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Evaluation of durability and functional performance of porous polyurethane mixture in porous pavement

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ABSTRACT

Porous pavements bring significant benefits in traffic safety and noise reduction. This study aims to investigate durability and functional performance of Porous Polyurethane Mixture (PPM) as an alternative to Open-Graded Friction Course (OGFC) in porous pavements. Two-component polyurethane was used to prepare PPM with different binder contents and aggregate sizes. The anti-clogging performance of PPM was evaluated through clogging test and permeability measurements. The raveling resistance of PPM was evaluated using Cantabro loss test considering different temperature, moisture, and freezing conditions. The cooling and quiet effects of PPM were investigated using the measured temperature and rubber contact noise in the laboratory setup. The clogging test results indicate that the PPM has better resistance to particle-related clogging caused by filtration of soil suspensions as compared to OGFC. Similarly, the permeability testing results show that the PPM maintains high permeability during the rutting test at high temperatures; while the permeability of OGFC decreases significantly. The Cantabro loss test results indicate that the PPM with 6% polyurethane content and the maximum particle size of 9.5 mm shows much less raveling potential than OGFC at different testing conditions. The increase of polyurethane content and the larger aggregate size can improve raveling resistance of PPM. The internal temperature of PPM specimen is lower than that of asphalt mixture specimen and OGFC specimen under the same sunlight exposure. On the other hand, the PPM has the greater acoustic absorption than OGFC, especially for tire vibration noise.

1. Introduction

The pavement community is actively using sustainable pavement options, such as extending pavement life to reduce life-cycle cost and work zones, increasing usage of recycled material and industrial by-product, improving pavement surface characteristics for high skid resistance and low noise. Open-graded friction course (OGFC) has been commonly used in the surface layer of porous pavements to improve traffic safety at wet weather conditions and reduce tire-pavement noise (Liao et al., 2014). Due to the interconnected pores and large porosity, the primary safety benefit offered by OGFC is improved drainage, reduced splash and spray, and enhanced visibility of pavement markings (Colwill et al., 1993; Huber, 2000).

However, OGFC is prone to get clogged due to permanent deformation or by debris and dust, which causes the reduction of permeability and accordingly the degradation of safety and noise benefits (Hamzah et al., 2012; Chen et al., 2016). Field study has showed that the drainage time of OGFC layer increased from 25 to 75 s after construction to 80–100 s after three years and 160–400 s after nine years (Kraemer, 1990). It was reported that the permeability of OGFC decreased significantly after two to three years in service (Mallick et al., 2000). Field observations found that the clogging of OGFC in urban roads generally occurred in three to four years after construction (Nielsen et al., 2005). Another study found that the permeability of OGFC decreased from 113 ml/s to 30 ml/s after eight months of construction (Hu et al., 2010).

Recently, the Porous Polyurethane Mixture (PPM) has been used as a functional surface layer in porous pavements to reduce tire-pavement noise. The PPM is a special mixture that uses polyurethane to replace asphalt binder. Compared to OGFC, the PPM can have the higher porosity (up to 40%) that offers the greater drainage

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capacity and safety benefit. If rubber particles are used to partially replace aggregates, the PPM can provide the greater noise reduction performance than OGFC (Amundsen and Klaeboe, 2005; Sandberg and Goubert, 2011; Goubert, 2014). On the other hand, PPM brings the environmental benefit of reducing heating energy and CO_2 emission due to its production at ambient temperature. During the production of conventional hot-mix asphalt (HMA) including OGFC, aggregates and asphalt binder need to be heated to 150 to 170 °C for drying and mixing in the asphalt plant. It has been reported that the CO_2 emission in the manufacture process of HMA cannot be neglected in the life-cycle environmental impact of asphalt pavement (Wang et al., 2016a; Thives and Ghisi, 2017). In addition, the PPM can eliminate the release of volatile organic compounds (VOCs) and smoke produced in mixing and placement of HMA, which can improve working condition at asphalt plant and paving site. From this point of view, PPM is cleaner and more environmentally friendly as compared to OGFC.

Previous research has used one-component polyurethane to prepare porous mixtures and found that the mixture had good high-temperature deformation resistance, low-temperature cracking resistance, and moisture resistance (Sun, 2016). The tensile strength and noise absorption performance of PoroElastic road surface (PERS) made of polyurethane and rubber particles and concluded that it was suitable for urban roads in cold regions (Wang et al., 2017). In addition, it has been found that polyurethane mixture have better deicing and anti-icing performance than traditional asphalt concrete (Chen et al., 2018). The interface shear strength between polyurethane mixture and sublayer was measured when different sublayer mixtures and adhesive bonding agents were used (Liao et al., 2018). However, it is not clear that if the large air voids of PPM will be clogged due to dust or deformation during the service period of pavement. In addition, the raveling resistance of porous pavement should be examined that is affected by repeated traffic loading and environmental conditions (temperature, moisture, and freezing-thaw cycles). Therefore, the durability of PPM needs to be evaluated along with functional performance of porous pavement.

