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Experimental investigation on freeze–thaw durability of Portland cement pervious concrete (PCPC)

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HIGHLIGHTS

- The deterioration characteristics of PCPC under freeze–thaw attacks are explored.
- Quantitative methods are proposed to characterize the freeze–thaw durability of PCPC.
- Laboratory molded PCPC exhibit superior mechanical performances than field paved PCPC.
- The relationship between field and laboratory produced PCPC is presented.

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ABSTRACT

Laboratory tests were conducted to evaluate the performance of Portland cement pervious concrete (PCPC) with a particular focus on freeze–thaw durability. The admixtures and modifiers such as air-entraining agent (AEA), ethylene-vinyl acetate (EVA) latex, and polypropylene (PP) fibers were considered in various mixtures to explore their influences on the performances of PCPC. In order to address the different behaviors of PCPC produced in field and laboratory, field specimens cored from experimental pavement sections were compared to the specimens molded in the laboratory, and appropriate quantification indicators were proposed in the study for the comparison. The test results showed that even with high porosities, a proper content of AEA added in the PCPC mixture could still improve its strength and increase its freeze–thaw durability to some extent. The mixture with latex modified could achieve much higher strength and better freeze–thaw durability due to the enhancement of interfacial bonding on the cementitious matrix. Apparent improvements on tensile strength and freeze–thaw durability were also observed for the mixture reinforced by PP fibers with various nominal lengths. In addition, the analysis of the relationship between field and laboratory produced PCPC showed that the pervious pavement paved in the actual field usually presented inferior overall mechanical performances than the PCPC produced in the laboratory, especially on the freeze–thaw durability. Therefore, a reduction coefficient should be considered when design a PCPC pavement and predict its performance with the standard laboratory methods that commonly used for ordinary concrete.

1. Introduction

Due to the open pore structure that allows high infiltration rates, PCPC has been increasingly used as an environmentally friendly material for pavements in urban areas [1–5]. The rapid drainage of water through the interconnected voids of PCPC pavements can not only minimize wet weather spray, improve skid resistance and visibility of pavement surface, but reduce traffic noise and heat island effect [6–10]. With the functions on pollution control and storm water management, pervious concrete pavements are considered a structural infiltration best management practice (BMP) by the U.S. Environmental Protection Agency (EPA) [1,11].

During the fabrication of PCPC, the open graded coarse aggregates are coated with a thin layer of cementitious paste, and when the coated aggregate particles bond with each other, a matrix with typical pore-structure is formed [12–14]. Due to the reduced contact area between neighboring aggregate particles associated with relatively low bonding strength, PCPC is more vulnerable to cracking, loosening and spalling under destructive stresses than

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ordinary Portland cement concrete (PCC) [15–18]. Accordingly, in addition to strength and abrasion resistance, another crucial concern about pervious concrete pavement is its durability to freezing and thawing attacks under harsh environments. Some researchers believe that because of the high permeability of pervious concrete, its pore structure could not be saturated with water, thus generally the freeze–thaw damage would not occur in PCPC. However, many practical cases demonstrated that due to its specific function of use and service conditions, pervious concrete under cold climate are even more susceptible to freeze–thaw damages than ordinary PCC, even in unsaturated or partially saturated conditions [19–25].

Furthermore, with increased serving time, the pores in the PCPC pavement could be gradually clogged due to accumulation of fines on the surface, which significantly decreases the infiltration rate of the pavement [26–32]. Fine particle deposition is typically a result from the wear of the pavement surface, or transport with wind and runoff from nearby disturbed soils. The pervious concrete with an effective pore-structure should be considered have sufficient voids for the movement of water and thus exhibit enough freeze–thaw resistance, but in many cases based on the survey results, infiltration rates of PCPC pavements could decline to 40–50% of its initial rate only after 2–3 years of placement [19,33,34]. Without special and timing surface treatment, precipitation on severely clogged pervious concrete would cause fully or partially saturated for its pore structure, and thus creating conditions for freezing and thawing damages. The relatively low bonding characterized by PCPC determines that once damages occur in the aggregate-paste-aggregate matrix, its pore structure would deteriorate much faster than that of ordinary concrete and cause large area distresses.

2. Research objective and scope

The primary objective of this study is to evaluate the deterioration characteristic of PCPC subjected to cyclic freezing-thawing attacks. The quantification criteria based on the mass loss (ML), relative dynamic modulus of elasticity (RDME), durability factor (DF), and relative durability (RD) were adopted or calculated as the indices for analyses and evaluations. In order to address the different behaviors of PCPC produced in the field and laboratory, comparisons were conducted on the specimens cored from experimental pavement sections and the specimens molded in the laboratory.

3. Experiment method

3.1. Materials and mixture design

Four mixtures were designed for both filed and laboratory produced PCPC in the study. The limestone with a grain-size distributed from 4.75 to 12.5 mm was used as the coarse aggregate. In order to achieve sufficient strength and gradation stability, a small amount of river sand (6% of the total aggregates by weight) was added in the mixtures as the fine aggregate. The grain-size distributions of the limestone and river sand used for the study are presented in Fig. 1.

