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A nondestructive method for evaluating the impermeability of mortar based on image processing

Zuguang Liu [a], Xuehui An [a,*], Shuyang Li [a,b]

[a] State Key Laboratory of Hydro Science and Engineering, Tsinghua University, Beijing 100084, China
[b] China Academy of Building Research, Beijing 100013, China

HIGHLIGHTS

- A new method to evaluate the permeability of mortar was proposed.
- Smart phone was used as the main instrument in the proposed method.
- An empirical formula to estimate the permeability of mortar was established.
- The proposed method can also be used to assess the effectiveness of water proof treatment.

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ABSTRACT

This paper proposes a new method, namely, the surface water-spray method, for rapid and convenient evaluation of mortar permeability. In this method, after sprayed a certain amount of water on mortar, the absorption process is recorded by smart phone and the water absorption rate of mortar is extracted by image processing. An index called K_{6th} is extracted as an indicator of the rate of water absorption. The mortar permeability test method as specified under the Chinese national standard also were conducted and the results of it are used as a reference. Several groups of experiments were designed and conducted. An empirical formula was established between the K_{6th} and the results of the standard method. Additional experiments were conducted to validate the results.

1. Introduction

The durability of structures is widely known as one of the most significant issues concerning the construction industry [1]. This is particularly relevant given the large annual global expenditure on repairing and maintaining structures [2,3]. A lack of durability relative to that anticipated is currently regarded as a matter that requires urgent attention [2,3].

The durability of structures is mainly determined by the permeability of cementitious materials. In general, concrete or mortar with lower permeability shows better resistance against chemical attack. Water penetration into mortar leads to corrosion due to some types of soluble salts [4–6]. Hence, an increase in the permeability and porosity of such materials is currently accepted as a reliable indicator of their degradation (at least on a qualitative level) regardless of whether it is of a mechanical or physicochemical origin, resulting from the cement matrix being attacked by aggressive products [7]. Furthermore, mechanical tests have shown that high compressive strengths must be confirmed by low permeability values as reliable indicators of concrete or mortar durability [8], as permeability is extremely sensitive to porosity changes and the micro-cracking phenomenon [9]. In summary, determining the permeability of these materials is essential to preventing degradation problems.

Various grades of concrete and mortar can be designed, manufactured, and tested in laboratory conditions in order to satisfy design specifications for different service environments. Researchers from different regions follow different standards, such as the Chinese national standard GB/T 50082-2009 [10], the British standard EN 123908-2000 [11], and the American Standard ASTM C6421997 [12], all of which facilitate the accurate direct evaluation of permeability in a laboratory. However, it is not safe to always assume that pre-specified permeability levels are achieved on site, as the ultimate engineering concrete/mortar properties are related not only to the materials, mix proportions, and service environments but also to factors that are difficult to control on site, such as manufacturing and delivery processes, as well as construction

* Corresponding author.
E-mail address: anxue@mail.tsinghua.edu.cn (X. An).

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practices adopted from initial placement to final curing [2,13,14]. As a result, cubes or cylinders manufactured in a standard manner do not represent the variations in the quality of concrete or mortar in the structure. Ideally, the correlation between performance assumptions and in situ construction quality should be considered.

Some approaches have been proposed for estimating the in situ permeability of mortar. These approaches can be roughly classified as destructive tests and nondestructive tests.

Although some nondestructive tests have been proposed for measuring the permeability of concrete or mortar on site, such as the AUTOCLAM water and air permeability test [15–17] and the Schönlin air permeability test [2,18], considerable efforts are being devoted toward developing a new method that is simpler and more convenient.

A new method based on a simple principle was proposed by Japanese researchers in 2013 [19,22]. The moisture content of certain construction materials influences the reflectivity of the surface [20]. Theoretical and experimental studies have shown that there is a correlation between the brightness and the moisture content of concrete surfaces [21]. Some researchers have investigated the brightness change process of the surface of a material after spraying a certain amount of water on the surface in order to evaluate the water absorption rate and strength of the material. Previous studies have shown that there is a correlation between the surface water-spray test indices and the concrete performance parameters such as concrete strength and chloride ion penetrability [19,22].