2. Objective and scope

This study aims to investigate the durability and functional performance of porous polyurethane mixture (PPM) as an alternative to traditional OGFC used as porous pavement surface layer. Two-component polyurethane was used to prepare porous mixtures with different binder contents and aggregate sizes. The anti-clogging performance of PPM was evaluated through clogging test and permeability measurements. The raveling resistance of PPM was evaluated using Cantabro loss test at different environmental conditions. The cooling and quiet benefits of PPM were investigated using the measured temperature and rubber contact noise in the laboratory setup. The durability and performance of PPM was compared to that of two traditional OGFC mixes with different aggregate gradations.

3. Preparation of testing materials

The polyurethane used in this study is two-component material system (A and B). The A component is isocyanate prepolymer (PM-200) and the B component is the mixture of polyether polyol and pentaerythritol. The mass ratio of A and B component was 32:68, which was determined by hydroxyl value of polyether polyol. After mixing, three-dimensional hybrid structure with covalent bonds between inorganic and organic phases was formed during the curing process (Rekondo et al., 2006).

It is noted that the curing time (pot life) of polyurethane varies depending on catalyst and temperature. Chemical analysis using Fourier transform infrared spectroscopy (FTIR) or differential scanning calorimetry (DSC) have been used for accurate determination of the degree of cure and cure time for polyurethane (Rath et al., 2008; Lee et al., 2015). Previous research used the rheometer to measure the resistance (torque) being the representative of viscosity during the curing process of polyurethane. It was found that the torques of two types of polyurethane started increasing rapidly after 25–30 min at 20 °C (Cong et al., 2018). Based on recommendations from the provider of polyurethane and laboratory trial tests conducted in this study, the curing time was found around 15 min when 2‰ catalyst (stannous isocaprylate) was used and the mixing temperature was 10 °C. If the catalyst was not used, the curing time was about 20 h at 10 °C and 15 h at 40 °C. The curing time increased as the mixing temperature decreased or the fewer catalyst content was used in general. Further study will be conducted to measure the changes of viscosity, functional groups, and heat release during the curing process of polyurethane for comprehensive evaluation of pot-life requirement.

The polyurethane content in the mixture was determined from the requirement of weight loss measured from Cantabro test, which is similar to the method used to determine the minimum amount of asphalt binder for OGFC following ASTM D7064. Fig. 1 shows the Cantabro loss amounts when the polyurethane content varies from 1% to 6%. The results show that the Cantabro loss is smaller than 20% when the polyurethane content reaches 5%. Therefore, the minimum content of polyurethane is determined to be 5%.

In the preparation of PPM, two different aggregate sizes (4.75–9.5 mm and 2.36–4.75 mm) and two polyurethane contents (5% and 6%) were used, respectively. Since the PPM is intended for use as road surface layer, relative small aggregate sizes need be used. The polyurethane and 2‰ catalyst was mixed with aggregates for 30–50 s and then compacted at 10 °C. The Marshall compactor was used for cylindrical specimen (100 mm in diameter and 65 mm in height) and the slab compactor for slab specimen (300 mm in length and width and 50 mm in height), respectively. The aggregate sizes, polyurethane content, and air void contents of PPM specimens are presented in Table 1. Fig. 2 presents the appearances of polyurethane and PPM prepared in this study.

On the other hand, two OGFCs with gap-graded mix designs, OGFC-10 and OGFC-13, were prepared for performance comparison with PPM. The aggregate gradation, asphalt binder content, and air void content used in the OGFC mixtures are shown in Table 2. The air void contents of OGFC specimens were around 20%, which were smaller than those of PPM specimen (30–35%).

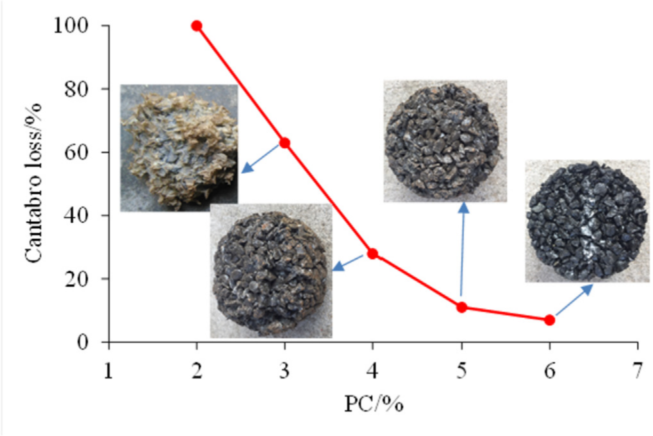

Fig. 1. Cantabro loss of PPM with different amounts of polyurethane binder.