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Preparation and performance evaluation of an innovative pervious concrete pavement

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HIGHLIGHTS

- High strength pervious concrete pavement based on reactive powder concrete.
- Solution of low strength, high likelihood clogging and inconvenient maintenance.
- Characteristics of high compressive strength and favorable permeability.
- Combination of efficient drainage and clogging-preventing in precast concrete pavement system.

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ABSTRACT

The low strength, high likelihood for clogging and inconvenient maintenance are three main challenges for the wider application of pervious concrete pavement. To overcome these challenges, a high strength pervious concrete (HSPC) pavement was designed and prepared by introducing reactive powder concrete (RPC) as the matrix in addition to constructing accessible pores. Optimized mix proportion of RPC and the porosity were also evaluated in the design and preparation stage. After successful production of HSPC, its performance (e.g. compressive strength, permeability) was evaluated via multiple mechanical and physical tests. As for the experimental results for HSPC, its 7 days compressive strength peaked at 61.37 MPa together with a 13.02 mm/s corresponding permeability coefficient, which indicates a favorable performance for wide application. In addition, referring to current technologies of prefabricated concrete pavement, (e.g., Miller super-slab system, Michigan system), a tongue-and-groove connecting structure was designed and fabricated in the pervious concrete. Finally, a drainage system was designed to exclude the clogging dusts in the pores of the HSPC pavement efficiently, where the clogging dusts were excluded from bottom to top. This innovative high strength pervious concrete has the potential to allow of a wider application of this material.

1. Introduction

Environmental issues, such as waterlogging, water pollution, atrocious climate and urban hot island phenomena, occur frequently and globally. The presence of impermeable pavement in highway and urban roads, which cuts off the moisture and heat exchange between earth and air, is one main reason for these environmental issues. Meanwhile, reported traffic accidents cause more than one million fatalities and nearly five hundred billion dollars' loss globally every year. The lack of water permeability in traditional pavement, which radically weakens the pavement's skid resistance under rain or snow, is responsible for traffic accidents. Unlike impermeable concrete pavement, pervious concrete pavement (PCP) provides better rain-drainage and snow-melting to prevent drivers' safety issues such as slippery, glare, mist and flood, under severe weather conditions. Additionally, the porous structure in pervious pavement can preliminarily purify the rain and serve as tunnels for atmosphere-pavement heat and moisture exchange, leading to positive environmental effects (maintaining water balance, relieving hot island phenomena and the protection of biodiversity, etc.) [1–4]. However, due to the high porosity, the two main types of permeable pavement (pervious concrete and permeable asphalt mixture pavement) are also suffering from several performance issues including concrete loose, pore clogging, lower strength and durability, and difficulty in maintenance. Besides physical and mechanical issues, asphalt oxidative aging

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fatigue, which is a chemical process relevant to porosity and pores structure, can significantly reduce the life span of asphalt mixture pavement as well [5–7]. Due to the deficiency in current pervious pavement technology, its application is limited to light loading constructions such as sidewalks, driveways, parking lots or residential streets. To utilize pervious concrete for heavier loading pavements and other relevant construction or transportation fields, demand for improved performance has increased significantly.

The term of Sponge City was introduced in China in 2012, which reflects the consideration of water absorption, reservation, permeability, purification and release. From that time onward, building more pervious concrete pavements as well as permeable asphalt pavements became more widely encouraged and practiced. However, it is very intriguing but challenging to overcome the performance bottlenecks of traditional pervious concrete pavement, especially on its low strength (28d's compressive strength hardly exceed to 35 MPa), high likelihood of clogging and inconvenient maintenance. The general methods to improve the strength of PCP are the optimization of aggregate quality [8–11], gradation [12–13] as well as the modification of binders by blending mineral and chemical admixtures [14–17] to strengthen the bond between the aggregates. Research on pervious concrete clogging is still premature, mainly focused on the pore characteristics and precipitates distribution [18–21]. Prefabricated concrete is believed to be an ideal solution for the difficulty in pervious concrete pavement maintenance. As a response to the demands of feasible maintenance for pervious concrete, the Strategic Highway Research Program 2 (SHRP2) includes the design, fabrication, installation and evaluation of prefabricated concrete as an important research objective [22]. Besides in the U.S., the investigation and application of prefabricated concrete also attracts researcher's attention from the Netherlands, France, Russian, Japan, etc. Recently, it was reported over 32 km prefabricated concrete pavement toll way was constructed in Indonesia.

