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Material design and characterization of high performance pervious concrete

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HIGHLIGHTS

- Development of high performance pervious concrete (HPPC) to advance and broaden the application of pervious concrete.
- Increase of strength and durability without sacrificing the hydraulic conductivity through tailored mix design.
- Use of ultra-high performance matrix for pervious concrete design.
- Material characterization regarding compressive behavior, hydraulic conductivity and freeze–thaw resistance.

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ABSTRACT

Continued urbanization and population growth further the growth of impervious urban areas, leading to concerning adverse environmental and societal impacts. Pervious concrete has remarkable potential to counteract these adverse impacts while providing necessary structural integrity, thus supporting continued urbanization. Broader application of pervious concrete could be achieved through increased raveling resistance and enhanced durability performance. This research emphasizes the development and characterization of high performance pervious concrete aiming at improved mechanical resistance and advanced durability properties. In pursuit of this goal an ultra-high performance cement-based matrix with compressive strengths in excess of 150 MPa (22 ksi) and high durability properties are designed and applied to the mixture design concept of pervious concrete. The research results show that compressive strength and elastic modulus increase by up to 150% and 100%, respectively, without sacrificing the hydraulic conductivity of the concrete. Furthermore, freeze–thaw tests have been carried out to compare the durability performance of conventional pervious concrete with high performance pervious concrete. Based on enhanced mechanical properties as well as improved durability, high performance pervious concrete potentially allows extending the application of pervious concrete and thus carries a vital potential in effectively counteracting the growth of impervious urban areas.

1. Introduction

By 2050 continued growth of population and urbanization will potentially add 2.5 billion people to the world's urban population [1]. This trend presses the extension of urban areas and accompanying impermeable surfaces. Pervious concrete (PC), also referred to as porous or permeable concrete, is a porous media which primarily consists of open-graded aggregates bonded by cement-based matrix. The connected pores, typically in the range of 15% to 30% per volume, "allow air and fluids to pass easily from the surface to underlying layers" [2] leading to the following features in comparison to conventional impervious concrete (Fig. 1):

Environmentally friendly potential combined with enhanced traffic safety [3–12] promotes pervious concrete as construction material for parking lots and road surfaces. However, broader application of pervious concrete could be achieved through mitigating the following three risks:

- Risk of clogging by organic and inorganic material reduces the hydraulic conductivity.
- Limited bond strength between the aggregates increases the risk of surface raveling, excessive cracking and wearing, leading to accelerated deterioration especially under high-volume and heavy load traffic.

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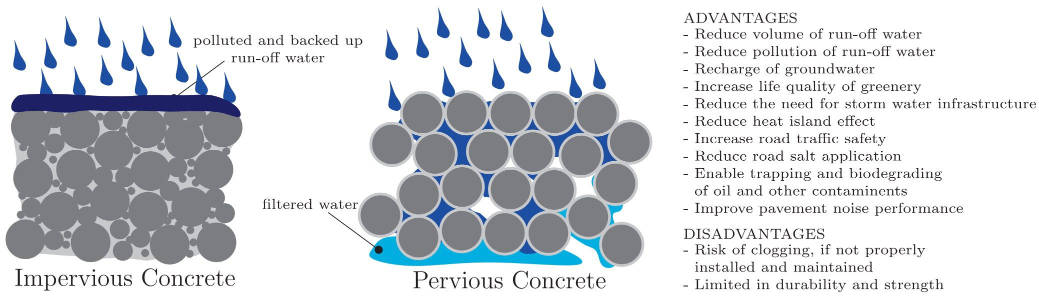

Fig. 1. Comparison of pervious concrete to impervious concrete.

- High proportion of material surface area exposed to environmental aggressors increases the risk of loss of structural integrity due to reduced durability.

