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Investigation of moisture condition and Autoclam sensitivity on air permeability measurements for both normal concrete and high performance concrete ☆

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HIGHLIGHTS

- We study variations of relative humidity and electrical resistance after drying and conditioning.
- We investigate influences of moisture content and distribution on results of the Autoclam air permeability.
- We examine the sensitivity of the Autoclam air test to measure permeability of HPCs.
- Drying in an oven at 50 °C and 35% RH for 14 days can eliminate the effect of moisture variation on the Autoclam air test.
- The Autoclam air test is unable to differentiate the differences between HPCs, but the BS-EN water penetration test does.

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ABSTRACT

While on site measurement of air permeability provides a useful approach for assessing the likely long term durability of concrete structures, no existing test method is capable of effectively determining the relative permeability of high performance concrete (HPC). Lack of instrument sensitivity and the influence of concrete moisture are proposed as two key reasons for this phenomenon. With limited systematic research carried out in this area to date, the aim if this study was to investigate the influence of instrument sensitivity and moisture condition on air permeability measurements for both normal concrete and HPC.

To achieve a range of moisture conditions, samples were dried initially for between one and 5 weeks and then sealed in polythene sheeting and stored in an oven at 50 °C to internally distribute moisture evenly. Moisture distribution was determined throughout using relative humidity probe and electrical resistance measurements. Concrete air permeability was subsequently measured using standardised air permeability (Autoclam) and water penetration (BS EN: 12390-8) tests to assess differences between the HPCs tested in this study.

It was found that for both normal and high performance concrete, the influence of moisture on Autoclam air permeability results could be eliminated by pre-drying (50 ± 1 °C, RH 35%) specimens for 3 weeks. While drying for 5 weeks alone was found not to result in uniform internal moisture distributions, this state was achieved by exposing specimens to a further 3 weeks of sealed pre-conditioning at 50 ± 1 °C. While the Autoclam test was not able to accurately identify relative HPC quality due to low sensitivity at associated performance levels, an effective preconditioning procedure to obtain reliable air permeability of HPC concretes was identified.

1. Introduction

Use of high-performance concrete (HPC) is an established approach to enhancing the durability of reinforced and pre-stressed concrete structures [1,2].

However, with performance levels of HPC typically based on laboratory-based testing [1], the long term, in service performance of concrete structures is largely dependent on contributing factors

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such as construction quality. Against this background, an ability to undertake accurate in situ quality assessment of HPC is very important.

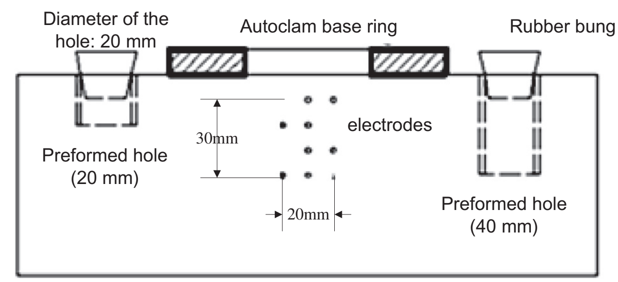
Most concrete durability problems are directly related to the ingress of various aggressive substances, such as Cl^-, SO_4^{2-} and CO_2 [3,4] and numerous techniques have been developed to measure related permeation properties in order to assess/predict structural durability [5,6]. Although water permeability tests are suitable for in situ performance assessment, air permeability tests have gradually become popular due to their simplicity, short test durations and lack of physical/chemical interaction during measurements [5,7].

While many researchers [8–10] have undertaken HPC air permeability assessments using available in situ techniques, reported results have not been conclusive. As air permeability is affected by concrete's pore structure and moisture condition, one explanation for this is the influence of moisture. As there is no standard preconditioning regime for field methods, most in situ experiments are carried out under site-specific moisture conditions. Without appropriate preconditioning methods, the influence of moisture is likely to be a significant cause of variable and leads to non-reliable test results. A secondary cause of HPC result variability is likely to be low levels of instrument sensitivity, as most systems currently on the market were designed to measure the permeability properties of normal concrete [11,12]. As HPC permeability levels are typically low, relative performance differences become difficult to detect.

