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Permeability interpretation for young cement paste based on impedance measurement

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HIGHLIGHTS

- The permeability of young cement pastes is evaluated using new impedance system.
- A fractal permeability model based on this measurement is proposed.
- The permeability value of cement pastes can be measured continuously.
- A fractal permeability simulation is conducted.

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ABSTRACT

This paper evaluates the permeability assessment of young cement pastes using innovative Non-Contact Impedance Measurement (NCIM). A fractal permeability model based on NCIM is proposed in this work. The permeability value of young cement pastes can be measured non-destructively and continuously with hydration by means of this model and NCIM. Furthermore, a fractal simulation is conducted to study the influence of porosity, minimal and maximal pore sizes on permeability. From the comparison of experimental and simulated results, the fractal model and simulation based on NCIM may provide an alternative way to evaluate the permeability of young cement-based materials in situ.

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1. Introduction

Permeability is defined as the property that governs the rate of flow of a fluid into a porous solid [1]. Measurement of permeability provides a means to evaluate the durability of cement-based materials [2]. Most of the permeability tests developed until now usually have complex test procedures, and permeability results often have high variability, from 10^{-24} m^2 to 10^{-16} m^2 (the unit of permeability mentioned in the paper is m^2), due to the disordered and complicated pore structure of cement-based materials [3,4]. In this work, permeability performance of young cement pastes will be investigated from Non-Contact Impedance Measurement (NCIM).

In permeability analysis, Katz–Thompson (K–T) equation seems to be a useful approach for the prediction of permeability value [5]. It is considered that intrinsic permeability of cement-based materials is associated with the square of the critical pore diameter and the formation factor. In this study, the critical pore diameter is obtained from mercury intrusion porosimetry; the determination of formation factor is with the help of NCIM [6,7]. Another conventional permeability evaluation analysis is the water penetration test, and thus, this test is also adopted to study the permeability performance of cement pastes in this paper.

In this study, a new NCIM has been developed [8,9]. This measurement system can modulate the frequency and amplitude domain of applied electrical stimulus through inductive components (transformer and leakage current meter), as shown in Fig. 1. A corresponding fractal model based on NCIM is established to study the permeability of cement paste and this model involves two fractal

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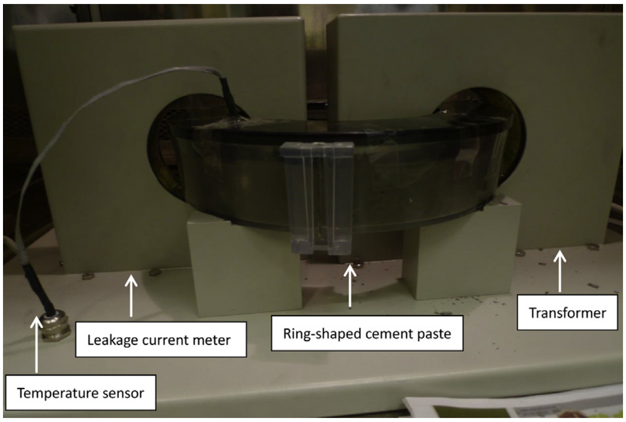

Fig. 1. Non-Contact Impedance Measurement (NCIM).

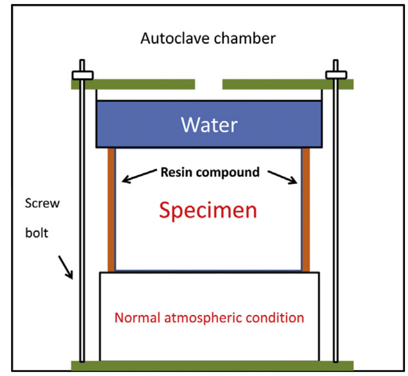

Fig. 2. Home-made permeability cell.

dimensions (D_f and D_t), specimen geometric parameters, minimal and maximal pore sizes. D_f can be derived from the combination of modified fractal electrical and pore structure networks. Besides, a fractal simulation is also proposed to illustrate the influence of porosity, minimal and maximal pore sizes on the permeability performance.

