1. Introduction

The emission of carbon dioxide in the atmosphere of the Earth is an environmental issue of great concern, since from it, it may result a changing in the climate that will significantly affect the human life in the planet. Further to affecting life on Earth, the emission of CO_2 also acts on the durability and the useful life of the structures and constructions produced in reinforced concrete.

For Sheng and Guo [1], the emissions of carbon dioxide generated by several human activities have increased along decades regarded the main factor for the global warming. Wang et al. [2] explored the relationship between urbanization, one of the most plausible markers for the economic development and the demographic structure along with the emission of carbon dioxide.

According to Villain et al. [3], in the reinforced concrete, the steel armour is physical and chemically protected against corrosion by the surrounding concrete. The interstitial solution of the pores constitutes a highly alkaline environment where the bars are passivated. When the carbon dioxide (CO_2) in the atmosphere penetrates into the pores of the concrete, it is dissolved in the interstitial solution, thus modifying the chemical balances between the solution and the hydrates, resulting in the carbonation phenomenon.

Jung et al. [4] and Torgal et al. [5] state that the carbonation of the concrete is one of the main factors affecting the durability of

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the structures and the major cause for their deterioration. Lo et al. [6] point out that such process interferes directly in the mechanical resistance of the reinforced concrete, once it contributes for the corrosion of the armours inside it.

Corrosion of the armours is a major issue in the maintenance of the structural integrity of the constructions [7–9], considered by many researchers as the most frequent issue found in reinforced concrete structures. In many cases, constructions must be repaired or reconstructed in a few decades, causing environmental problems due to the waste generation besides of technical-economical issues [10].

Both the performance and the useful life of the constructions have become an increasing concern to civil construction companies and consumers. Consequently, such subject has also awakened a lot of interest by part of the researchers in that area. According to Park [10], the cost of the maintenance in relation to the total investment in the execution of a building has grown in the last years. Some of the major issues approached are the early degradation of newly built constructions and the recovery of structures presenting pathologies still during the execution.

In order to guide and foster improvements in the execution of the engineering and architectural projects both in Brazil and abroad, it has been created normative documentation related to the construction performance and durability. It may be mentioned the 13823 ISO: "General principles on the design of structures for durability" [11], and ISO 2394: "General principles on reliability for structures" [12]; the American rule ACI 318 – 14: "Building Code Requirements for Structural Concrete" [13]; Eurocode 2: Design of structures in concrete – Part 1.1: General Rules and Building Rules [14], in force in Europe; and Brazilian ABNT NBR 15575-1 rule: Residential Building – Performance [15].

Those standards set the minimum performance parameters used in constructive systems, for habitational buildings as well in such extent as to comply with the requirements and demands of users along the housing cycle of life.

The forecast of the advancement of the carbonation front and the execution of the accelerated test are recommended as methods to assess the durability of the structural systems in the 15575-2 ABNT NBR [16]. The 13823 ISO [11] also encompasses the determination of the useful life of the structures in reinforced concrete through the carbonation-induced corrosion.

According to Lo et al. [6], the natural carbonation of the concrete is a chemical reaction between the carbon dioxide (CO_2) in the air and hydration products in the concrete cement. The carbon dioxide in the atmosphere is dissolved in the water of the pores, producing a poor carbonic acid (Eq. (1)), which is dissociated (Eqs. (2) and (3)) reacting with the calcium hydroxide (Eqs. (4) and (5)), and later with the calcium silicate hydrates (Eq. (6)), resulting in the formation of water and calcium carbonate precipitation ($CaCO_3$), consequently reducing the pH level of the concrete [17].

$$CO_2(g) + H_2O(l) \leftrightharpoons H_2CO_3(aq) \tag{1}$$

$$H_2CO_3(aq) \leftrightharpoons H^+(aq) + HCO^{3-}(aq) \tag{2}$$

$$HCO^{3-}(aq) \leftrightharpoons H^+(aq) + CO_3^{2-}(aq) \tag{3}$$

$$Ca^+(aq) + H_2O(l) \leftrightharpoons CaOH^+(aq) + H^+(aq) \tag{4}$$

$$Ca(OH)_2(s) + H_2CO_3(aq) \leftrightharpoons CaCO_3(s) + 2\,H_2O(l) \tag{5}$$

$$CaSiO_3.(\eta - 1)H_2O + H_2CO_3(aq) \leftrightharpoons CaCO_3(s) + SiO_2.\eta H_2O \tag{6}$$

