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A new suction method for the measurement of pore size distribution of filter layer in permeable formwork

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HIGHLIGHTS

- A method for determining pore size distributions have been developed for filter layer.
- Results from three kinds of permeable formwork are analyzed and interpreted.
- The theoretical models for predicting the pore size distribution were discussed.
- There is a good agreement between the theoretical and experimental results.

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ABSTRACT

A water suction method for determining pore size distributions have been developed that is especially used for, but not restricted to, characterizing filter layer in permeable formwork. The laboratory method was presented for determining the distributions of pore sizes. The construction and the use of the apparatus are outlined. Results from three kinds of permeable formwork are analyzed and interpreted. The test results are compared with that obtained by the existing theories to predict the pore size distribution of nonwoven structures. The comparisons between measured and predicted pore size distributions confirmed the good accuracy of the Faure model.

1. Introduction

Corrosion of reinforced concrete structures is a major problem throughout the world, leading to significant costs of repairs and remediation. Changes to the bulk composition of concrete can be used to improve durability, but as the concrete surface itself is the first line of resistance to penetration of chlorides and carbonation, modifications to the surface zone itself may be more effective [1–3]. Permeable formwork is a special class of lined formwork intended to improve in the strength and durability of the concrete surface [4–7]. The bracing and the liner in the formwork are engineered to resist the pressure of plastic (or fresh) concrete, but to allow trapped air and excess water to pass through and be removed during concrete placement and consolidation [8]. The use of permeable formwork has shown to be able to eliminate surface defects such as scouring, inclusions and aggregate bridging, and to increase the strength and durability of the concrete surface layer [9,10].

A properly designed layer in the permeable formwork has an adequate discharge capacity for the life of the structure. There are three basic filter criteria which are used for the selection of a material for the filter: (i) a retention requirement, to prevent the migration of cement particles through the layer; (ii) a permeability requirement, to ensure the free flow of liquid through the layer; and (iii) a non-clogging requirement, to ensure the layer adequately meets the permeability and retention criteria. The ability of a filter layer to meet these requirements is primarily a function of the pore size distribution of the materials [11–14]. Despite the importance of the pore size distribution of the filter layer in the permeable formwork, there are few investigations into this aspect.

Perhaps the most obvious and direct way to measure the pore structure of filter layer is the image analyses [15,16]. This method can be successfully used for materials that essentially two dimensional but does not lend itself to the bulkier ones where filter thickness is many times that of the individual fibers within them. The

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dry sieving test is more commonly used because and ASTM standard (ASTM D 4751) [17] is available for this test method. The dry sieving test provides a direct way of measuring apparent pore sizes. However, recent studies have shown that the smaller pore sizes may impact the filtration performance of a material significantly. Therefore, a complete pore size distribution should be determined [18]. But the dry sieving test is far from providing a complete curve because the accuracy of the test for pore sizes smaller than 90 μm is questionable. A further method, used to look at the distributions of fine pores in soil, concrete and rock, is the mercury intrusion [19,20]. In this technique mercury is forced into pores under pressure and intrusion volume and pressure are measured. However, mercury intrusion requires very high pressures, which may significantly distort the pore structures of the filter medium. Mercury used in this technique is harmful to one's health and the environment. Finally, a method may be used whereby the amount of water extracted from a sample at various suctions is determined and this related, using surface tension principles, to the pore size distribution. This technique is commonly used to determine the water desorption characteristics of soils [21–23] and may be extended to indicate the pore size distribution of filter layer in permeable formwork.

This paper presents a recently developed version of the soil suction method, which, has two advantages over other methods for determining the pore size distribution of the filter layer in the permeable formwork. First, specimens are evaluated when wet as they would be in use. Second, a large number of pores are involved. In this paper, the test results for pore size distribution were also compared with that predicted by theoretical models.