Research on long-term surface permeability has shown that clogging particles asymptotically reduce the permeability, albeit to an infiltration rate still considered to be high [13]. Additionally research results point out that the loss of permeability depends on the clogging particle size to pore size ratio, leading to losses in the range of negligible to 80% [14]. On-site experience has also shown that clogging can be successfully minimized with proper material installation and maintenance using vacuum sweeping or pressure cleaning [15,16]. While clogging of pervious concrete becomes less concerning, its limited bond strength and durability properties remain an unresolved issue.

Motivated by the application potential of pervious concrete and the potential benefits of enhancing bond strength and durability properties, this research emphasizes the development of high performance pervious concrete.

2. Conceptual approach

The following principles are followed to design high performance pervious concrete (HPPC):

I. *Employment of optimized ultra-high performance matrix*. Ultra-high performance matrix (UHPM) is replacing conventional matrix to cover the aggregate and bind them together (Fig. 2).

Based on prior research [17] the incorporation of silica fume (SF) and ultra-fine silica powder (SP) in tailored proportion significantly improves the packing density of the fine particle system of UHPM. Fig. 3 illustrates the packing density of matrices of different performance levels.

II. *Enhanced interfacial transition zone (ITZ) between matrix and aggregate*. This is achieved through the incorporation of silica fume and the use of MPEG type polycarboxylate ether (PCE) based high range water reducer (HRWR). Silica fume densifies the matrix through pozzolanic reaction and filler effect (Fig. 4). MPEG type PCE is able to efficiently disperse the fine particle system due to its balanced affinity to cement, silica fume and silica powder [18]. This enables w/c ratio as low as 0.2 leading to densification of the microstructure.

III. *Balanced aggregate to binder (A/B) ratio and tailored aggregate size*. High performance pervious concrete (HPPC) aims at higher bond strength (indirectly evaluated by the compressive strength of the material) without sacrificing its functional requirement to allow water penetrating through. Higher amount of matrix (lower A/B ratio) leads to reduced total porosity and hydraulic conductivity but higher compressive strength whereas lower amount of matrix (higher A/B ratio) results in increased total porosity and hydraulic conductivity but lower compressive strength. Additionally, the aggregate size affects the pore system characteristics (total porosity, pore size and its distribution) and thus the compressive strength and hydraulic conductivity [19]. Therefore a balanced A/B ratio and tailored aggregate size are necessary to satisfy both of the competing performance criteria.

Other approaches, such as reduction in A/B ratio, incorporation of supplementary cementitious materials (SCMs), and addition of fine sand or polymer modification of matrix, are also employed

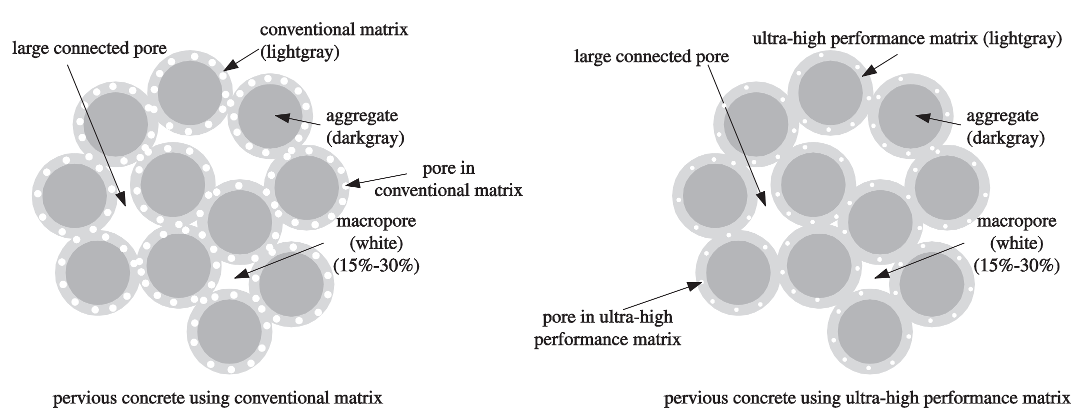

Fig. 2. Schematic comparison of pervious concrete employing different matrices.