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Performance evaluation of epoxy modified open-graded porous asphalt concrete

Sang Luo [a,*], Qing Lu [b], Zhendong Qian [a]

[a] Intelligent Transport System Research Center, Southeast University, No. 35 Jinxianghe Road, Nanjing 210096, China
[b] Department of Civil and Environmental Engineering, University of South Florida, 4202 E. Fowler Ave. ENC 3209, Tampa, FL 33620, USA

HIGHLIGHTS

- Superior overall performance of epoxy modified open-graded porous mix is proved.
- Epoxy asphalt can significantly improve the resistance to raveling of porous mix.
- Epoxy modified open-graded porous mixes have excellent resistance to rutting.
- Negative aspect of using epoxy asphalt is the high cost of the material.

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ABSTRACT

Open-graded porous asphalt (OGPA) mixes are applied to pavement surfaces to increase driving safety under wet conditions, and recently, to reduce tire/pavement noise. The durability of OGPA mixes, however, has been a concern since conventional OGPA mixes last typically less than ten years before major maintenance or rehabilitation is needed. This study investigates a new open-graded porous asphalt mixture that uses epoxy asphalt as binder to improve mix durability. One type of epoxy asphalt that has been successfully applied in dense-graded asphalt concrete for bridge deck paving was selected for this study. A procedure of compacting the mix into slab specimens was developed and a series of laboratory tests were conducted to evaluate the performance of the new mix, including Cantabro loss, permeability, acoustic absorption, indirect tensile, friction, shear stiffness and strength, and wheel rutting tests. Results showed superior overall performance of the epoxy modified open-graded porous asphalt mix compared to conventional open-graded porous asphalt mixes.

1. Introduction

Pavement surface properties have a direct impact on driver's comfort and safety. To improve the functional performance of an asphalt pavement, surface mixes are typically specially designed for sufficient surface performance in terms of friction, smoothness, permeability, and tire/pavement noise.

In the last few decades, open graded porous asphalt (OGPA) mixes have been placed in many Chinese provinces and US states to reduce the dangers of hydroplaning and poor visibility caused by splash and spray during wet weather [1]. Due to its high air-void contents and surface permeability, OGPA mixes can also reduce tire/pavement noise. The durability of the mixes, particularly with regard to raveling distress, and the long-term effectiveness of noise reduction, however, have been a concern as various studies have shown different results [2,3]. The structural integrity of the mix is significantly reduced by the high porosity, when compared to a conventional dense-graded asphalt mix. To increase the bonding forces among aggregates, thick asphalt films are desired and in many OGPA mix designs as much as possible asphalt binders are added into aggregates before causing excessive draindown or leakage of binders during construction. Sometimes fibers are used as additives in the mix to further increase the allowable amount of binders. Polymer modified binders or asphalt rubber binders are also often used to increase the structural integrity and durability of OGPA mixes. For example, a field investigation of OGPA mix performance in California, United States and Nantong, China revealed that the use of asphalt rubber binder instead of unmodified binder may increase mix durability (in terms of noise reduction and permeability) by about two years [4,5]. The added benefits of these approaches, however, are sometimes limited.

* Corresponding author. Tel./fax: +86 25 8379 2869.
E-mail addresses: luosangseu@gmail.com (S. Luo), qlu@usf.edu (Q. Lu), qianzd@seu.edu.cn (Z. Qian).

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Under some extreme environmental conditions (e.g., at very high pavement temperatures) or at certain unusual locations (e.g., bus stop, intersection, long and steep climbing lane), these mix modification approaches may not work. Therefore, it is worthwhile to explore more approaches to modify asphalt binders for better bonding among aggregates and for a broader range of applicable traffic and climate conditions.

Epoxy asphalt is a two-phase system in which the continuous phase is a thermosetting epoxy resin and the discontinuous phase is asphalt and curing agent. After curing, the material is not only tough but also elastic over the range of expected pavement service temperature. When mixed with dense-graded aggregates, the resulting mix will have a stiffness value between typical values of a conventional dense-graded asphalt concrete and a cement concrete. It has high stability and good resistance to cracking, rutting, and fatigue.

Dense-graded epoxy asphalt was first used to pave the steel deck of San Mateo-Hayward Bridge in 1967 by the California Bay Bridge Authority. The epoxy asphalt pavement on San Mateo-Hayward Bridge has been performing extremely well [6]. During the last two decades, it has also been widely on the long-span orthotropic box-girder bridges in China. Although having good properties for pavement use, epoxy asphalt is generally not widely used for roadways, primarily due to the high cost of epoxy and strict construction requirements, such as the allowable construction time window between end of mixing and completion of compaction is less than two hours for the type of epoxy asphalt most widely used in the US and China. The limitations on the wide application of epoxy asphalt on roadways can be alleviated by modifying the material compositional design of epoxy for a less expensive and less temperature susceptible product. Furthermore, at some unusual locations where a high-performance OGPA mix is needed, it may be economically feasible in the long run to use epoxy asphalt as the binder.

