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Design and laboratory evaluation of small particle porous epoxy asphalt surface mixture for roadway pavements

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HIGHLIGHTS

- One small aggregate size porous epoxy asphalt mixture was designed and evaluated.
- Small aggregate sizes in porous mixtures reduce permeability and rutting resistance.
- Epoxy asphalt can significantly improve the rutting resistance of porous mixtures.
- Porous epoxy asphalt mixtures may be designed to have good surface performance.

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ABSTRACT

To improve the smoothness and to increase the durability of pavement surface with porous asphalt mixtures, a small particle porous asphalt mixture modified with epoxy resin is proposed. This paper presents a laboratory study on the design and performance evaluation of small particle porous epoxy asphalt mixture. The mixture was designed based upon a binder drainage test and a raveling test. Mixture properties, including high temperature stability, low temperature crack resistance, moisture resistance, friction, and permeability, were evaluated in the laboratory. The results show that the proposed mixture has good mechanical properties while retaining satisfactory friction resistance and permeability.

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1. Introduction

The structural design of pavements is generally based upon the objective to provide a structurally sound pavement system that can sustain repetitive truck loading over its design life without excessive damage. From a roadway user's perspective, the more interested functions of a pavement are more related to its surface performance, including smoothness, safety, low noise, and good visibility of markings at night and during raining. These surface performance needs typically cannot be all met by dense-graded asphalt mixtures that are used as the structural layers of a pavement since they have low air-void contents. Instead, asphalt mixtures with high porosity, named as porous asphalt (PA) in Europe or open-graded friction course (OGFC) mixtures in the US, are generally placed at pavement surface as a wearing layer to provide the desired surface functions.

In the last few decades, PA or OGFC mixtures have been placed in many European countries, Japan, the United States, China, and other countries, mainly to improve pavement surface drainage during raining so as to reduce the risk of hydroplaning [1]. Due to their high air-void contents (around 18–25 percent), these mixtures have also the potential of reducing tire/pavement noise [2,3]. In recent years, several research efforts have been spent to revise the current OGFC mix designs, which are primarily aimed at high surface drainage, to specifically incorporate the needs of noise reduction, surface smoothness, and durability [4–6].

To provide a high surface drainage, the PA or OGFC mixtures typically use an open aggregate gradation with a relatively large nominal maximum aggregate size (NMAS) of 9.5 mm, 12.5 mm, 19.0 mm or even 25.4 mm and a target air-void content of 18–25 percent. Such design features are accompanied with a short service life, which was revealed in some field studies to be around 5–7 years [2]. One major distress form of these mixtures is raveling

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(disintegration of mixture and loss of aggregate particles) after a few years in service, due to stress concentration at the reduced aggregate contact area and aging of asphalt binders. Raveling leads to a rough pavement surface, which deteriorates the riding comfort and increases traffic noises. Efforts to increase the durability of the porous asphalt mixtures have been made in some practices, including using fibers in the mixture to allow more binders to be added in the mixture, using thermoplastic binder modifiers such as polyethylene (PE), styrene butadiene styrene (SBS), styrene butadiene rubber (SBR), and ethylene-vinyl acetate (EVA), and using asphalt rubber binders to improve the mechanical properties and durability of the binders. Application of these approaches has exhibited improvements in the durability of the porous asphalt mixtures. The improvements, however, are sometimes limited. For example, a recent survey of OGFC mix field performance in California revealed that use of asphalt rubber can increase mix durability (in terms of noise reduction and permeability) by two years compared to the use of unmodified binders [2]. Under some extreme environmental conditions (e.g., at very high pavement temperatures) or at locations with heavy slow loads (e.g., bus stop, long and steep climbing lane), these mix modification approaches may not be sufficient. Therefore, it is worthwhile to explore new asphalt binder modifiers for better bonding among aggregates and for a broader range of applicable traffic and climate conditions. One of the promising binder modifiers is epoxy resin.