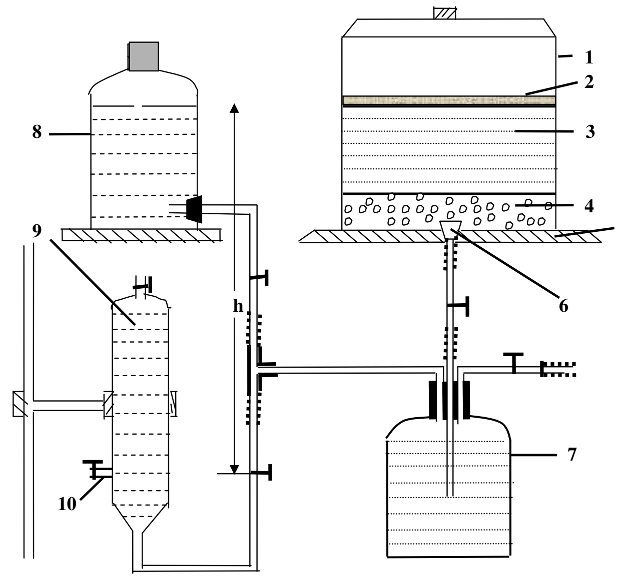
2. Experimental

2.1. Materials and sample preparation

Three kinds of commercial permeable formwork made in China were analyzed in this paper. The properties of formwork surface liners were detailed in Table 1. The fiber type used for permeable formwork is Polypropylene fiber. The fibers were obtained during extraction of line fiber. The cost-effective processing of such fibers into viable products requires an appropriate preparation. Fibers were shaken over a sieve table to remove other loosely attached. Nevertheless, it was difficult to eliminate them all by means of simple shaking. Therefore, fibers were thereafter pretreated in a fearnought, i.e., fiber opening machine, for initial cleaning, opening and separation, before subjecting them to mechanical cottonization so as to achieve the desirable fiber fineness and length distribution suitable for processing on needle-punching equipment. The following parameters were the same in each material: supply punching and 2.6 m/min for main punching, 15 m distance of plate for pre-punching and 25 mm for main punching, and 8 mm needle depth for pre-punching and 48 mm for main punching. For each type of material, three samples were prepared. The morphology of the samples was observed by scanning electron microscopy (SEM; JSM-6300, Tokyo, Japan) at 1 kV.

2.2. Principle of method

Suction cups were constructed using hydrophilic materials with fine pores. When suction is generated within the sampling system, water is sucked inwards out of the pores the cup until a corresponding capillary pressure occurs in the pores. If the capillary pressure in the suction cup is lower than that in the specimen, water flows from the material into the suction cup until the capillary pressure in the suction cup and in the material are equal. The use of pumps can possibly generate suction down to −90 kPa. In order to achieve such suction in the sampling system, no air must pass through the pores of the cups. For this, the diameter of the largest pore must not exceed a certain size. The maximum capillary pressure in a pore can be calculated by the following equation [23]:



Key:
(1) Sample chamber
(2) Sample
(3) Fine sand
(4) Coarse sand
(5) Support
(6) Drain system
(7) 500 cm^3 reservoir
(8) Water bottle
(9) Leveling bottle
(10) Air inlet

Fig. 1. Principle features of the sand sunction table.

$$p_c = \frac{2\gamma\cos\theta}{r} \quad (1)$$

where p_c is capillary pressure; γ is the surface tension; and θ is the contact angle; r is the radius of the pore.

This equation is valid for pores with a circular cross-section. The contact angle of water on soil particles is usually assumed to be 0°, which is the value of water on silicate minerals and glass [24]. However, the contact angle between water and most plastics is usually between 0° and 90°. In addition to the hysteresis between advancing and receding contact angles, contact angles that are greater than 0° on fibers are variable due to differences in exact chemical composition, trace contamination of the fiber surfaces, and surface roughness of the fibers [25]. The polymer fibers used in permeable formwork is polypropylene. And contact angle of polypropylene fibers that have been reported by Henry and Patton is 86° [25]. The surface tension of water at 20° is 0.072 N/m [22].

2.3. Testing system and test procedure

Sand (from −0 kPa to −10 kPa) and kaolin suction tables (from −10 kPa to −90 kPa) were used. The results obtained provide an assessment of the equivalent pore size distribution (e.g. identification of macro- and micropores). The principle of the sand baths relies on the application of a negative matric pressure to a coarse silt or a very fine sand held in a rigid watertight container. Constructing a flushable drain system from semi-rigid tubing to fit the floor of the container allows a 2 cm margin from the walls. Cement all joints with waterproof adhesive. Cut slits 1 cm long in the underside of the tubing at 1–2 cm spacing. Wrap the tubes in three layers of nylon voile. Fit tubing through the bung to the drain system and cement the bung into the sink outlet. Ensure that the drain system slopes upwards to a point

Table 1
Properties of formwork surface liners.

Sample ID	Mass/unit area (g/m^2)	Thickness (mm)	Tensile strength (N)	Break-off stretch (%)	Penetration resistance (N)
A	403.5	2.881	611.2	120.58	476
B	412.7	1.56	762.81	85.16	430
C	415.7	1.569	732.67	82.24	425