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Laboratory evaluation of permeability and strength of polymer-modified pervious concrete

Baoshan Huang *, Hao Wu, Xiang Shu, Edwin G. Burdette

Dept. of Civil and Environmental Engineering, The University of Tennessee, Knoxville, TN 37996, USA

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ABSTRACT

Pervious concrete has been increasingly used to reduce the amount of runoff water and improve the water quality near pavements and parking lots. However, due to the significantly reduced strength associated with the high porosity, pervious concrete mixtures currently cannot be used in highway pavement structures. A laboratory experiment was conducted in this study to improve the strength properties of pervious concrete through the incorporation of latex polymer. This study focused on the balance between permeability and strength properties of polymer-modified pervious concrete (PMPC). In addition to latex, natural sand and fiber were included to enhance the strength properties of pervious concrete. The test results indicate that it was possible to produce pervious concrete mixture with acceptable permeability and strength through the combination of latex and sand.

1. Introduction

Portland cement pervious concrete (PCPC), also referred to as porous concrete or permeable concrete, is a mixture of portland cement, uniform coarse aggregate, with either a small amount of or without fine aggregate, and water. Appropriate amounts of water and cementitious material are employed to create a paste that forms a thin coat around aggregate particles but leaves free spaces between them. Thus, pores are formed in the pervious materials [1,2]. PCPC has been used for over 30 years in many countries, especially in the United States and Japan. It is increasingly used in the United States because of its various environmental benefits such as controlling storm water runoff, restoring groundwater supplies, and reducing water and soil pollution [3–5]. In the meantime, it has the potential to reduce urban heat island effects and can be used to reduce acoustic noise in roads [5,6].

PCPC contains little or no fine aggregate, using an adequate amount of cement paste to coat and bind the aggregate particles together to create a system of high porosity and interconnected voids that can drain off water quickly. Generally, the void content of PCPC is between 15% and 25%, and the water permeability is typically about 2–6 mm/s [5,7]. However, relatively low strength is usually associated with the high porosity in PCPC. The low strength of conventional pervious concrete not only limits its application in heavy traffic highways but also influences the stability and durability of the structures, because of, for example, susceptibility to frost damage and low resistance to chemicals. Therefore, PCPC with low strength can only be utilized in some applications, such as sidewalks, parking lots, recreation squares and subbases for conventional pavement [8–10]. And with some effective improvement in strength and using smaller size aggregate, PMPC could be applied in pavement shoulder and local roads.

However, by using appropriately-selected aggregates, fine aggregates mixtures, and organic intensifiers and by adjusting the concrete mix proportion, strength and abrasion resistance of PCPC can be improved greatly [11]. Previous studies show that gradation, particle size of aggregate, and mass ratio of aggregate to cement are the primary factors affecting porosity, permeability and compressive strength of PCPC. Water cement ratio has a minor effect on properties of PCPC [12]. Using smaller size aggregate can increase the number of aggregate particles per unit volume of concrete, the specific surface of aggregate, and the binding area, which eventually results in an improvement in the strength of pervious concrete. Wang [10] used river sand to replace approximate 7% (by weight) coarse aggregate to improve the concrete strength. Their results indicated that the 7-day compressive strength increases from 9.6–14.5 MPa to 22.2–22.7 MPa. Although the void content is reduced due to the fine sand in the mixtures, all void content values are still within an acceptable range (>15%) for PCPC applications, and the permeability value is still higher than the minimum requirement to drain [10]. Yang and Jiang [11] showed that use of silica fume (SF) and superplasticizer (SP) in pervious concrete can enhance its strength significantly. The results also

* Corresponding author. Tel.: +1 865 974 7713.
E-mail address: bhuang@utk.edu (B. Huang).

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indicated that SF had a better effect for improving the properties of pervious concrete than polymer when used with SP. Their results indicated that the compressive strength of PCPC can reach 50 MPa and the flexural strength 6 MPa. At the same time, the requirements of water penetration, abrasion resistance can also be satisfied. Some fibers are helpful in improving the tensile strength and permeability of pervious concrete. Generally, the fibers in PCPC slightly increase the void content, significantly increase the permeability, and more significantly improve the splitting tensile strength of PCPC [10,13]. The addition of polypropylene fiber at 0.56% by volume of the concrete causes a 90% increase in the indirect tensile strength and a 20% increase in the flexural strength. Polypropylene fiber does not significantly affect the other mechanical properties [12]. Another effective method to improve strength is to use some chemical additives, such as polymer. Kevern [13] also presented that the addition of polymer (styrene butadiene rubber, SBR) significantly improves workability, strength, permeability, and freeze–thaw resistance, which makes pervious concrete obtain higher strength at relatively lower cement contents and results in relative higher porosity.

2. Research objective and scope

The objective of the present study is to evaluate the effect of polymer modification on the mechanical and physical properties of PCPC. The research efforts were made to balance the permeability and strength of the polymer-modified pervious concrete (PMPC) so that the mixtures are permeable and also strong enough to support traffic loading.

In this study, three types of single-sized limestone aggregates (12.5 mm, 9.5 mm, and 4.75 mm) were used, and one type of polymer (SBS latex) was considered to make the pervious concrete mixture. The properties of pervious concrete were evaluated through air void test, permeability test, compressive strength test, and split tensile strength test.

