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The effect of drying preconditioning on the South African durability index tests

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ABSTRACT

This study investigated the effect of different drying regimes in the preconditioning stage on Durability Index (DI) test results. The moisture condition of specimens needs to be stable and uniform for the tests to be accurate and reliable. Three drying regimes were used: (a) standard oven drying method of 50 °C for 7 days, (b) oven drying at 50 °C to constant mass, and (c) drying using a solvent replacement method with isopropanol. Concrete mixes were designed using three w/c ratios (0.40, 0.50 and 0.65) and four binders. The isopropanol and oven drying to constant mass methods were found to remove different amounts of moisture compared with the standard drying method. Most (about 80%) of the moisture was removed within 7 days when oven dried. Statistical analysis suggested that, for certain mixes, the drying method had an effect on the DI results, with the chloride conductivity test being the most sensitive. For quality control purposes, it is impractical to wait until specimens are completely dry, which in some cases took up to 17 days, before performing the DI tests. The practical solution is for specimens to be tested at not less than 7 days and not more than 8 days of drying.

1. Introduction

Recent decades have seen an increase in awareness of the importance of the durability of reinforced concrete structures. Premature deterioration, largely as a result of the corrosion of reinforcement due to ingress of deleterious substances, has led to additional costs of repair and loss of serviceability [17].

Traditional prescriptive, or recipe type, approaches with limits on parameters such as water/cement (w/c) ratio are inadequate in addressing durability concerns [6]. The move to performance-based approaches is seen as the way forward, whereby the concrete is tailored for its specific environmental exposure and required level of performance. This encourages innovation in materials design, since there may be multiple options to achieve certain targets.

In the South African context, the durability 'performance' of the concrete is measured using a suite of Durability Index (DI) tests, comprising the Oxygen Permeability Index (OPI), Water Sorptivity Index (WSI), and Chloride Conductivity Index (CCI) tests. This 'performance' concerns the quality of the covercrete. The DI tests reflect the transport processes of gaseous diffusion, water absorption, and ionic diffusion respectively, by which deleterious substances enter and move through the pore structure of the concrete [9].

The DI tests have been developed over a long period of time and have undergone improvements through multiple stages of round robin tests, resulting in more refined test procedures [4,13]. Although the tests have been in practical use for some time, there is still room for further incremental improvements, particularly regarding test variability and preconditioning of test specimens, so that they can be more confidently used in the construction industry.

Although concrete durability parameters are inherently variable, the variability should be attributed to the concrete and not be as a result of the test. One aspect that can influence the variability of the DI test results is the preconditioning phase. Before the tests are conducted, specimens are placed in an air ventilated oven at 50 °C for 7 days to remove the moisture in the concrete pores. The moisture state of specimens in the DI tests is important as it influences the transport processes. The presence of moisture in the concrete pores effectively acts as a barrier to the passage of oxygen in the OPI test, while it may prevent full saturation of the NaCl solution in the CCI test [1,15,14]. Thus, the specimens need to be sufficiently and uniformly dry before undergoing tests in order to obtain reliable and comparable results.

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This study investigated the effect on the DI test results when two drying methods which differed from the standard one were used, namely oven drying at 50 °C to constant mass, and solvent replacement using isopropanol. The situation of oven drying beyond the standard 7 days might arise, for example, where there are many specimens to be tested and not enough test equipment, resulting in the required tests only being able to be performed after the required 7 day mark. (The standard 7-day drying period is largely necessitated by test results being required within a relatively short time period for effective quality control of construction).

2. Drying methods

There exist several methods of moisture removal from concrete. These include oven drying at elevated temperature, vacuum drying, freeze drying, and solvent replacement methods. In this study the oven drying and solvent replacement methods were used.

2.1. Oven drying

This method involves the phase transformation of water from liquid to vapour. As this occurs, capillary suction is experienced which can induce micro-cracking and the collapse of the paste microstructure [19].

Oven drying at 105 °C is widely used to remove moisture from concrete [5,12,8]. Galle [2] compared the effect of different drying methods on the pore structure of hardened cement paste. The methods included oven drying at 60 °C and 105 °C, as well as vacuum drying and freeze drying. He found that oven drying at 105 °C significantly degraded the microstructure of the concrete and increased its porosity. Oven drying at 60 °C for 7 days had similar results. When developing the OPI test Ballim [1] found the most effective drying method to cause minimal microcracking to be oven drying at a relatively mild 50 °C for a period of 7 days. However, high quality dense concretes containing silica fume dried at 50 °C have been found to have different levels of microstructural damage [10]. Thus, as is often the case, the current preconditioning for the DI tests, which requires oven drying the specimens at 50 °C for a period of 7 days after which they are cooled to 23 °C, is an attempt at reconciling somewhat conflicting demands.