Against this background, the objective of the present study is to propose a method similar to the above-mentioned Japanese researchers [19,22]. The new method, namely, the surface water-spray test, only uses a few ordinary equipment. Meanwhile, the method is nondestructive, convenient, rapid, and is expected to be applied in situ. An empirical formula between the new method and the results of standard permeability test is built. the new method can be used to assess the permeability of mortar.

2. Theory

Mathematical descriptions of liquid flow in porous media are based on Darcy's law [23], which is usually expressed as

$$u = -K_S \nabla P, \tag{2.1}$$

$$K_S = k\rho g, \tag{2.2}$$

where u (LT^{-1}) is the flow rate, K_S (LT^{-1}) is the conventional saturated permeability of the material, ∇P is the hydraulic gradient, and ρ is the density of the liquid. Further, k is the Darcy permeability. Many scholars have confirmed that k is not constant in time[21]. It is clear that the permeability defined above depends on both the material and the fluid.

K_S represent the permeability of cement-based materials. For the same materials, K_S also represents the connectivity and the length scale of the percolating porosity, which is determined by the combined effects of water/cement ratios, curing time, and whether waterproof material is used.

In the surface water-spray test (SWST), the water absorption process is the diffusion of water in pores. Diffusion is normally assumed to follow Fick's law [23], the mathematical description of which is usually given by

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}\left(D\frac{\partial \theta}{\partial x}\right) \tag{2.3}$$

The liquid concentration in Fick's law is replaced by θ, which is the water content of the material. Further, D (m^2s^{-1}) is the hydraulic diffusivity. Many scholars regard D as the controlling material property [21,24]. Although the strong dependence of D on the water content presents difficulties in solving this equation, it can be qualitatively determined that, when the water content and temperature are constant, D is related to the pore structure.

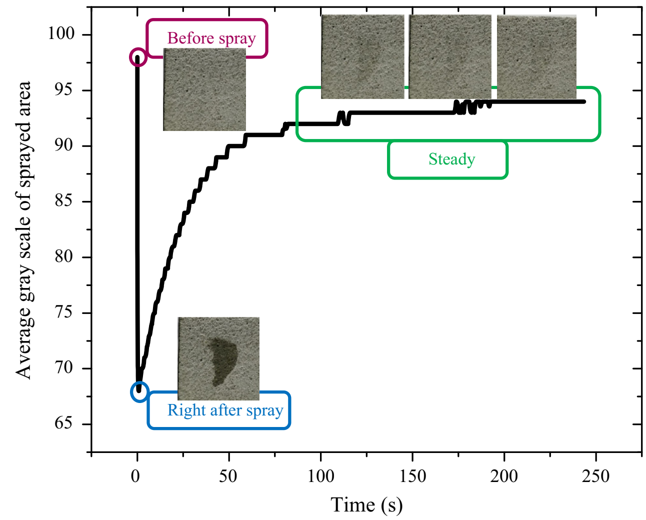

Fig. 1. Gray scale change process of sprayed area.

As discussed above, when the water content and the temperature are constant, both K_S and D are affected by the pore structure. Theoretically, there should be a correlation between the permeability and the water absorption rate of mortar when the water content and temperature are constant. In this article, a number of experiments were conducted to determine whether the two are related.

Since the moisture content influences the reflectivity of the surface, this principle can be used to detect the absorption performance of mortar by monitoring the absorption process. The mortar surface becomes dark after spraying. At this time, the gray scale of the sprayed area reaches the minimum value (convert color images to gray images). The surface of the mortar gradually becomes brighter with the absorption of water, and the gray scale of the sprayed area also increases with this process (as shown in Fig. 1). By monitoring the gray scale of the mortar surface, the absorption rate can be measured. Then, we can consider the water absorption index and the permeability index together to determine whether there is a correlation between the two tests.

3. Experimental programs

3.1. Materials and mortar mixes

The experimental programs were divided into two groups. The first group was used to validate if there is a relationship between two tests and establish the correlation between the permeability and the SWST. Mortar specimens with different permeabilities can be obtained by varying the water cement ratio and the curing period.

Table 1
Experimental cases of first group.

Case no.	Mixture ID	Water/cement	Fine aggregates/cement	Curing time (d)
1	M86D14	0.867	4.50	14
2	M86D28	0.867	4.50	28
3	M75D14	0.750	4.22	14
4	M75D28	0.750	4.22	28
5	M65D14	0.647	3.97	14
6	M65D28	0.647	3.97	28
7	M55D14	0.567	3.74	14