Influence of the age on air permeability of concrete

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A great interest is being taken in the measurement of concrete permeability because of increased concerns about the durability of concrete when exposed to aggressive environments. However, the variation of the concrete permeability with time has not been systematically studied. Air permeability results recorded for 20 years in six 0.2 m³ concrete slabs are presented. These results have a qualitative value as boundary effects are unknown. The great difference in flow between the specimens with the same mix design, casting and curing procedure, which have been kept in the same testing room sheltered from rain, is noticeable. The air permeability coefficient increases with time, reaching an almost stable value after 20 years. The pore evaporated water creates a path for air flow through the concrete and this is supposed to be the main cause of the increase in permeability. The method presented in this paper gives reliable information about the quality of the concrete studied in terms of air permeability and hence, durability.

1. Introduction

The long-term performance of concrete is at present a topic of great interest. This has led to increased study of the parameters related to its durability and the testing methods for its determination as in the case of air permeability. Concrete structures are designed to ensure acceptable limits of deformation and ultimate strength values, and for a long time the compressive strength has been considered the only indicator for durability. Currently, control of durability is being realized by means of requirements of minimum values of strength, cover thickness, time of curing and restrictions of constituents and mix proportions [1]. However, these parameters are not completely valid for ensuring the long-term performance of the concrete because they neither take into account the chemical and physical changes of the concrete due to the penetration of aggressive external agents nor the influence on the rate of intrusion of these agents. Therefore, studies of other properties of the concrete related to its permeability have to be considered.

The permeation characteristic of concrete is one of the most important factors affecting the service life of a concrete structure. The relationship between permeability and porosity of hardened cement pastes has been discussed in the literature [2–5]. Depending on the pore structure, the environmental agents could penetrate more or less easily. Permeability in cement pastes appears to depend mainly on pores that have diameters greater than 0.132 μm [3], even though the shape and interconnection also play a leading role. For instance, the pastes of blended cements have a lower permeability than those of Portland cements, although they show a greater porosity [6]. This seems to be a consequence of the blocking of the narrow connecting pores by means of dissolution, transport and precipitation phenomena [7]. Apart from the porosity of the cement paste in the concrete, it is also necessary to take into account the presence of aggregates, which are sometimes not randomly distributed, and the transition zone between these and the cement paste.

Summing up, it can be deduced that a direct correlation between porosity and permeability in concrete remains uncertain and, therefore, the direct measurement of the permeability is nowadays the most reliable method of assessing this property. In particular, the permeability of the concrete cover to CO₂, air (oxygen), chlorides and water is critical for problems related to corrosion of reinforced concretes, while for bulk concrete air permeability is especially important, for nuclear containment vessel applications, for example.

Several types of fluids have been used to measure concrete permeability: water, salt solutions, oils, air, oxygen, carbon dioxide, water vapour, and so on [8–10]. The disadvantage of water and water solutions lies in the possible reaction with the solid, reducing the actual permeability. On the other hand, gas permeability tests strongly depend on the moisture content of the sample, and therefore, the concrete is usually preconditioned. This process involves prior drying of the specimen; the manner in which this operation is performed has an appreciable effect on
the outcome of the tests [6,11]. Thus, measuring permeability with gases is more delicate than testing using water as a permeable fluid.

The microstructure of the concrete may be altered during the preconditioning process producing microcracking and damage of the C–S–H sheets when it is subjected to an energetic drying. Various preconditioning methods have been proposed to avoid extreme drying such as solvent replacement or freeze drying, for instance [12]. The differences in permeability due to the type of treatment are ascribed to the transformation of the fine-pore structure into a coarser one due to the tensile stresses resulting from the water meniscus [6,13]. Besides, cracks can be induced, thereby promoting an increase in the permeability coefficient. Since reinforced concrete structures kept in a natural environment, not immersed in water, at least partly undergo drying, microcracks will form in the cement matrix and will contribute, together with the capillary pores, to determine the concrete permeability. Microcracking is also induced by the action of external forces [14] and heating gradients [15]. A drying conditioning that does not induce crack formation can only be obtained under controlled laboratory conditions. It is therefore necessary for technical applications to know how the concrete will behave under actual conditions, that is, its ability to crack. For the moment, only a few studies have been carried out on the air permeability of microcracked concrete [16].

In the present work, an air permeability test procedure is presented as a reliable method to assess the durability of the concrete. This is because of its relationship with the microstructure, and hence relates to the ingress of aggressive external agents. The objective of this paper is to demonstrate the importance of the ageing of the concrete on the air permeability as a consequence of the internal changes of moisture and microstructure, forming gradients from the surface layer to the bulk concrete. The significance of the research presented in this paper lies in the systematic study over 20 years (1965–1985) of air permeability measurements and the reliability of the testing method for technical applications.

2. Experimental procedure

2.1. Materials

An ordinary Portland cement P-350 was used whose average chemical characteristics are given in Table I. All the materials employed followed the Spanish Standard PCCH-64 [17].

2.2. Mix design

Six slabs with a water/cement ratio of 0.37 were made with the mix design shown in Table II. The dimensions were $200 \times 1000 \times 1000$ mm$^3$. This means that 0.2 m$^3$ of concrete were placed in each mould. The casting was done in two layers and the mass was vibrated with a poker vibrator working at 9000 r.p.m. The specimens were cast in moulds made of steel (passing sides) and wood (lateral sides and bottom).

![Figure 1](image-url)  

**Figure 1** Air permeability apparatus: (1) compressor of 10 kg cm$^{-2}$ of maximum pressure; (2) and (3) metallic manometers of 8 kg cm$^{-2}$; (4) compressed air reservoir; (5) pressure gauge “Billman” type PD38 (AP from 3 to 8 kg cm$^{-2}$); (6) safety valve set at 4 kg cm$^{-2}$; (7) 1/2 inch intake valve; (8) relief valve; (9) metallic manometer of 5 kg cm$^{-2}$; (10) 1/2 inch intake valves; (11) connecting nuts 3/8 inch SAE; (12) connecting nut 1/2 inch SAE; (13) solenoid check valve “DANFOSS” type EVJ 10–220 V; (14) inlet pressurized air cell; (15) outlet air cell; (16) connecting nut 3/8 inch SAE; (17) mercury thermometer; (18) Cylinder with a piston containing the outflow (50 cm height and 12 cm diameter); (19) manometer U-type; (20) safety valve (set at 2.5 kg cm$^{-2}$); (21) relief valve; (22) metallic manometer of 3 kg cm$^{-2}$; (23) connecting nuts 3/8 inch SAE; (24) manometer U-type; (25) Electrical control system of inlet air pressure.

The 28 days compressive strength was about 40 MPa in $\Omega 15 \times 30$ cm cylindrical specimens. The specimens were placed in a test room of $33 \times 13 \times 7$ m$^3$ which was sheltered from rain. The hydrothermal conditions of relative humidity and temperature ranged between 40–70%, and 15–25 °C, respectively.

2.3. Testing procedure

An experimental device was designed to measure air permeability in concretes. Fig. 1 shows schematically the equipment used. The device is composed of two metallic cells placed at each side of the specimen. In the first one having 1501 capacity, inlet air is held at the chosen pressure by means of a compressor and a precision pressure regulator. In the second one of 101 capacity, the passing air is measured at atmospheric pressure in a cylinder with a piston in which the outflow is collected. The air flow rate is measured