In general, the cement present in the concrete is hydrated to produce an alkali, $Ca(OH)_2$, in the solution inside the pores, providing a chemical protection to the steel against corrosion. That chemical protection provided to the steel is performed by a protective oxide film formed on its surface in an environment with pH around 13 [18].

Cui et al. [19] expose that whenever the concrete presents pH values between 8.5 and 9.5, it occurs the depassivation of the steel. The carbonation phenomenon leads to a decrease in the alkalinity of the concrete for a lower than 9 pH, thus decreasing its protective ability and making the steel bars susceptible to corrosion [20].

It is known that the carbonation front of the concrete advances over time [21,22]. Hence, within the period of useful life foreseen for a specific structure, it must be avoided that the carbonated depth reaches the armour, in order to avoid the above mentioned effects.

Jiang et al. [23] performed the measurement of the carbonation depth by employing pH markers constituted of a phenolphthalein solution, as well as Leemann and Moro [24], and Turcry et al. [25]. It is solution a colorless with a lower than 8.3 pH, and carmine-red for higher than 9.5 pH, and it may present a varied pink color in pH values between 8.3 and 9.5.

According to Pan et al. [26], the factors controlling carbonation are the CO_2 diffusivity and the reactivity of the gas with the concrete. By its turn, diffusivity depends on the porous structure of the hardened concrete, its properties and humidity state [21].

Houst and Wittmann [27] complement that information stating that among the main factors influencing the carbonation speed are: the water/cement ratio, the cure, the amount and type of the cement, the carbonic gas concentration, the amount of water, temperature, content of alkalis and cracks.

A form to assess how the carbonation phenomenon affects the concrete is by applying accelerated tests through the use of carbonation chambers. Such process is performed by adding higher CO_2 concentrations than the ones found in the atmosphere in environments with controlled conditions.

Castellote et al. [28] performed tests in a controlled environment presenting 65% equilibrium moisture, 22 °C temperature, and concentration of 0.03% (natural), and 3%, 10% and 100% (accelerated). Carbonation was followed-up by the evolution of the mass gain. They indicated that in the environment with 100% CO_2, the stabilization occurs between the 7th and 40th day, a little earlier in relation to the environment with concentration of 10% CO_2. Applying a concentration of 3% CO_2, the beginning of stabilization occurs near to the 90th day, and the mass gain increases at a slower rate. Regarding the carbonation rate, stabilization occurred more quickly and abruptly under the 100% CO_2 concentration. However, it is not possible to say that carbonation occurred faster, since the number of measurements was limited.

In recent years, some researchers have used accelerated tests to assess the durability of concretes, mortars or pastes as to the carbonation [29–34]. The authors have applied different controlled environmental features, and different times of exposition under such conditions. Bernal et al. [29], Lovato et al. [30] and Morandeau et al. [33] adopted relative humidity between 57 and 70%, temperature of 25 °C, and CO_2 concentration ranging between 6 and 10%. Neves et al. [31], Aguiar and Júnior [32], and Duprat et al. [34], on the other hand, opted for an environment with the same equilibrium moisture range, but under temperature of 20 °C and 5% CO_2. Morandeau et al. [33] evaluated the phenomenon in the long run, with up to 112 days of exposure, while in the others researches the carbonation was observed in minor ages, from the 7th day.

Fattuhi [35] performed an accelerated carbonation test to study the influence of the cure regimen in concrete proof-bodies in relation to the 0.70 water/cement submitted to a 100% CO_2 concentration. In his experiments, it was used sampling without wet cure and sampling water-cured for periods of 1, 3, 5, 7, or 28 days, being the remaining time air-cured, so each proof-body would complete