In addition, the comparisons of permeability results from NCIM and literature are conducted to further analyze permeability evolution with hydration time or porosity.

2. Raw materials and preparation procedure

In this study, Portland cement (ASTM Type I) was used to prepare cement paste with water cement ratios (w/c) 0.3, 0.4 and 0.5 by mass. The chemical composition of cement is shown in Table 1. Water used in the present study was de-ionized and de-aired. The paste was mixed in a planetary-type mixer at 45 rpm for 2 min first and then at 90 rpm for 2 min. The cement pastes were cured in the environmental chamber with temperature 20 °C and relative humidity 100% for 3 days.

3. Conventional permeability characterization

3.1. Permeability characterization by Katz–Thompson equation

In this work, the intrinsic permeability (K) of the cement paste can be determined through classical Katz–Thompson (K–T) equation [7]:

$$K = \frac{1}{226} d_c^2 \frac{1}{F} \tag{1}$$

where d_c is the critical pore diameter; F is the formation factor.

The test cement pastes were consistent with the ones previously described. The formation factor in Eq. (1) can be obtained from NCIM, according to Ref. [10]; while the critical pore diameter of cement pastes with hydration age of 1 day and 3 days, which is the most frequently occurring diameter in the interconnected pores that allows maximum percolation, is derived from differential distribution curve in mercury intrusion porosimetry (MIP) test [7,11,12]. This MIP test was performed according to Ref. [9].

3.2. Permeability characterization by water penetration test

The water penetration method is also adopted in this study in order to determine the intrinsic permeability of cement paste at 3 days. The test procedure is presented as follows [13,14]:

Table 1
The chemical composition of cement (wt%).

CaO	SiO_2	SO_4	Al_2O_3	Fe_2O_3	MgO	K_2O	TiO_2
65.41	19.47	5.72	3.86	3.21	1.58	0.50	0.25

(1) Cement pastes with water to cement ratio 0.3, 0.4 and 0.5 were cast as cylinders with a diameter of 100 mm and length of 50 mm. Three cylinders for each kind of cement paste were tested at the same time under the same operating conditions (temperature 20 °C and relative humidity 100%) for the calculation of average permeability value.
(2) The cylinders were put into the vacuum coating setup for further resin compound coating after demould [13]. A 3 mm thick layer surrounding the cement pastes was created to prevent the leakage from the sides.
(3) The cylinders followed by the mechanical polishing were assembled in home-made permeability cells, as shown in Fig. 2. One end of the cylinder was subjected to a pressure head while the other one was exposed in normal atmospheric condition. The permeability cells were tested in the autoclave chamber. About 120 g of de-ionized water was poured into the water reservoir on the top of permeability cells. The water penetration test was conducted under specific pressures for specific time duration.
(4) After removing specimens from the autoclave chamber, the gained weight of the cylinders was measured, and the specimens were subsequently split along the water penetration direction. Depths of water intruded were determined visually by the darkened boundary of the moisturized specimens.

The intrinsic permeability (K) from water penetration method can be further derived as [13,15]:

$$K = \frac{d_w}{2ht} \cdot \frac{M}{\rho_w A_w} \cdot \frac{\eta}{\rho_w g} \tag{2}$$

where d_w is the depth of water penetration; h is hydraulic head, which can be transferred from gas pressure inside the autoclave; t is time duration under pressure; ρ_w is density of water; A_w is the cross sectional area of the specimen for water penetration test; g is the acceleration due to gravity; η is the dynamic viscosity of water; M is the gained weight of specimen.

4. Permeability characterization by Non-Contact Impedance Measurement

4.1. Test system and test procedure

The Non-Contact Impedance Measurement (NCIM) has been invented recently [8]. Its working principle and corresponding test procedure can be consulted in Ref. [9].

The exact total volume (V_s), cross-section area (A) and equivalent length (L_e) of the ring-shaped cement paste in NCIM test can

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