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Properties of pervious concrete made with electric arc furnace slag and alkali-activated slag cement

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HIGHLIGHTS

- The 28-d compressive strength of pervious concrete made with EAFS and AASC is 35 MPa.
- Pervious concrete made with AASC has a lower BPN than that made with OPC.
- Pervious concrete made with AASC has low-frequency absorption for 125–250 Hz.

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ABSTRACT

In this paper, the properties of pervious concrete made with electric arc furnace slag (EAFS) and alkali-activated slag cement (AASC) were investigated. It was found that the mechanical strengths of pervious concrete made with AASC were higher than those of pervious concrete made with Portland cement. The 28-day compressive strength for pervious concrete made with EAFS and AASC exceeded 35 MPa while its permeability was higher than 0.49 cm/s. The British pendulum number (BPN) for the pervious concrete made with AASC was lower than that made with Portland cement, which implied the pervious concrete made with AASC had a better anti-skid performance. In addition, the sound absorption ratio for the pervious concrete made with EAFS and AASC (void filled percentage of 90%, and aggregate size in the range from 0.24 cm to 0.48 cm) could reach 0.94 for low frequency noise (125 Hz).

1. Introduction

Pervious concrete is an environmentally friendly material in many aspects. Due to its superior permeability, pervious concrete is considered as a good alternative in flood control [1]. Pervious concrete is also beneficial in reducing the 'heat-island effect', which makes the temperature of urban area higher than that of suburban area [2]. In addition, pervious concrete can provide a better anti-skid performance in rainy days and better sound absorption capability [3].

Park et al. [4] studied the sound absorption properties of pervious concrete using recycled aggregate and various target void ratios. They reported the sound absorption characteristics of the porous concrete using recycled waste concrete aggregate showed that the Noise Reduction Coefficient (NRC) was optimum at the void ratio of 25% but the percent content of the recycled aggregate had very little influence on the NRC. Therefore, they concluded that the optimum void ratio is 25% and the recycled aggregate is 50%. Park et al. [5] studied water purification capability of pervious concrete. A porous concrete with a smaller size of aggregate and a higher void content was found to have superior ability of the removal of the total phosphorus and total nitrogen in the test water. They concluded this effect is due to the large specific surface area of the porous concrete.

For studying the mixture design of pervious concrete and the effects of aggregate size on mechanical behaviors, the following references may be helpful. Fu et al. [6] studied the influence of aggregate size and binder material on the properties of pervious concrete. Fu et al. [7] used the Taguchi method to study the design of pervious concrete. Crouch et al. [8] studied the aggregate effects on the static elastic modulus of pervious concrete. They reported an increased aggregate amount resulted in a statistically significant decrease in both compressive strength and static elastic moduli.

The following researches adopted waste to make pervious concrete. Gesoğlu et al. [9] studied the effect of adding three types of rubber to replace aggregates for pervious concrete. They found that the use of rubber significantly aggravated the pervious concrete mechanical properties and its permeability in different degrees according to the rate and type of rubber used. However, replace-

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ment of natural aggregate with rubber particles resulted in a significant increase of toughness and ductility of concrete as well as better damping capacity. Gesoğlu et al. [10] further investigated the effects of particle size and volume content of waste tire rubber on the flexural strength, abrasion and freezing thawing resistances of pervious concretes. Kuo et al. [11] used washed municipal solid waste incinerator bottom ash as a substitute for natural aggregate in pervious concrete. They reported that the split tensile and bending strengths were approximately 1/9 and 1/4 of the compressive strength, respectively. Cheng et al. [12] used recycled aggregate to make pervious concrete, and they reported that among their trials the optimal mixture was described as the followings: w/b = 0.35, nominal diameter for the recycled aggregate is 11.1 mm; the volume fraction for the binder is 0.5; and aggregate to cement ratio is 3.9.

To extend the use of pervious concrete, how to promote the compressive strength becomes an important issue. Fujiwara et al. [13] reported that a high strength pervious concrete could be made by coating the coarse aggregates with a high-strength mortar, then applying vibration to fuse them. Huang et al. [14] reported the properties of polymer-modified pervious concrete. They concluded that it was possible to obtain pervious concrete mixture with acceptable permeability and strength through the combination of latex and sand. Chindaprasirt et al. [15] reported that good porous concretes with void ratio of 15–25% and strength of 22–39 MPa were produced using paste with flow of 150–230 mm and top surface vibration of 10 s with vibrating energy of 90 kN m/m^2. Chindaprasirt et al. [16] also investigated the effects of aggregate size and cement paste strength on the compressive strength and void ratio of pervious concrete.