Epoxy asphalt (i.e., asphalt modified with epoxy resin) is a thermosetting material. Before mixing, it is typically stored in two separate components: epoxy resin and curing agent/asphalt. Once the two components are mixed, they begin an irreversible chemical reaction that increases the stiffness and strength of the mixture. After curing, the mixture is not only tougher but also more elastic than conventional asphalt mixtures, and it does not soften as much as conventional asphalt binders at high temperatures. Epoxy asphalt was first used in the mid-1960s by the California Bay Bridge Authority to pave the steel deck of the San Mateo–Hayward Bridge in 1967, which has been performing extremely well [7]. Since then, dense-graded epoxy asphalt has been used exclusively to pave orthotropic bridge decks in the U.S., Canada, China, and other East Asian countries. Although its success on steel bridge decks, epoxy asphalt is generally not used widely on roadways, primarily due to the high cost of epoxy resin. Recent research on long-life wearing courses, however, has led investigators to focus their attention on the use of epoxy asphalt in porous asphalt mixtures [8,9]. Although the cost of epoxy resin is high, when its use in asphalt mixtures is limited to a certain level, the overall cost of constructing a pavement wearing course will not be significantly increased. Furthermore, from a life-cycle cost point of view, the increased material cost may be well justified by the extended service life.

Another approach that has been recently attempted to improve the durability of porous asphalt mixtures, particularly the durability of noise reduction, is the use of smaller aggregate sizes [10]. For current porous asphalt mixture designs that use a NMAS of 9.5 mm through 25.4 mm, raveling distress significantly increases pavement roughness and therefore the tire vibration related noise. Using small aggregate sizes in the mixtures may better retain the pavement surface smoothness, even when raveling occurs. However, using smaller aggregate sizes may also reduce the permeability and friction of pavement surfaces. These conflicting interests need to be evaluated carefully in the laboratory to reach a balance.

Based on the above background, it is worthwhile to investigate the properties and performance of porous asphalt mixtures with small aggregate sizes and epoxy asphalt binder. This paper presents results of such a study.

2. Objective

The objective of this study is to design a small particle porous epoxy asphalt (SPPEA) mixture and evaluate in the laboratory its pavement surface related performance, including high temperature stability, low temperature crack resistance, moisture resistance, friction, and permeability.

3. Experimental design

3.1. Materials and mix design

The experiment includes one aggregate gradation and one epoxy asphalt binder for the SPPEA mixture. The aggregate gradation, as shown in Fig. 1, has a nominal maximum aggregate size (NMAS) of 4.75 mm and was determined in a previous study [4]. For comparison, two common OGFC mixtures, OGFC-10 and OGFC-13 were also tested in the study. These two mixtures use larger aggregate sizes, as shown in Fig. 1 for their gradations, and common polymer modified binders. The aggregates were all produced from a basalt quarry located in Jiangsu Province, China.

The epoxy asphalt was obtained from a U.S. manufacturer who had supplied the same material to many steel bridge deck paving projects in China and the U.S.

The typical target air-void content of current PA or OGFC is around 18–25 percent. For the mixture in this study, considering the difficulty in forming a highly porous structure by the small-size aggregates, a relatively low air-void content, 20 percent, was selected as the target air-void content in specimen fabrication.

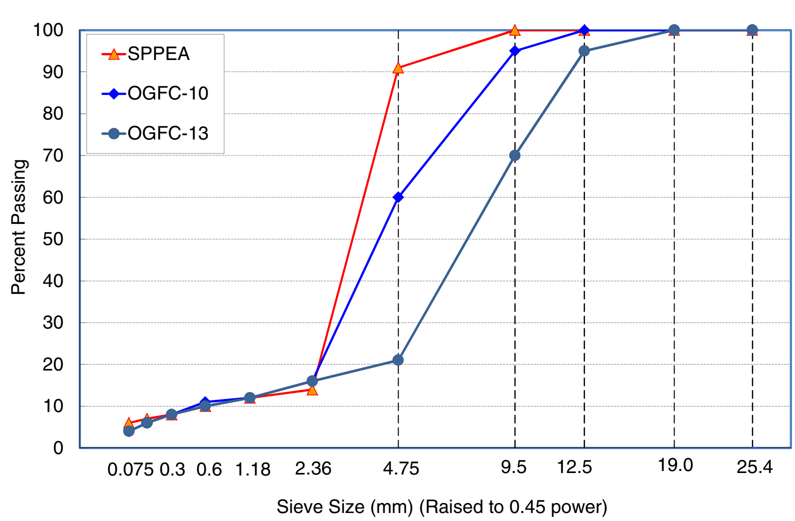

Fig. 1. Aggregate gradations used in the study.