3. Laboratory experiment

3.1. Materials

Ordinary Type I portland cement was selected in the experiments. Three gradations of single-sized sieved limestone were considered as coarse aggregate: 12.5 mm, 9.5 mm, and 4.75 mm. The properties of coarse aggregate were measured according to ASTM specifications and listed in Table 1. The grain-size distribution of the river sand from the Tennessee River used in this study is shown in Fig. 1.

Latex polymer, styrene butadiene rubber (SBR), was selected and incorporated into the mixtures in order to improve the strength of pervious concrete. Styrene butadiene rubber (SBR) latex is a type of high-polymer dispersion emulsion composed of butadiene, styrene and water, etc., which is similar to natural rubber in its resistance to mild solvents and chemicals and, like natural rubber, can be successfully bonded to many materials. It is one of the popular raw materials in the tire dip fabric industry, because of its good intermiscibility with vinylpyridine latex for fabric dipping. For the application in engineering construction, it can be used to supply or replace cement as binder to improve tensile, flexural and compressive strength of concrete. The SBR used in this study is manufactured by anionic solution polymerization using an organo-lithium initiator. It is a product with medium styrene and high vinyl content. A white thick liquid in appearance, it has good viscosity with 52.7% water content.

In addition to latex, polypropylene fiber was also added into the mixture to further enhance the mechanical properties of PMPC. Polypropylene fiber has features and benefits as follows: inhibits and controls the formation of intrinsic cracking in concrete; reinforces against impact forces, reinforces against the effect of shattering forces, and provides improved durability. The polypropylene fiber was 100% virgin polypropylene fibrillated fibers containing no reprocessed olefin materials with an average length of 20 mm.

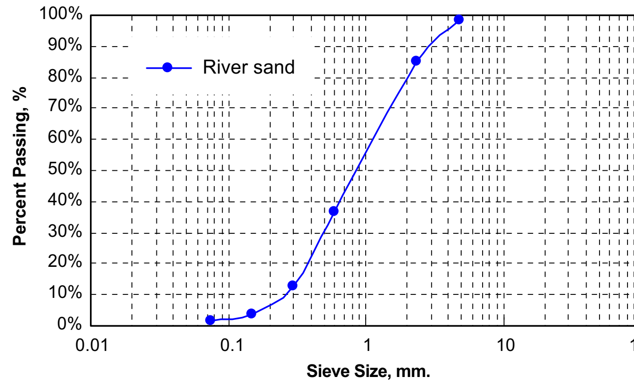

Fig. 1. Grain-size distribution of river sand.

3.2. Mix design

The control pervious concrete mixture was comprised of portland cement, water, and coarse aggregates of three gradations. To improve the overall behavior of PMPC, latex, fiber, and fine aggregate (natural sand) were selectively added into the mixture. The mix proportions are presented in Table 2. The basic mix proportion for the control mix is cement: coarse aggregate: water = 1:4.5:0.35 by weight. When latex and/or fine aggregate were included in the mixture, the solid portion of latex was used to replace 10% cement and natural sand to replace 7% coarse aggregate by weight. The performance and properties of PMPC were compared to those of the conventional pervious concrete.

3.3. Sample preparation

Pervious concrete mixtures were mixed using a mechanical mixer, and cylindrical specimens 152 mm in diameter and 305 mm high were made by applying standard rodding for compaction. The specimens were cured in a standard moisture curing chamber until the days of testing. Except for the compression test, the samples were cut into about 76 mm thick small specimens for other tests before testing. The specimens were prepared in triplicates.

3.4. Test methods

3.4.1. Air voids test

In order to obtain the air voids content, it is necessary to know the bulk volume of the compacted concrete. Since the pervious concrete has high interconnected air voids, it is not suitable to use the submerged weight measurement to obtain the bulk volume. Geometrical measurement of the specimen dimension will not reflect the surface texture (for different sized aggregates). A vacuum package sealing device, CoreLok, commonly used to measure the specific gravity for asphalt mixtures, was used to obtain the effective air voids for the pervious concrete specimens in this study. The test was conducted by following the ASTM D 7063 procedures.

3.4.2. Permeability test

Permeability is an important parameter of pervious concrete since the material is designed to perform as drainage layer in pavement structures. Due to the high porosity and the interconnected air voids path, Darcy's law for laminar flow is no longer applicable for pervious concrete. In this study, a permeability measurement device and method developed by Huang et al. [14] for drainable asphalt mixture (similar to pervious concrete in function) were used. Fig. 2 shows the specimen and device for permeability test.

Two pressure transducers installed at the top and bottom of the specimen give accurate readings of the hydraulic head difference during the test. Automatic data acquisition makes continuous reading possible during a falling head test so that the

Table 1
Properties of coarse aggregate.

Aggregate size (mm)	Unit weight (kg/m^3)	Bulk specific gravity	Apparent specific gravity	Absorption (%)	Void content (%)
12.5	1426	2.759	2.797	0.48	40
9.5	1393	2.758	2.801	0.56	43
4.75	1374	2.760	2.811	0.66	41