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Influence of matrix and pore system characteristics on the durability of pervious concrete

Rui Zhong [a,*], Kay Wille [b]

[a] Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hung Hom Kowloon, Hong Kong
[b] Civil and Environmental Engineering, University of Connecticut, 261 Glenbrook Road, Unit 3037, Storrs, CT 06269-3037, USA

HIGHLIGHTS

- Freeze-thaw durability of pervious concrete with various matrix strength.
- Enhanced F-T behavior of high performance pervious concrete using ultra-high strength matrix.
- Hypothesis of crack initiation from micro pores in matrix, ITZ or macro voids.

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ABSTRACT

The application of pervious concrete (PC) is still limited primarily due to the three challenges it faces: limited strength, vulnerability to clogging and durability concerns. The last challenge is assessed in this research. Especially in the cold northern area where cyclic freeze–thaw (F-T) is not uncommon, it is necessary to understand the F-T performance and corresponding failure mechanism of PC. In this research, PCs varying in matrix type (normal strength matrix, high strength matrix and ultra-high strength matrix), pore system characteristics (void size and tortuosity) and fiber reinforcement (reinforced and non-reinforced) were proportioned. The influence of matrix, pore system characteristics and fiber reinforcement on the F-T durability of PC is investigated and potential F-T failure mechanisms are discussed.

1. Introduction

Pervious concrete (PC) is a class of concrete with a connected pore system allowing water to drain through the material. It positively impacts the environment through facilitating storm water run-off, water purification, heat island effect alleviation and tire-pavement interaction noise abatement [1–6]. These environmentally friendly properties have attracted renewed interest in this material.

Nevertheless, PC faces three major challenges: the limited strength, vulnerability to clogging and durability concerns due to the open pore structure. Because of these drawbacks currently the application of PC is still restricted primarily to parking lots and sidewalks where strength is not a determinant requirement. Extensive investigation has been conducted accessing the mechanical [7–14] and hydraulic [15–22] properties of this material. Recently, a high strength pervious concrete with compressive strength in excess of 50 MPa has been designed while pertaining its required hydraulic conductivity [23]. Research also proved that reduced hydraulic conductivity resulted from clogging can be restored approximately to its original status if proper maintenance is conducted regularly [24,25]. On the contrary, very few literatures are available with regards to the durability properties of PC [26–31]. This partially explains the limited application of PC in regions where cyclic freeze-thaw is not uncommon, such as Canada and the northern United States [32,33].

Although the F-T failure mechanism and methods to design F-T resistant conventional impervious concrete (CIC) are well known, their applicability to PC is still unknown due to the micro structural difference between CIC and PC. This research aims to explore the F-T failure mechanism of PC. The influence of different types of matrices (ultra-high strength matrix, high strength matrix and normal strength matrix), characteristics of pore system (void size and tortuosity) and fiber reinforcement (reinforced and non-reinforced) are assessed.

* Corresponding author.
E-mail addresses: rui.zhong@polyu.edu.hk (R. Zhong), kay.wille@uconn.edu (K. Wille).

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2. Mixture proportion and test set up

2.1. Mixture proportion

In order to investigate the influence of the matrix on the F-T durability of PC, three different types of matrices varying in water to cement ratio (w/c), compressive strength (f'_{c0}) and spread (Γ) were used. These matrices are designated in accordance to their compressive strength as normal strength matrix (NSM), high strength matrix (HSM) and ultra-high strength matrix (UHSM). The mixture design of UHSM was based on a previous research on the material design of ultra-high performance concrete (UHPC) [34,35]. Compressive strength and spread (see Fig. 1) of different matrices were tested in accordance to ASTM C109/C109-13 and ASTM C230/C230M, respectively.

Key properties of these matrices are summarized in Table 1.

In order to evaluate their durability properties their performance at the presence and absence of deicing agent was investigated. As deicing agent magnesium chloride solution with a concentration of 9% was used to simulate a scenario of extreme conditions. This concentration was selected by trial to maximize the potential chemical interaction between deicing chemical and matrix, and to ensure that the samples would freeze under the designed F-T conditions [36].

Table 2 summarizes the PC mixtures varying in matrix type, aggregate size and fiber volume fraction, which were used for F-T durability testing. The designation includes the matrix type (NSM, HSM or UHSM), the aggregate size (1.19 or 4.75), exposure to deicing salt (S) and the addition of fiber reinforcement (F). More detailed information regarding the sample preparation were reported in a previous study [7].

