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Experimental and Numerical Investigation on the Development of Pore Clogging in Novel Porous Pavement based on Polyurethane

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ABSTRACT: Permeable pavements are often affected by pore clogging, which leads to their functional failure and reduced service life. However, the clogging mechanism and its impact on the permeability and complex pore microstructures in pervious pavement remains unclear. The aim of current study is to quantify the clogging behavior in pervious pavement materials and carry out investigations on the development of pore characteristics and permeability. Novel Polyurethane bound pervious mixture (PUPM) were adopted for comparative study in present research with conventional Porous Asphalt (PA). The Aachen Polishing Machine (APM) was selected to perfectly serve as a simulator for clogging process of pavement in the actual service condition. The development of pore characteristics in terms of clogging was experimentally illustrated. The developed experiments and analysis can further strengthen the understanding of the clogging mechanism within the porous pavement material.

1 INTRODUCTION

In contrast to a natural plant-soil system, sealed road surfaces have lower specific heat capacity and higher solar absorptivity, which results in higher temperatures in urban areas surrounded by suburbs with lower temperatures. This phenomenon is called the Urban Heat Island Effect (UHIE) [1][2].

To address these issues, urban roads with functionalities that support a healthy environment can be constructed as pervious pavement material (PPM). Such systems mostly contain different layers of materials with porous structures (e.g. porous asphalt, porous concrete). In addition to serving as a traffic-bearing system, the PPM also fulfils other functionalities such as the absorption, storage, and evaporation of rainwater [3]. Compared to conventional pavement designs, the structure of PPM facilitates fluids flow through the porous material, thus reducing and controlling surface runoff. Common types of permeable roads include: Porous Asphalt (PA), Porous Concrete (PC) and Permeable Interlocking Concrete Pavement (PICP) [4].

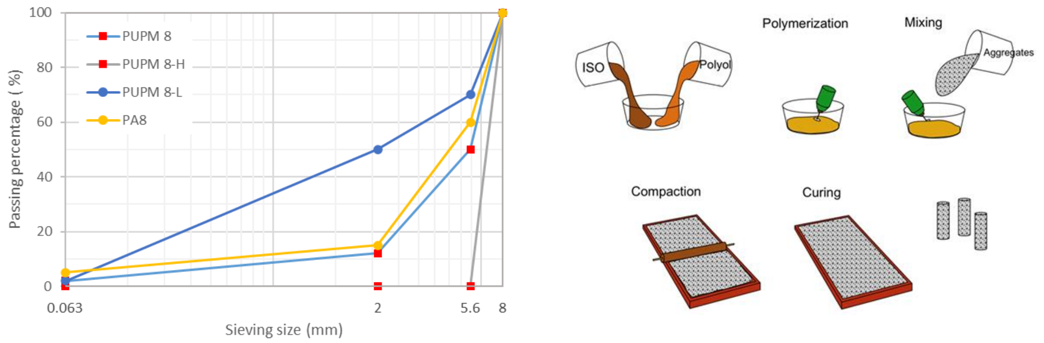
Polyurethane-bound pervious mixtures have demonstrated excellent functionality and more importantly good mechanical properties not exhibited by conventional PA mixtures. Additionally, PUPM has the advantage of being cleaner and more environmentally friendly. One of the reasons is that polyol is made up of organic oils. Furthermore, it’s production at ambient temperature reduces energy consumption for heating and CO2 emissions. Working conditions for laborers can be improved because the release of volatile organic compounds (VOCs) and smoke produced in mixing and placement of conventional mixtures is completely avoided [5].

However, as a porous pavement, the long-term service performance is greatly hindered by clogging characteristics [6]. Studies have been conducted by applying fine particles accumulating in the void spaces of porous pavements based on different watering methods [7]. Clogging is found to be highly correlated with the particle size and volume, the flow rate and pore characteristics of the pavement [8]. previous researches conducted were mainly focused on the observation of field measurement and the macroscopic laboratory experiments. The microscopic characterization on the clogging such as the development of pore characteristics, particles distribution and kinematic etc. are still not clarified. Additionally, most of the existing clogging experiments are based on modified permeameters by only changing the flow conditions, none of them can effectively simulate the clogging by considering the tires-road interaction. Hence, a mesoscopic study on the clogging mechanism in PPM must be carried out with a clogging test set up which can closer simulate to actual service conditions. A systematic understanding of the development hydraulic and clogging mechanisms within the PPM should be further established.

