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Comparative study of white and ordinary concretes with respect of carbonation and water absorption

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HIGHLIGHTS

- Degree of carbonation and water absorption of concretes are evaluated.
- Concretes with white cement are compared to ordinary Portland cement.
- Results were analyzed statistically.
- Results show that the type of cement plays a major role.
- Water permeability or surface water absorption tests presented a good correlation with carbonation.

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ABSTRACT

This research compares the degree of carbonation and water absorption of concretes with white cement versus ordinary Portland cement. For this, four types of white concrete (WPC1–4), ordinary Portland concrete (OPC) as control, and three water/cement (w/c) levels. Results were analyzed statistically. Compressive strength was used as control for the durability tests. Results show no carbonation in concretes with w/c ratio 0.4. Concretes WPC1, WPC2, and OPC with w/c 0.6 showed the highest carbonation level. The best performance was with WPC3, demonstrating that the type of cement plays a major role. Water permeability or surface water absorption tests presented a good correlation with carbonation.

1. Introduction

Concrete is one of the most versatile and useful building materials. Nevertheless this material sometimes displays two undesirable features: poor aesthetic properties, i.e. poor visual appearance and poor durability in aggressive environments [1]. Different types of Portland cement are manufactured to attain different physical, chemical, and mechanical properties in concrete structures, depending on the type of structure and where it is to be located. White Portland cement (WPC) is produced following same specifications as type I or III cements, i.e., ASTM C 150 [2]; however, its production requires additional care [3]. White cement is differentiated from ordinary Portland cement by its color—which is obtained using raw materials with low iron and manganese oxide contents and special care during manufacture, mainly cooling and milling process. Because this produces a material with different characteristics compared to OPC, comparative studies are needed to evaluate its performance and durability. The main advantage of using WPC instead of OPC is that it can be used either without or with pigments, thus avoiding the use of dyes. Many architects use WPC because of its flexibility in terms of color aesthetic.

The ability to prevent the ingression of harmful chemical or gaseous species is directly related to the durability of the concrete applied in structures that last to a long term, the major index for this capacity is their own permeability. Permeability governs the permeation of moisture, ionic, and gaseous species into concrete, and affects durability properties, such as carbonation, sulfate attack, acid attack, air permeability, freeze-tawn, water absorption, corrosion of steel rebar and alkali-aggregate reaction [4,5]. Regarding the durability of concretes with WPC, some studies were done in order to analyse and improve its behavior with respect to the sulfate resistance [6], the electrical resistivity and conductivity [7] and also shrinkage, oxygen permeability and the chloride penetration properties [8] with addition of blast-furnace slag activated by sodium sulfate. Ferraro and Nanni [9] presented a fundamental investigation on the strength, porosity, corrosion resistance and thermal conductivity of white concrete blended with an off-white

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rice husk ash. Also Jang et al. [1] assessed the color expression characteristics and physical properties of colored mortar with the addition of ground granulated blast-furnace slag and Muynck et al. [10] evaluated 12 different products formulations to prevent algal fouling in white architecture concrete. Comparing the results to concretes without mineral admixtures or treatments all the analysed properties were greatly improved.

Carbonation resistance of concrete has also been highly concerned, especially when concrete structures are reinforced with steel rebar [4]. Steel is maintained passive in the high alkalinity of the concrete pore solution, however this passivity can be disrupted and corrosion takes place. As corrosion is a gradual process it is often difficult to detect its development in the early (initiation) stages [11]. One of the processes behind these anomalies is concrete carbonation. The natural carbonation of concrete depends simultaneously on the materials' characteristics and the surrounding environment [12]. CO_2 diffusion in the concrete mass will change its initially strongly alkaline environment to lower pH values, which will lower alkalinity of concrete to such an extent that steel embedded may rust and spall the concrete cover [4]. These parameters are key in evaluating the accessibility of aggressive agents and estimation of corrosion propagation.

Eventhough there are lots of research regarding carbonation for OPC mixtures in different levels (micro, macro, chemical and physical) and conditions ([12–27], among many others), there is a lack of information in this field for WPC concretes. The differences in chemical components proportions are critical in comparing WPC with OPC because these differences reflect changes in performance properties for both fresh and hardened concrete; characterizing these properties is critical. The objective of this work is to assess the carbonation depth and the water absorption in WPC concretes and compare OPC samples in the same condition. The compressive strength for the mixtures was used as control.

Table 1
Chemical, physical and mechanical characteristics of the cements used.

