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Investigation on the properties of porous concrete as road base material

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HIGHLIGHTS

- Porous concrete is modified by suitable content of fine aggregate and fly ash.
- A linear interrelation between effective porosity and total porosity is matched.
- A power function between coefficient of permeability and effective porosity is fitted.
- The modified porous concrete has outstanding pavement performance.

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ABSTRACT

As a kind of materials applied in road base course, porous concrete is required to have satisfactory strength, permeability, dynamic stability, scouring resistance and volume stability. In this paper, properties of porous concrete modified with fine aggregate and fly ash were investigated comparing with those of several ordinary road base materials. The results indicate that fine aggregate can improve compressive strength and durability of porous concrete as road base material. Porous concrete, especially modified porous concrete with additional fine aggregate, has advantages over other road base materials on erosion and shrinkage resistance. The image processing analysis also demonstrates that fine aggregate enhances the conjoint point between the aggregates in porous concrete. And fly ash can significantly improve compressive strength and dry shrinkage resistance of porous concrete. Furthermore, the results demonstrate that the total porosity of porous concrete shows a linear relation to effective porosity, and a power function relation exists between permeability and effective porosity. This modified porous concrete can be used as road base course for the sponge city project and also highway.

1. Introduction

Every summer, heavy rainfall could overwhelm the drainage systems of most cities in south China. On April 2, 2015, sixteen cities in China have been identified by the central government to participate in Sponge City pilot projects (Fig. 1) [1]. As a kind of pervious material with a high proportion of macropores, the porous concrete has strong drainage and can recharge groundwater to supply water resources [2], therefore, it has promising application to pavement, sidewalk and level ground. In China, high volume and overloading vehicles require the highway to have a higher bearing capability. However, as prevalent type of road base material, the semi-rigid road base materials, e.g. cement stabilized granular materials or lime-fly ash stabilized granular materials, has not satisfactory anti-cracking and anti-erosion ability, so the water damage become one of the most common failures of highway. Porous concrete is studied as an alternative semi-rigid road base material which can drains out the water entering into the pavement structure to resolve the problem of water damage [3]. The physical and functional performances depend on aggregate and paste [4–7], and the main factors can be described as types and sizes of aggregate, method of compaction, replacement of coarse aggregate with sand and cement with supplementary cementitious materials (SCMs) [8–16].

The aggregate gradation of porous concrete is a key issue affecting its strength and permeability. Aggregate sized 9.5–12.5 mm results in higher strength of porous concrete than aggregate sized 2.36–9.5 mm at the same porosity because of a higher amount of

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Fig. 1. Schematic diagram of sponge city [1].

paste between conjoint points [2], while fine aggregate can improve the distribution of cement paste and thus enhance the compressive strength and the flexural strength [3,8,17]. In terms of permeability, larger aggregate makes the porous concrete form larger pores and achieve better connectivity thus better permeability [18,19].The type of aggregate also affects the performances of porous concrete obviously. Porous concrete prepared with air-cooling electric arc furnace slag and steel slag as aggregate can achieve better mechanical strength [8,20], while palm oil clinker substituting natural aggregate decreases the compressive strength and abrasion resistance irrespective of the curing [21].

Typically, the increase of cement paste implies the decrease in permeability coefficient [7,22,23]. Chindaprasirt et al. [24] used cement paste with flow of 150–230 mm to prepare porous concrete. Although high flowability cement paste improves the compactability of porous concrete mixture, it has a tendency of enriching to bottom and clogging the pores of the concrete.