2 MATERIAL AND METHODS

2.1 *Material*

To investigate the pore characteristics of the PUPM, three types of the PUPM with different porosities were produced in this study: PUPM 8-H, PUPM 8, and PUPM 8-L, which denotes mixture with maximum aggregate size 8mm and high, normal, and low porosity level respectively. Conventional PPM, PA 8, was also selected as the reference material. The grain size distribution of all four chosen samples which were used in this study is illustrated in Figure 1, a and the manufacturing process can be seen in Figure 1, b:



(a) (b)

Figure 1 Grain size distribution of PUPM 8-H, PUPM 8, PUPM 8-L and PA 8

2.2 *Methods*

To simulate the clogging in the laboratory, a simulation based on the Aachen Polishing Machine (APM) was carried out, as shown in Figure 2 a. By the aid of the APM, pavement samples can be exposed to a real loading condition. For the clogging simulation in this study, sand, which has a grain size of up to 2 mm, was chosen as the clogging material. During polishing process, water was sprinkled on the surface of the specimens. In this way, the sand would enter the void of the sample with the water and the pressure of the tire. Each sample was processed for 4 different clogging periods: 20 minutes, 40 minutes, 60 minutes, and 80 minutes. These samples were then applied to the permeability tests and CT scanning respectively shown in (Figure 2 b and Figure 2 c).

(a) (b) (c)

Figure 2 Test methods: (a) APM test; (b) Permeability; (c) CT scanning

3 RESULTS

3.1 *Text and indenting*

During the permeability test of the specimens, the data were collected in 5 hydraulic heads (from 100 to 300 mm, 50 mm per level). In each level, four measurements for each specimen were obtained at the hydraulic head from 100 to 300 mm every 50 mm. Thus, 1200 data points were recorded and were then analyzed respectively. As can be seen in the following figure, the permeability coefficients at 300mm hydraulic head of the specimens during the clogging periods were obtained. The specimens PUPM 8-H with the highest permeability can conduct $1.x10^{-3}$ m/s of water. Followed by the PUPM 8 with the second highest permeability, and at the third position is the PA 8. In the figure, it can be recognized that the PUPM 8-L has the lowest permeability, with $3.x10^{-3}$ m/s.

For PA 8, the permeability of PA 8 decreased sharply once the clogging period started. In the first 20 minutes, the specimen's permeability sharply reduced from $1.08x10^{-3}$ m/s to $2.9x10^{-4}$ m/s, approximately 26% of its initial permeability. Conversely, during the same periods, the permeability of the PUPM 8 reduced slowly. Unlike the PA, the PU can perfectly cover the surface of the aggregates and provide a smooth surface for the aggregates. Therefore, the sediments can be easier caught in the PA specimen. The characteristic of the binder of the PA is, however, another influencing factor. Because of the high viscosity of the bitumen, the sediments tend to become attached to the bitumen. The flow behavior of the PA in the experiment is consistent with the previous study. After 20 minutes of clogging simulation, the permeability of the PA 8 decreases continuously and steadily. 60 minutes later, the permeability of PA 8 reaches the 7.5x10-5 m/s which can be classified as permeable. However, the initial permeability was highly permeable. In comparison with the PUPM 8 and PUPM 8-H, the permeabilities of PA 8 are nineteen to thirteen times lower than that of PUPM 8 and PUPM 8-H.