Generally speaking, pervious concrete does not have a high compressive strength since fruitful connected porosity exists inside it to keep high water permeability. Most pervious concretes have 28-day compressive strength lower than 21 MPa, which is the minimum required compressive strength for structural use. Most applications for pervious concrete are limited to parking lot pavement, pedestrian walkway, bike route and places where concrete compressive strength is not important. It is quite controversial for requiring the high permeability and high compressive strength at the same time. According to [17], three ways to increase the compressive strength of pervious concrete were suggested:

(1) Enhancing the characteristics of cement paste by decreasing the water–cement (w/c) ratio and adding pozzolanic materials such as silica fume.
(2) Adopting different cementitious materials such as epoxy.
(3) Applying slight pressure and increasing the temperature during the curing stage.

Recently, Yeih et al. [18] provided an alternative to improve the compressive strength of pervious concrete. They reported that cement paste could penetrate into the air-cooling electric arc furnace slag (EAFS) and formed a strong interlocking effect. Consequently, a pervious concrete with higher compressive strength but greater water permeability could be made. Based on this idea, in this article the pervious concrete made with EAFS and alkali-activated slag cement was investigated.

The alkali-activated slag cement concrete was known to have a stronger mechanical property than the ordinary Portland cement (OPC) paste although quick setting and a more apparent shrinkage were existing drawbacks. Some recent researches about the alkali-activated slag concrete were given in [19–24].

Although Yeih et al. [18] developed pervious concrete to meet the requirement of structural concrete (28-day compressive strength exceeds 21 MPa) and pervious concrete (permeability coefficient greater than 0.01 cm/s), pervious concrete with a higher compressive strength is required to be developed due to two reasons. First, the pervious concrete developed in [18] had a maximum compressive strength of 28 MPa only. Considering the possible degradation due to the differences between laboratory and in-situ conditions, pervious concrete with a higher compressive strength is still a goal for engineers. In addition to that, although for concrete with 28-day compressive strength exceeding 21 MPa can be used for pavement engineering a high traffic volume pavement or airport runway might require a higher 28-day compressive strength such as 35 MPa. According to these requirements, it is our goal to develop a pervious concrete system to have 28-day compressive strength exceeding 35 MPa and permeability coefficient higher than 0.01 cm/s at the same time. Based on this motivation, pervious concrete made with EAFS and AASC will be proposed here.

2. Experimental

2.1. Materials

Type I Portland cement was used. Another cement paste adopted the blast furnace slag with the following properties: (specific area of 405 m^2/kg, specific weight of 2.67. 7-day activity index of 76.6%, 28-day activity index of 103.3% and its major chemical components: 38.38% SiO_2; 17.46% Al_2O_3; 2.08% Fe_2O_3; 33.71% CaO; 5.52 MgO and 0.40% SO_3). The alkali-activator was prepared by mixing the sodium silicate and sodium hydroxide according to our previous research [25], and phosphoric acid was added to play as the retarder to inhibit quick setting. The details of the alkali-activator are stated in the follows: SiO_2 = 100 g/L; Na_2O = 100 g/L; H_3PO_4 = 0.74 M. Two aggregates, gravel and air-cooling EAFS, for the same size (0.24–0.48 cm) were prepared as the coarse aggregates. In [18], they reported aggregates with a greater size reduced the compressive strength of pervious concrete. Therefore, the smaller size of aggregates in [18] was considered. The properties of aggregates are given in Table 1. The chemical compositions of EAFS are tabulated in Table 2.

2.2. Mixture design

The idea of making the pervious concrete is first described in the follows. First, one can pack aggregates into a unit volume and check the initial porosity after packing. The values of initial porosities using different aggregates are shown in Table 1. These values represent the initial volume of voids after packing aggregates. Theoretically, this volume of voids then should be fully filled by the binding material for the conventional concrete design. However, for pervious concrete this volume is only partially filled by cement paste such that a significant amount of void volume exists to allow water penetration. In this study, different filled percentages of voids by binder (denoted as V) were selected as variables. Two different binders, the OPC and AASC, were adopted for this research. In order to have an easy comparison, for the OPC the water/cement (denoted as w/c) ratio of 0.35 was selected while for the AASC the Liquid/Slag (denoted as L/Sg or L/S) ratio of 0.35 was used.

Therefore, the variables considered here include the aggregate types and the filled percentages of voids by binder. Mix designs and the variables considered are tabulated in Table 3.

2.3. Specimen preparation

The pervious concrete specimens were made according to mixture designs in Table 3. Cylindrical specimens (diameter of 10-cm and height of 20-cm) were made for unit weight test, connected porosity test, water permeability coefficient and compressive strength. For the British pendulum test, concrete blocks with size of (5 cm × 10 cm × 2.5 cm) were made. For the sound absorption coefficient test, cylindrical specimens were made and the specimen sizes were determined according to the specification, which will be given in the next subsection. For each individual test for pervious concrete of a specific mixture, five specimens were made. Therefore, every data point represents the average value of five specimens. After

Table 1
Physical properties of aggregates.

Aggregate types	EAFS	Gravel
Label	A	B
Maximum aggregate size	0.48 cm	0.48 cm
Range of aggregate size	0.48–0.24 cm	0.48–0. 24 cm
Specific weight	3.44	2.69
Initial porosity (%)	40.75	37.5
Water absorption (%)	3	–