Table 3 lists the properties of PVC fibers used in this investigation.

2.2. Test set up

Specimens were cured under water at temperature of 20 °C for 14 days. Prior to testing, specimens were taken out of the curing tank and air dried at room temperature. The F-T test was conducted according to the ASTM C666-03 standard of which procedure A, rapid F-T in water was followed [37]. At the beginning of each test, specimens were submerged either in tap water or in magnesium chloride solution. The specimens were removed from the F-T test table (Fig. 2) in thawed condition at intervals of 30 cycles. After testing the fundamental transverse frequency (Fig. 3) the specimens were returned to the steel holder to positions according to the predetermined rotation schedule. This will ensure that each specimen is subjected to conditions in all parts of the F-T test table. Specimens were tested until reaching 300 cycles or until their relative dynamic modulus of elasticity (RDME) dropped below 60% of the initial modulus, whichever occurred first. The relative dynamic modulus of elasticity can be calculated by Eq. (1).

Table 1
Properties of different matrices.

Matrix Type	w/c	f'_{c0} (MPa)	Γ (mm)
NSM	0.55	29	220
HSM	0.45	61	240
UHSM	0.22	174	340

$$P_c = \frac{n_c^2}{n^2} \times 100 \quad (1)$$

where P_c is the relative dynamic modulus of elasticity (RDME), after c F-T cycles, n is the fundamental transverse frequency at 0 F-T cycles, and n_c is the fundamental transverse frequency after c F-T cycles.

3. Results and discussion

The influence of matrix, macro void system between aggregates and fibers on the F-T durability of PCs are summarized in Fig. 4.

The general trend describes an increase in F-T durability of PC with the increase of matrix strength and the decrease of aggregate size. Incorporation of a proper amount of fiber can improve the F-T durability of P-UHSM series but failed to enhance the F-T durability for P-NSM and P-HSM series. It is well known that the interfacial transition zone (ITZ) is the weakest part for conventional concrete where cracking initiates. This is also applicable for pervious concrete. In addition to ITZ, failure may also initiate from the macro pore system if the saturation condition of pervious concrete is in excess and the water in the pore system expands when it freezes. This induces pressure and cracking occurs. Therefore, the following two failure mechanisms of PC under F-T are hypothesized: I) micro-cracks initiate internally from the micro pores in the matrix and propagate outwards; II) micro-cracks initiate from the macro voids between aggregates and propagate towards the interface between aggregates and matrix. Fig. 5 schematically illustrates these two F-T failure mechanisms. The influence of the matrix type, characteristics of voids between aggregates and fibers on the F-T durability of PC is discussed in more detail in the following sections.

3.1. Influence of the matrix

Fig. 6 compares the effect of matrix type on the F-T durability of PC. In general, F-T durability of PC increases with increase in matrix

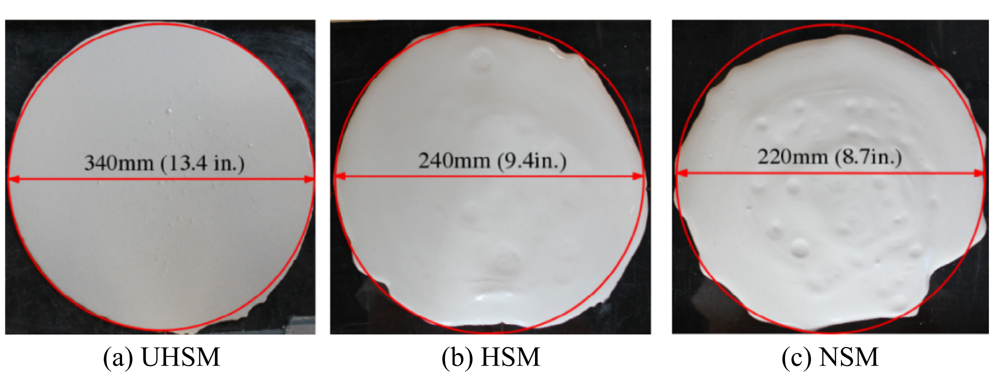

Fig. 1. Spread of matrices according to ASTM C230/C230M.