Supplementary cementitious materials, chemical admixtures and fibers are often used in porous concrete. The research indicates that silicon fume particles easily concentrated over a small region, which could not realize the benefit of silicon fume [17]. Together with dispersion agent, silicon fume obviously improves mechanical properties and durability of porous concrete [13,17,25]. High-strength (32–46 MPa) porous concretes were prepared by adding silica fume, superplasticizer and polymer [26]. Furthermore, with smaller sized aggregate used, much higher strength porous concrete is obtained [13,27]. Reasonable content of rice husk ash could enhance the compressive strength and tensile strength. While not all of pozzolanic material can be used as sumpplementary cementitious material to improve porous concrete, the mechanical properties of the porous concrete marginally decreased with the increased content of trass and zeolite [28,29]. Latex, polymer and fibers can efficiently improve the mechanical properties and freeze–thaw durability [30–35], and fibers also can reduce mass loss in Cantabro and suface abrasion [34,35].

The voids content of pervious concrete is usually 15–35% [36], and as drainage materials, the interrelation between the porosity and permeability is an important issue to the material design of porous concrete. Neithalath [10] has studied porosity and pore structure of porous concrete with different sized aggregate. Literature 37 provides a method to predict the permeability of porous concrete [37]. Martin III [38] considers that coefficient of permeability calculated by vertical porosity distribution is more precise than that calculated by average porosity. Permeability predicted by Katz-Thompson equation has a higher value than permeability experimentally measured by Sumanasooriya [39]. Some researchers obtain more apparent relationship of porosity and permeability [40–42].

In this study, a type of porous concrete modified by fine aggregate and fly ash was prepared as road base material. The properties and performance of this road base material were investigated comparing with several ordinary road base materials. Simultaneously, the regression analysis on the relation between porosity and coefficient of permeability was studied based on 278 specimens. The pavement performances of this porous concrete were evaluated and the modification mechanism was interpreted with image analysis.

2. Experiment

2.1. Materials

A commercial Ordinary Portland Cement P.O 32.5 and fly ash (FA) were selected as cementitious materials to prepare porous concrete, and the properties are listed in Tables 1 and 2. Crushed limestone and diabase with various gradations were used as coarse aggregate in this research, sizes of which ranged from 2.36 to 26.5 mm. The whole kinds of coarse aggregate were used to study the relationship of permeability coefficient and porosity of porous concrete. One kind of limestone was selected to investigate the influence of fine aggregate and FA on the porous concrete and the properties of different road base materials, which gradation curve is shown in Fig. 2. The specific gravity of limestone was 2.72, and the dry-rodded density was 1633 kg/m^3. Artificial calcareous sand as fine aggregate mainly ranged from 0.06 mm to 4.75 mm in size, and its gradation curve is shown in Fig. 2.

2.2. Methods

2.2.1. Image processing analysis

The pore size distribution of porous concrete section was measured with image processing analysis. As shown in Fig. 3, firstly, digital photographs were adjusted to gray mode, thus the pictures were transformed to two-value division by Max variance, then contour tracking program was written to obtain independent pore image, eventually, diameters and areas of pores were measured and calculated.

2.2.2. Porosity

Total porosity is defined as the volume of closed and accessible pores. As shown in Eq. (1), the total porosity of porous concrete can be estimated using bulk density and theoretical density, and Zheng [43] has presented the equation to calculate theoretical density. The masses of oven-dry specimens (m_1) were weighed after they were dried at 60 °C for 24 h. The bulk volumes of specimens (v) were calculated with diameters and heights of samples measured with Vernier caliper. Effective porosity is the volume of accessible pores, which can be evaluated with Eq. (2) using the weight difference between a weight of oven dried specimen in air and a weight of water saturated specimen in water (m_2).

$$v_t = \left(1 - \frac{\rho_s}{\rho_t}\right) \times 100 \quad (1)$$

$$v_e = \left(1 - \frac{m_1 - m_2}{v \cdot \rho_w}\right) \times 100 \quad (2)$$

Table 1
Properties of Portland cement.

Properties	P·O32.5
Retained on 45 μm sieve (%)	0.6
Normal consistency (%)	26.0
Setting time (min)	
Initial	140
Final	195
Compressive strength (MPa)	
7-days	31.1
28-days	47.8
Soundness	Qualified