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Influence of preloading-induced microcracking on the durability of concrete produced with different types of cement

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HIGHLIGHTS

- Self-healing may contribute to reducing chloride penetration over time.
- Cement chemical composition can mitigate in different ways the effects of preloading.
- Pozzolanic reactions improve the effects of self-healing as curing ages increased.
- Remote sensing techniques are innovative approaches to the detection of microcracking.

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ABSTRACT

As many concrete structures present premature degradation, large environmental and financial impacts are associated with repairing. It is essential, therefore, to understand mechanical and durability performance of concrete in different conditions of use. This study investigated the chloride penetration resistance of microcracked concretes after being exposed to early loading. So, cylindrical test specimens were prepared with two Brazilian cements, a high initial strength Portland cement and a pozzolanic one, with a water/cement ratio of 0.50. At the age of 3 days, some of the specimens were subjected to a load of 75% of their ultimate compressive strength while reference ones were not preloaded. All specimens were cured by immersion in water tanks for 3, 7, 28 and 91 days. After these periods, preloaded and reference specimens were tested in accordance with chloride penetration resistance (ASTM C1202/12). The best results were observed in the reference samples for both cement types. It was observed a significant reduction in chloride penetration for longer curing times in preloaded and reference specimens due to self-healing. Differences between preloaded and reference specimens were identified, at ages of 3 and 91 days, using scanning electron microscopy and electromagnetic radiation spectra, a non-destructive and low-cost remote sensing technique.

1. Introduction

The widespread use of concrete has led to a large number of technological developments in the civil construction industry. However, many gaps between theory and practice still persist. Despite all the available knowledge about concrete, its properties and recommendations for use, many structures are degraded even before reaching the intended service life. The strategy to bridge these gaps should be considering the properties of concrete and their interactions with the structure, with a focus on durability [1].

Preloading-induced microcracking can cause premature incidence of pathologies in concrete structures. Microcracking increases permeability and makes the structure more susceptible to degradation [2]. It is a fact that concrete integrity is a prerequisite for ensuring concrete durability, particularly when the structure is exposed to aggressive environments. For this reason, longer curing periods contribute to development of concrete strength capacity and the microcracking control from early ages.

Several studies have discussed how to develop more efficient and durable materials in order to maintain concrete performance during the structure lifetime. In this sense, a topic that has attracting a great deal of interest is concrete self-healing. Autogenous healing or self-healing is the ability that cracked cementitious materials have to seal themselves if water is available. The self-healing phenomenon can occur under natural conditions when microcracks are filled by hydration products of unreacted cement grains. The complete sealing of cracks can occur just in some extreme cases [3]. It is possible at least to reduce the microcracking and so the need for external repair services.

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This study may increase the available knowledge about the behavior of pre-cracked concretes when subject to chloride ions penetration. Besides, it can offer contributions on the better understanding of the capacity for self-healing of concrete when water immersion cure is adopted.

2. Concrete microcracking

Before being submitted to any load, concrete can show microcracking due to shrinkage and heat release that take place during the early curing phase [4,5]. Therefore, even in the presence of very low stress levels, microcracking can take place. This early cracking can then expand during loading of the structure.

If formwork or struts are removed before curing is complete, this can result in excessive deformation and microcracking due to early loading. Mechanical stress causes microcracking to increase over time, which in turns results in larger cracks and permanent deformation. While some types of cracks may have no effect on the stability of the structure, they may operate as entry pathways for aggressive agents.

Chlorides are aggressive agents that can penetrate the structure through the concrete pore network. The ingress and diffusion of these ions are affected therefore by the capillary porosity and water/cement ratio of the concrete. As chlorides have small atomic radius, they can also ingress into concrete through microcracks. It was developed a study to simulate the ion chloride transportation on cracked concrete [6]. The authors concluded that the chloride content in the cracked zone depend on the crack width, which affects deeply the chloride supply and the diffusion coefficient of chloride ions.

Researchers [7] studied chloride diffusion and water permeability in concrete samples with different crack widths (0.1–0.4 mm). Diffusion coefficients showed the following increases when compared to reference samples: 23.5 times (0.1 mm crack width), 38.4 times (0.2 mm crack width), 70.6 times (0.3 mm crack width), and 145.4 times (0.4 mm crack width).

To assess the influence of different widths and depths on chloride penetration into concrete a investigation [8] was developed using the NT BUILD 492 test (NORDTEST, 1999). The researchers found that: i) a higher penetration of chlorides is obtained at the notch tip in comparison with the 'un-cracked' part of the test specimens; ii) the penetration depth increased as the notch depth increased; and iii) this effect was more pronounced for longer test durations. They also stated that the influence of the notch width on chloride penetration was not clear.

It was conducted a study [9] to determine the corrosion behavior of different stainless steel alloys on reinforced concrete samples using different settings. Some samples had no cracks, some had cracks oriented across the steel rebars and others had cracks running along the rebars. Concrete exposure to aggressive environment was significantly accelerated, as the test specimens were exposed to a solution of NaCl 3–5% for over 2 years, at temperatures ranging from 20 to 25 °C. Results showed corrosion signs at the intersection of the cracks with the rebars in all tested concrete samples, while no corrosion was observed in the uncracked ones. It was observed that corrosion quickly started at the bottom of the cracks and then spread along the surface of the reinforcing steel.

Because the existence and development of microcracking are fundamental factors to the chlorides ingress into concrete, specific measures have to be adopted early on to protect the structure and ensure its durability. Some authors [10] highlighted the fact that the long-term performance of concrete may be affected by the structure behavior in early ages. Even when reliable and scientifically proven project methodologies are used to ensure the structure service life, this will not be sufficient if also quality assurance procedures are not adopted in the mixing and initial curing of concrete [11].

This study investigates the effects of microcracking in concrete mixes produced with different cement types when exposed to chlorides. It also looks into the influence of extended curing periods in the self-healing of microcracks and assesses the impacts of self-healing on the mechanical properties and durability of concrete.

3. Materials and experimental program

To cast the test specimens were used two different types of Brazilian cements: CP V ARI, a high initial strength Portland cement equivalent to Portland cement type III [12] and CP IV, a pozzolanic cement equivalent to Portland cement type IP [13]. The CPV ARI cement, which has lower concentration of additions, was used as reference. The physical and chemical properties of the cement types used are shown in Table 1, according to the manufacturer's data. As can be observed, there are differences between the two cements, which may influence the behavior of the concrete. Through the result of the test of insoluble residue, it is possible

Table 1
Physical and chemical properties of cement types used.

Physical Properties Specification	Unit	Cement CPV ARI [14] Results	Cement CPIV [15] Results
Blaine fineness	cm^2/g	4585	4384
Time of setting Vicat (initial)	h:min	3:26	3:40
Time of setting Vicat (end)	h:min	5:15	5:30
Fineness sieve # 200	%	0.28	1.01
Fineness sieve # 325	%	1.93	4.84
Specific gravity	kg/dcm^3	3.16	2.82
Compressive strength 1 day	MPa	21.40	–
Compressive strength 3 days	MPa	36.70	17.66
Compressive strength 7 days	MPa	41.80	22.41
Compressive strength 28 days	MPa	49.00	36.15
Chemical Properties Specification	**Unit**	**Cement CPV ARI [14] Results**	**Cement CP IV [15] Results**
% Sulfur trioxide	%	3.12	2.39
% Magnesium oxide	%	1.99	4.60
Loss on ignition	%	2.55	3.42
Insoluble residue	%	0.68	31.33
Free CaO	%	–	–

Source: Manufacturer's data (Sep. 2012).