The use of epoxy asphalt in OGPA mixes has been tried and investigated in a few studies. The first application was in 1969 on the San Francisco-Oakland Bay Bridge (SFOBB), on which a 12.5 mm thick open-graded epoxy asphalt concrete was placed on a 14,400 m^2 test area of the west end of the upper deck of SFOBB [7]. This surfacing provided sufficient skid and hydroplaning resistance during rain and stayed in place until the entire bridge was repaved seven years later. A recent study completed in New Zealand revealed the superior resistance to oxidation and abrasion of an epoxy modified open-graded porous asphalt [8–10]. A limited accelerated loading trial using an indoor circular test track demonstrated that the construction of epoxy OGPA pavement does not need any significant modification to conventional plant, machinery or operating procedures [8]. In December 2007, two road sections at Belfast in Christchurch, New Zealand were paved with epoxy asphalt OGPA mix, with 20% and 30% air-void contents, respectively, and after over three years of dense traffic loading, these epoxy asphalt OGPA surfaces were found to be in good condition [9].

In the New Zealand laboratory study, the performance of epoxy asphalt OGPA mix was mainly evaluated in terms of indirect tensile modulus and Cantabro raveling potentials before and after accelerated oxidation using local greywacke aggregates. Other desired pavement surface properties, such as permeability, resistance to moisture damage, and resistance to rutting or reflective cracking, have not been well studied. With this background, it is worthwhile to further investigate the properties and performance of epoxy asphalt OGPA mixes.

This paper presents a laboratory study conducted to evaluate the pavement surface performance of an epoxy asphalt OGPA mix, as compared to a conventional OGPA mix and an epoxy asphalt DGAC mix.

2. Experimental design

2.1. Materials and mix designs

The experiment includes two aggregate gradations and two asphalt binder types. The aggregate gradations, as shown in Table 1, include an open-graded one (OGPA) and a dense-graded one (DGAC), both with a nominal maximum aggregate size (NMAS) of 9.5 mm. One PG 64-16 asphalt binder is used with the open gradation to form a conventional OGPA mix, while one epoxy asphalt is used with both gradations. The epoxy asphalt was obtained from a manufacturer who supplies epoxy asphalt products to most paving projects in the US and in China. The basic properties of the two components of the epoxy asphalt are shown in Table 2. One basaltic-volcanic nature aggregate was used for all three mixes.

Optimum binder contents (OBC) for the two OGPA mixes were determined following California Department of Transportation (Caltrans) Test Method (CTM) 368 (2003 version), which mainly tries to add as much binder as possible into a mix without excessive draindown during mix production. The OBC for the epoxy DGAC mix was determined following a standard Marshall mix design procedure. The selected OBC is 5.9% (by mass of aggregates) for the two OGPA mixes, and 6.5% (by mass of aggregates) for the epoxy DGAC mix.

2.2. Compaction and curing

A rolling wheel compactor was used with a 0.5 m by 0.6 m steel mold to compact slab specimens for testing. Calculated amount of loose mix based on a 20% target air-void content was compacted to a predetermined volume so that the target air-void content can be reached. The mixing and compaction temperatures for PG 64-16 binder were selected at 143 °C and 132 °C corresponding to 0.17 Pa s and 0.28 Pa s viscosities respectively, while the mixing and compaction temperatures for epoxy asphalt mixes are selected at 121 °C, based on the manufacturer's recommendation.

Compacted epoxy asphalt mixes were cured at 121 °C for at least four hours before being extracted from the mold.

2.3. Test methods

The mix properties that are critical to pavement surface performance were evaluated in the study, including air-void content, permeability, acoustic absorption, moisture sensitivity, premature failure potential, resistance to raveling, friction, and resistance to permanent deformation and reflective cracking.

The air-void content of specimens was calculated from the theoretical maximum specific gravity measured in accordance with AASHTO T 209 and the bulk specific gravity measured using the CoreLok method following AASHTO T 331.

Permeability was measured with a field falling head permeameter developed by National Center for Asphalt Technology (NCAT) on slab specimens compacted by a rolling wheel compactor.

The acoustic (sound) absorption coefficient of a material represents the proportion of acoustic energy not reflected by the surface of the materials for a normal incidence plane wave. In an earlier study [11], it has been found that the sound absorption value is correlated with the California On-Board Sound Intensity (OBSI) value (a measure of the tire/pavement noise level) at high frequencies for open-graded asphalt mixes, and at all frequencies for dense- and gap-graded mixes. In the study, acoustical absorption was measured in accordance with ASTM E 1050, using a Bruel & Kjaer Type 4206A impedance tube.

Moisture susceptibility of the mixtures was determined using the AASHTO T 283 test method with some modifications as specified in ASTM D 7064.

Premature failure potential (including both moisture sensitivity and rutting resistance) was evaluated with a Hamburg wheel tracking device (HWTD) following AASHTO T 324.

Table 1
Aggregate gradations used in the study.

Mix ID	PO95 PG 64-16 OGPA	EO95 Epoxy OGPA	ED95 Epoxy DGAC
Sieve size (mm)	Percentage passing		
19.05	100	100	100
12.7	100	100	100
9.525	95	95	97.5
4.75	32.5	32.5	75
2.36	12.5	12.5	60
1.18	5	5	47
0.6	5	5	34
0.3	4	4	26.5
0.15	3	3	18.5
0.075	1.5	1.5	10.5
Binder content (%)	5.9	5.9	6.5