In this research, reactive powder concrete (RPC, a developing composite material with characteristics of super-high strength, favorable toughness and durability) [23] is designed and manufactured to be the matrix of an innovative high strength pervious concrete (HSPC) pavement. Superior to the traditional technologies for pervious concrete preparation, this new method achieves water permeability by constructing physical interconnected pores for prefabricated pervious concrete, based on mortar-similar materials but no-fines concrete, so, this paper considers pervious concrete in its untraditional form. The objectives of this study are to overcome the obstacles in traditional pervious concrete such as low strength, concrete clogging and maintenance difficulty, aiming a solution towards safe, durable, widely applicable and environmentally friendly pavement design and construction.

2. Materials and methods

2.1. Materials

Ordinary Portland cement (P.O 52.5R, similar to Type III in ASTM C150-07 with a strength grade of 52.5 MPa) was employed to prepare the high strength pervious concrete. Silica fume (SF), fly ash (FA, Grade II) (selected as reactive powder, featured with pozzolanic activity) and U-type expansion agent (UEA) (which consists aluminum sulfate, aluminum oxide and aluminum potassium sulfate, with strong resistance to undesirable shrinkage) were selected as the mineral admixtures. A superplasticizer (water-reducing rate above 30%) was used to improve the product strength by reducing the water-binder ratio. River sand (passing through a square sieve size of 0.6 mm prior to use) was also used in this research. In addition, other additives including styrene-butadiene latex, silica sol and polypropylene fibers (PP) were applied, with the purpose to get favorable mechanical properties, especially toughness.

2.2. Methods

The process of high strength pervious concrete preparation can be described as follows (Fig. 1) and the steps are fivefold:

a) Materials preparation: In this step, the raw materials were prepared and weighted.
b) Model design: The pore size, arrangement and shape were designed as shown in Fig. 2. To meet the mechanical and permeable properties requirement of the sample, the pore size selected was 3 mm in diameter and there were four different types of layouts (3×3, 3×4, 4×4 and 4×5). The sample was prepared by apical plate and pore making components.

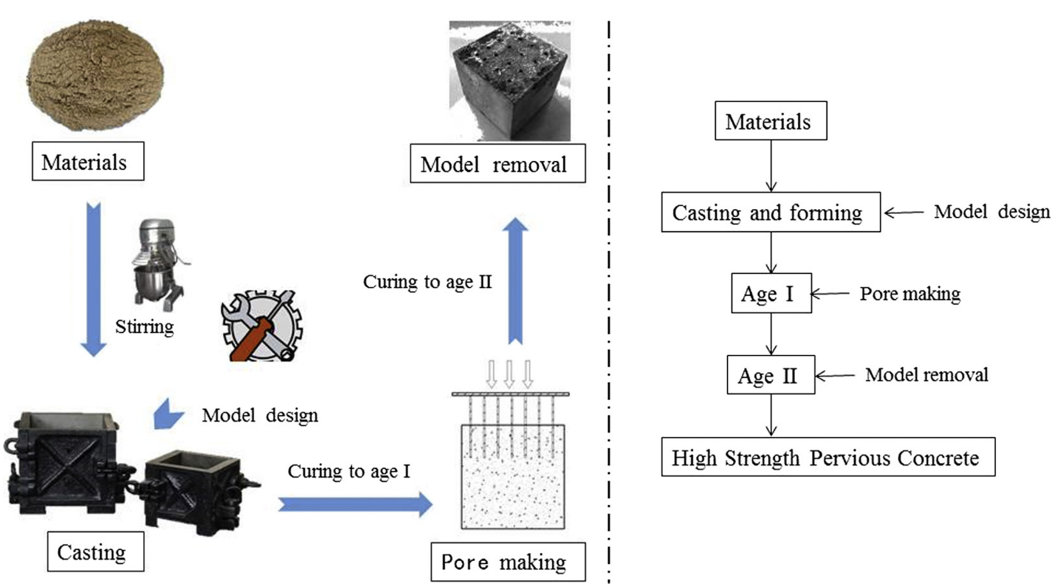

Fig. 1. The process of HSPC preparation.