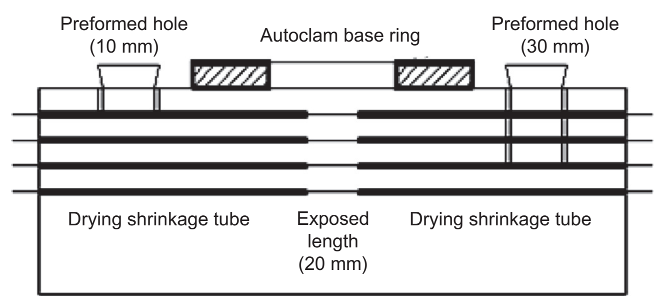
Against this background, the aim of this study is to propose a suitable pre-conditioning regime for air permeability tests and to assess the ability of the Autoclam test to identify relative HPC performance levels. In order to achieve this aim, concrete specimens were dried and conditioned before moisture conditions were examined using relative humidity and electrical resistance measurements. Air permeability was measured using the Autoclam test method at different moisture conditions. In addition, standard water penetration laboratory-based testing was carried out to examine relative HPC permeability and to enable comparisons with Autoclam air testing results.

Table 2
General properties of concrete in this work.

Property	Concrete mix		
	NC	HPC1-PC	HPC2-MF
Air content (% by volume)	0.7	1.3	0.8
Slump (mm)	180	205	235
28 day compressive strength (MPa)	24.1	78.6	80.2
56 day compressive strength (MPa)	33.7	86.3	85.3



(a) The sectional view of the specimen



(b) The sectional view of the specimen

Fig. 1. Details of the test specimens.

2. Experiment programme

2.1. Materials and concrete mixes

Based on previous experimental work undertaken at Queen's University [8,13], two HPCs and one normal concrete were considered as part of this study. The mix compositions are reported in Table 1.

With a water/binder ratio of 0.68, the reference, normal concrete contained Portland cement as a binder material only. Similarly, the first HPC considered (labelled HPC1-PC) contained Portland cement only but at a water/binder ratio of 0.30. Typical for HPCs [1], the second HPC considered contained a ternary binary blend of Portland cement, micro silica (MS) and pulverised fuel ash (PFA). The water/binder ratio in this case was 0.3. In all cases the cement used was type CEM-II confirming to BS EN 197: 2000 [14]. The PFA, conforming to BS EN 450: 2005 [15], was sourced from Kilroot Power station in Northern Ireland and the MS in slurry form, conforming to BS-EN 13263-1: 2009 [16], from Elkem. A polycarboxylic acid-based polymer superplasticiser, commercially available as Chemcrete HP3, was additionally used for the HPC mixes to maintain a constant slump range.

The fine aggregate was medium graded natural sand and the coarse aggregate both 10 and 20 mm crushed basalt used in equal proportions. The moisture condition of the aggregates was controlled by pre-drying in an oven at 105 ± 5 °C for 24 h followed by cooling to 20 ± 1 °C for one day before mixing.

Each concrete mix was tested for air content [17], slump [18] and compressive strength [19], the results of which are shown in Table 2. The disparity between the normal concrete and HPC is evidenced by the variation in 28-day compressive strength, which was approximately 24 N/mm^2 for mix NC and 80 N/mm^2 for both HPC mixes.

Table 1
Concrete mix proportions.

Constituents	Concrete mix		
	Normal concrete (NC)	HPC1 (PC)	HPC2 (MF)
PC[a] (kg/m^3)	375	485	352
Microsilica (kg/m^3)	0	0	36
PFA (kg/m^3)	0	0	97
Sand (kg/m^3)	625	689	652
Coarse aggregate (kg/m^3)	1136	1150	1150
Water (kg/m^3)	256	145	145
Superplasticiser[b] (%)	0	1.3	1.5
Water/binder ratio	0.68	0.30	0.25

[a] PC was CEM II contained 85 ± 0.5% Portland cement clinker and 15 ± 0.5% limestone powder.
[b] Polycarboxylic acid based polymer superplasticiser, as percentage of binder content.

2.2. Specimen preparation and testing

For each concrete mix, fifteen 230 × 230 × 100 mm slabs were manufactured for both moisture-conditioning and air permeability testing, and 100 mm cube specimens for compressive strength testing. The slab specimens contained preformed cavities at depths of 10, 20, 30 and 40 mm and embedded four pairs of stainless steel electrodes for testing relative humidity and electrical resistance (see Fig. 1). The cavities were sealed by rubber plugs to ensure that the reading in the hole is not affected by the ambient conditions.

Concrete mixing was undertaken in accordance with BS 1881, Part 125: 2005 [20] and the fresh concrete was assessed for consistence (slump test) and air content. Concrete was compacted in moulds in two layers using a vibrating table, covered with wet hessian and placed in a constant temperature room (18 ± 2 °C).