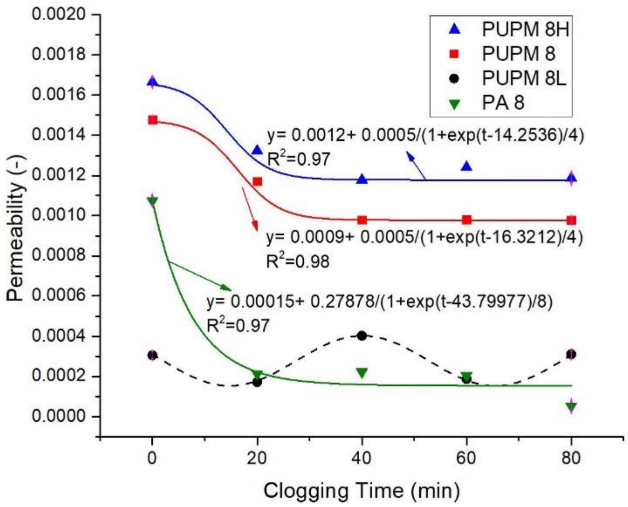
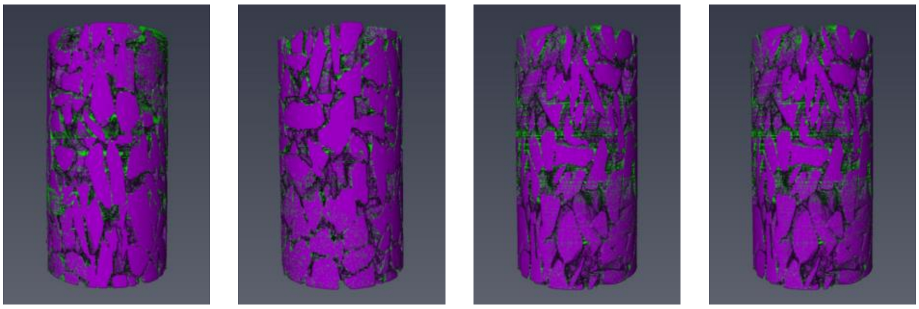


Figure 3 Constant permeability test

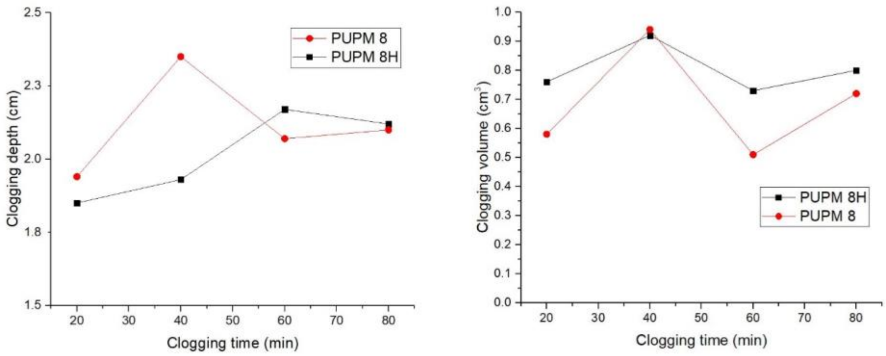
3.2 *Pore clogging characteristics*

By the aid of MATLAB and Avizo software, the aggregate, polyurethane binder and clogging mixture was successfully separated. Identically, 3D visualization and quantitative analysis were performed (in Figure 4), and volume and longitudinal distribution of the polyurethane and clogging mixture are calculated. The relevant results are shown in Figure 5 (a) and (b).



(a) (b) (c) (d)

Figure 4 3D visualization and clogging quantitative analysis



(a) (b)

Figure 5 (a) Depth of clogging center; (b) Clogging volume

According to Figure 5 (a) and (b), it can be found that the clogging depths of specimen center are generally increasing, which indicates that as loading time increases, clogging such as dust tend to be pushed in deeper. At the same time, volume of clogged mixture of two groups indicates fluctuation and local increasing trend, which suggest time interval might not be long enough or surface blockage might prevent more blockage from being pushed to larger depth. The reason why these two parameters do not show a strictly increasing trend might be that the gray level of mixture and the edge of the aggregate are too close, and more badly the interference of external light during the CT scanning process, resulting in some black backgrounds being recognized as part of the mixture, which is recommended to be improved in the test technology in the future test.

4 CONCLUSION

The current research focused on the novel method to meso-evaluate the clogging characteristics in PPM. PPMs including three types of PUPM and one PA were applied for the clogging and permeability experiments. Self-developed APM and X-ray CT were firstly utilized together to comprehensively analyze the development of pore characteristics in PPM by the consideration of clogging effect.

The research further strengthened the understanding of the development of pore characteristics and clogging mechanism, which laid the foundation for future material design optimization.

As can be summarized by the current research, the clogging has a significant influence on the permeability and pore characteristics of pervious pavement materials. To further understand the clogging mechanism, experiments under more loading conditions are highly recommended. Apart from it, the theoretical models and the experimental analyses of clogging mechanism should also be enhanced.

5 PREFERENCES, SYMBOLS AND UNITS

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