Chemical composition	Content (wt%)				
	OPC	WPC1	WPC2	WPC3	WPC4
Loss on ignition (LOI)	3.76	9.37	7.01	2.09	2.16
Silicon dioxide (SiO_2)	19.53	19.20	20.29	22.27	24.52
Aluminum dioxide (Al_2O_3)	3.91	3.53	3.66	4.29	2.10
Iron oxide (Fe_2O_3)	2.89	0.16	0.17	0.21	0.36
Calcium oxide (CaO)	63.19	62.46	63.86	66.04	67.42
Magnesium oxide (MgO)	1.94	1.53	1.02	1.06	0.53
Sulfur trioxide (SO_3)	3.07	2.87	3.16	3.26	2.01
Sodium oxide (Na_2O)	0.04	0.01	0.01	0.01	0.08
Potassium oxide (K_2O)	0.61	0.08	0.08	0.18	0.11
Insoluble residue	0.54	1.80	1.29	0.35	0.26
Carbonic anhydride (CO_2)	2.45	8.61	5.27	0.33	0.58
Free calcium oxide (CaO)	1.27	–	–	–	–
C_3S	78.37	84.36	80.89	70.42	73.43
C_2S	–	–	–	10.74	14.92
C_3A	5.47	9.09	9.41	11.01	4.96
C_4AF	8.79	0.49	0.52	0.64	1.10
Fineness – residue on 75 μm sieve – 200%	0.5	0.4	0.4	0.9	10.3
Density (g/cm^3)	3.09	2.99	2.99	3.05	3.07
Specific surface (cm^2/g) – Blaine	4190	4500	4380	3490	3950
Water for normal consistency paste (%)	29.8	33.0	31.4	28.2	31.8
Initial set (h:min)	3:05	2:35	2:40	1:20	2:05
Final set (h:min)	4:25	3:25	3:40	2:10	3:25
Expandability of Le Chatelier – cold (mm)	1.0	1.5	2.5	3.0	0.5
Expandability of Le Chatelier – warm (mm)	0.5	0.5	0.5	1.0	10.0
Compressive strength (MPa)					
3 days	34.6	23.4	26.0	29.1	22.7
7 days	40.7	31.3	35.4	36.7	33.1
28 days	–	45.4	51.1	47.1	51.0

2. Materials and methods

2.1. Materials

Four types of white cement were used for producing concrete specimens, which are identified herein as WPC1–4. A high initial strength OPC was produced as a control sample. It is similar to WPC because of (1) the absence of any additional supplementary cementitious materials, and (2) the similar particle size distribution. The OPC sample used as control had a composition similar to ASTM type I cement. The chemical, physical, and mechanical characteristics of all the cements used are described in Table 1. Granulometric distribution of the aggregates (sand and gravel) are described in Table 2. A modified polycarboxylic ester superplasticizer base was used in some mixes to maintain the necessary workability.

2.2. Mix proportions and specimen preparations

A total of 15 mixtures were tested, with five different types of cement and three water/cement (w/c) ratio. Each mixture was repeated twice. The mix proportions are described in Table 3. The slump was fixed in 70 ± 10 mm. The concrete was produced and consolidated with mechanical equipment. After the samples were mixed, they were left in molds for 24 h, removed, and then transferred to a cure chamber with controlled temperature (23 ± 2 °C) and relative humidity higher than 95%.

After 28 days, the carbonation samples were placed in a homogenization chamber, while the water absorption samples were cut and dried on stove (60 °C) until the water loss was stabilized. More details on each test are described in the following section.

2.3. Test methods and procedures

2.3.1. Compressive strength

Samples were tested under compressive strength according to the Brazilian standard NBR 5739/2007 [28]; this standard correlates to ASTM C 39 [29]. The cylindrical 9.5 × 19.5 cm samples were tested at 3, 14, and 28 days, three samples of each type per age. ASTM C192 [30] was followed for making and curing the samples, and ASTM C617 [31] for capping the cylindrical samples for compressive tests.

Table 2
Granulometry of fine and coarse aggregates.

	Sieve size # (mm)	% Retained	
		Fine aggregate	Coarse aggregate
	19.0	0	0
	12.5	0	61
	9.5	0	89
	6.3	0	98
	4.80	0	99
	2.40	5	100
	1.20	21	100
	0.60	52	100
	0.30	92	100
	0.15	100	100
	<0.15	100	100
Maximum characteristic dimension		2.4 mm	19.0 mm
Fineness module		2.70	6.88
Density		2.63 kg/dm^3	2.81 kg/dm^3

2.3.2. Water absorption test

Designed by Kelham [32], the water absorption test method consists on 10 × 10 × 6 cm molded prisms that were cured for 28 days. At that point, the top and bottom were cut from the prism to obtain a 2.5-cm-thick core section. This section was kept at ambient temperature for one hour and then weighted and placed in an oven at 110 °C until a steady mass was reached. The lateral surfaces were sealed with epoxy resin to fix an unidirectional flux of water inside the sample. A plastic lid was placed on top with a vent to allow air circulation. Samples were immersed in pure water and the gain of mass was measured at 2, 5, 15 and 30 min and 1, 2, 3, 6, 8, 24, 48, 72, 96 and 120 h intervals. The gain of mass was measured over time up to the saturation of the sample, at which point the weight was considered stable.

By graphing the mass gain over the root square of time, it possible to identify two different phases during the absorption process. The first is related to capillary water absorption itself, and the second is related to saturation of water. The