Attempting to improve the strength and durability of PCPC, water-based ethylene-vinyl acetate (EVA) emulsion and monofilament polypropylene (PP) fiber were incorporated into the mixtures. The fundamental properties of the EVA latex and polypropylene fiber used in the study are presented in Table 1.

In addition, air-entraining agent (AEA) was also added into the mixtures as additives to understand its influence on the properties and freeze–thaw durability of the PCPC mixtures. The mix proportions for the pervious concrete mixtures are presented in Table 2. The water-cement ratio for all the mixtures was controlled as 0.25, and the dosages of AEA, EVA latex, PP fiber, and superplasticizer (SP) are 0.01%, 12%, 0.2%, and 0.25% of the cement, respectively.

3.2. Specimen preparation

Considering the current application situations, two compaction methods were considered in the study, one is the roller compaction method commonly used for PCPC pavements in the field, and the other one is the standard rodding compaction method used for the preparation of concrete specimens in the laboratory. A PCPC pavement (as a part of a low-traffic road) with several experimental sections was paved with a manual roller without vibration. The gravel base of the experimental pavement was about 200 mm in height, and the height of the pervious concrete surface was 100–120 mm. After placement, the pavement was sprayed with water and covered with thin plastic films to maintain a moist and humid environment for the concrete to cure. The field-cored specimens for testing were sawed from the pavement sections with a portable grooving machine. The air temperature during the placement and testing period was around 25–30 °C, and the relative humidity was about 80–85%.

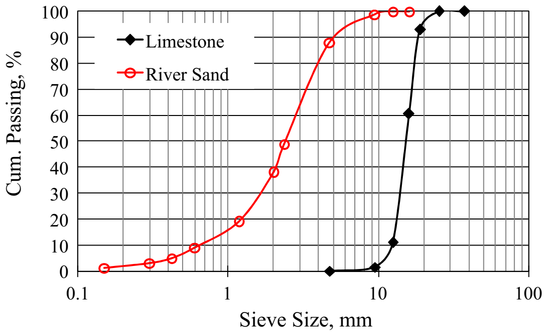

Fig. 1. Grain-size distributions of the limestone and river sand.

The laboratory produced PCPC specimens were molded with the standard rodding efforts in accordance with the Chinese specification GB/T 50081-2002 [35] in two layers (shown in Fig. 2). After molding, the laboratory specimens were all covered with thin plastic films for curing until the days for testing.

3.3. Effective porosity test

Effective porosity is one of the most crucial properties of PCPC, which is not only closely related to its service functions but also mechanical performances. In this study, the vacuum sealing method as specified in ASTM D7063 [36] was adopted to determine the effective porosity of pervious concrete. This method is commonly used to measure the interconnected air voids of compacted asphalt mixtures with high porosity, such as open graded friction courses (OGFC). It is reported that this method can also be effectively applied for pervious concrete due to its open-pore structure [12,17].

3.4. Strength tests

The ability of pervious concrete in resisting frosting damage is closely related to its bonding strength between cement paste and aggregate. In the study, strength tests were conducted on PCPC specimens by following the testing procedures specified in GB/T 50081-2002 [35]. Triplicate cubic specimens with side length of 100-mm were used for testing. Compressive strength tests were performed on the specimens at the 7, 14 and 28 curing days to understand the characteristics of strength growth. The splitting tensile strength tests were only carried out at the 28-day.

3.5. Freeze–thaw test

Cyclic freeze–thaw tests were conducted to determine the freeze–thaw resistance of pervious concrete mixtures referring to the Chinese specification GB/T 50082-2009 [37], in which specimens were subjected to repeated freezing and thawing cycles. Total 300 freeze–thaw cycles were conducted on the specimens. The specimens were measured every 25 cycles to evaluate the deteriorations caused by freezing and thawing attacks.

The mass loss (ML) and relative dynamic modulus of elastic (RDME) were measured to reflect the deterioration rate of the specimens under freezing and thawing cycles, and the durability factor (DF) and relative durability (RD) were calculated to evaluate their freeze–thaw durability. To obtain the RDME, fundamental transverse resonant frequencies of specimens were tested using a forced resonance apparatus. For the specimen with severe surface damages, the testing spots on the specimen need to be smoothed with epoxy resin or silica gel to maintain an even surface for testing.

The RDME of the specimen can be determined with the following formula:

$$RDME = (f_n^2/f_1^2) \times 100\% \tag{1}$$

where,

f_n = fundamental transverse frequency after n cycles of freezing and thawing;
f_1 = initial fundamental transverse frequency.

Based on the RDME, the durability factor, DF, can be obtained as follows:

$$DF = P \cdot N/M \tag{2}$$