2.2. Solvent replacement drying

Solvent replacement methods involve replacing the pore water with organic volatile liquids and then removing the solvents to obtain dry concrete samples. Samples are soaked in the solvent which is absorbed and diffuses into the paste and replaces the aqueous pore solution. The solvent is then removed by evaporation at ambient or elevated temperature [19]. Solvents are miscible with the pore water and have a lower surface tension than water so their expulsion from the pores does not cause significant capillary suction as experienced with straight oven drying [7]. While many solvents such as acetone and methanol can be used to perform this procedure, the use of isopropanol has been found to be the most effective at preserving the concrete microstructure [19].

A drawback of this method is that it takes a much longer time to complete for larger specimen sizes compared to oven drying. In one study, a specimen of thickness 10 mm took nearly 3 weeks for drying to be complete [3]. Thus, there is a need to accelerate the process, which can be done using vacuum saturation to speed up the ingress of the solvent into the specimens.

3. Experimental methods

Table 1 shows the mix proportions and average slump and compressive strength values for the various concretes that were used in this study. Three w/c ratios were investigated, i.e. 0.40, 0.50, and 0.65, providing mixes over a wide strength and durability spectrum. Four binder types were selected which included a plain Portland Cement (CEM I 52.5N), a PC-based factory blend (CEM II B-M (L-S) 42.5N), as well as supplementary cementitious materials (GGBS and FA) to provide a range of binders. The coarse aggregate was a greywacke stone with a nominal maximum size of 19 mm. A blend of 50/50 Philippi dune sand and Klipheuwel pit sand from the Cape Town area was used as the fine aggregate. 100 mm cubes were cast and water-cured for 28 days at 23 °C. Water content for all the mixes was kept constant at 170 L/m^3. Durability index test specimens were prepared according to the 2010 DI Manual [16]: 70 mm diameter cores were drilled from 100 mm cast cubes, perpendicular to the direction of casting of the cubes. Two 30 mm thick DI test specimens were then cut from the cores using a diamond tipped saw blade.

The oven drying and isopropanol drying regimes were used to investigate the effect of drying on the DI tests. Two 50 °C oven drying durations were selected: seven days (the 'standard' regime), and oven drying to constant mass, defined as a ≤0.05% change in mass over 24 h. These two durations were chosen to determine the efficiency of the current 7-day drying duration in producing sufficiently dry specimens. The solvent replacement drying regime was used to determine if an alternative to oven drying was feasible and if comparable DI results could be obtained.

The solvent used was analytical grade isopropanol. Specimens were vacuum-saturated with isopropanol to accelerate the replacement process. This was done in a vacuum desiccator (Fig. 1) by firstly evacuating the chamber for 3 h at a vacuum of −80 kPa, and then introducing the isopropanol under vacuum and re-establishing the vacuum for 1 h. The vacuum was then released and the specimens were allowed to soak in the isopropanol for a period of 18 h. The specimens were then placed in an air ventilated oven maintained at 30 °C and the mass change was monitored daily until a mass change of ≤0.05% was experienced over 24 h. Once this was achieved, the specimens were tested in the OPI, WSI and CCI tests, with testing done in accordance with the 2010 DI Manual.

3.1. Durability index tests

The OPI test involves measuring the pressure decay across a cylindrical concrete disc specimen described and conditioned as given earlier. The specimen is securely fitted in a falling head permeameter, after which oxygen is passed through the specimen under an initial pressure of 100 ± 5 kPa. The pressure is recorded at regular time intervals until it has decayed to 50 kPa, or for a period of 6 h, whichever occurs first, and the D'Arcy permeability coefficient (denoted as k) is calculated. This is transformed into an 'oxygen permeability index' (OPI), using the negative log of k, for characterising the transport process of gaseous diffusion.

The water sorptivity test is based on measuring unidirectional flow of water under capillary suction into a concrete disc specimen of the same dimensions and conditioning as used in the OPI test. The bottom face of the specimen is exposed to a few millimetres of $Ca(OH)_2$ solution, with the curved faces sealed. The mass change due to absorption is measured at regular intervals over a period of 25 min. The water sorptivity index (WSI) is determined as a function of the mass gain versus square root of time, and relates to the water absorption transport process.

The chloride conductivity test was developed as a means of characterising the transport (conductivity) of chloride ions in