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Fatigue behavior of epoxy asphalt concrete and its moisture susceptibility from flexural stiffness and phase angle

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HIGHLIGHTS

- The phase angle was utilized to estimate fatigue life of epoxy asphalt concrete (EAC).
- The fatigue life estimation using four criteria was compared.
- Moisture damage has a noticeable impact on fatigue life of EAC.
- The fatigue life of EAC is higher than regular asphalt concrete with one or two orders of magnitude.
- The steel bridge deck pavement design procedure using EAC was proposed.

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ABSTRACT

Epoxy asphalt concrete (EAC) has been widely used in large span steel box girder bridges recently. The fatigue performance of EAC is critical in the pavement design on steel box girder. The four-point beam fatigue test was employed to evaluate the fatigue performance of EAC. The moisture susceptibility was evaluated by comparing the fatigue behaviors of the dry and moisture conditioned samples. The fatigue life was determined through four criteria: the yield point from Weibull plot, the half modulus ratio (SR) point, the peak phase angle point, and the sample failure. The results showed that the fatigue lives of EAC can be higher than conventional asphalt concrete by one or two orders in magnitude, indicating an excellent fatigue performance. Both the strain level and testing temperature have a significant influence on the fatigue behavior of the EAC, similar to conventional asphalt concrete. While phase angle has been rarely reported in previous studies, the finding indicated the peak phase angle point has a good potential to be used as a criterion of determining fatigue life of EAC after compared with other parameters. Moisture damage has a great influence on the fatigue performance of EAC according to the noticeable fatigue life reduction.

1. Introduction

Epoxy asphalt concrete (EAC) is made of epoxy asphalt binder and aggregate. Epoxy asphalt is a mix of epoxy resin and petroleum asphalt. Since its application on the Nanjing second Yangtze River Bridge in the year of 2000, EAC has been widely used in pavement construction on long-span steel bridges [1–4]. It has solved the problem of permanent deformation which used to occur in traditional asphalt pavement materials [5,6]. The high performance of EAC include the excellent rutting resistance and low moisture susceptibility [7]. However, based on investigation of the performance of EAC pavement on some steel deck bridges, it was found that longitudinal cracks may appear on the pavement near the U-rib of steel box girder and vehicle wheel path after a few years of service under heavy traffic and overload. Therefore, it's important to study the characteristics of fatigue damage for EAC based on the mechanical properties of long-span steel box girders, and use it as a theoretical basis for pavement preventive maintenance.

The properties of epoxy asphalt binders and concrete have been widely investigated in recent years, such as viscoelastic properties and thermal performance [8,9]. It was found that the EAC is stiffer than conventional asphalt concrete under all the loading frequencies and the time-temperature superposition is not valid for EAC. The crack initiation and propagation of EAC has been investigated through laboratory testing and numerical simulation [10]. The cracking mechanism and repair techniques of EAC has also been

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investigated and it was reported that traditional asphalt sealing material cannot meet the requirement of EAC pavement repairing but the epoxy resin-repairing could be a good candidate [11]. It has been found that the epoxy resin content has a great influence on the performance of epoxy asphalt, such as the rotational viscosity and elongation at break [1,12]. Yu et al. [13] investigated the rheological and microstructural properties of foamed epoxy asphalt and found that the water foaming can enhance the dispersion of epoxy resin in asphalt and improve the performance of epoxy asphalt. In addition to traditional dense-graded epoxy asphalt concrete, the open-graded epoxy asphalt concrete has been investigated recently. The open-graded epoxy asphalt concrete has a much better resistance to raveling and rutting as compared to traditional asphalt concrete [14,15]. Some modified epoxy asphalt concrete has also been investigated. Xue and Qian [16] developed a mineral fiber modified EAC and made some preliminary evaluations on the performance. They found that the moisture resistance and fatigue resistance of EAC can be enhanced with the addition of mineral fibers. In addition to the traditional application as construction materials, the epoxy asphalt has been used as the repairing material of steel bridge pavement [17]. Zhou et al. [18] applied molecular dynamics simulation to study the curing process of the epoxy resin in asphalt matrix. Li et al. [19] design a novel toughened epoxy asphalt based on vegetable oil for the purpose of steel bridge deck paving. It was found the proposed epoxy asphalt can meet the requirement of bridge deck paving materials.

At present, the four-point bending fatigue test is one of the most widely used test methods for studying asphalt mixture fatigue performance [20,21]. The Strategic Highway Research Program (SHRP) pointed out that this test method best represents the real load condition on pavement compared with other laboratory fatigue test methods, and its test results can be used as a direct input for pavement design. Published researches have shown that the four-point bending fatigue test method is mostly used for asphalt pavement materials on highways, but few studies have investigated the fatigue performance of EAC in detail. Thus it is difficult to directly use the test results in EAC pavement design [22,23].

Considering the issues, this study conducted the four-point bending fatigue test on EAC under different temperatures and strain levels. The strain levels were obtained through numerical analysis of a composite structure of orthotropic steel deck and pavement. The composite structure enabled the consideration of the influence of bridge structure on pavement loading condition, which matches the real loading conditions. Test results from this study may be used to guide the practice of fatigue life prediction and maintenance of EAC pavement. The EAC is a thermosetting material composed of epoxy asphalt binder and dense-graded basalt aggregates.

2. Objectives

The objective of this study is to investigate the fatigue performance of EAC and its susceptibility to moisture damage. To achieve this goal, three temperatures were selected for the four-point beam fatigue test. Various strain levels are used at different temperatures in accordance with the real condition. The fatigue lives of samples at dry conditions and that after moisture damage are compared to evaluate the moisture susceptibility.

3. Material preparation and methods

3.1. Epoxy asphalt binder and concrete

The epoxy asphalt binder consists of two components, namely component A and component B, which were produced by ChemCo System in the United States. The epoxy asphalt binder is a mix of components A and B with a certain ratio by mass. The requirements of the physical properties of the component A, component B and the epoxy asphalt binder are shown in Table 1, Table 2, and Table 3, respectively.

3.2. Aggregates

The aggregate used in this study is the basalt from Solano County, California. Some physical properties of the aggregates are shown in Table 4. It can be seen that all the physical properties of aggregates meet the requirements. The gradation of the aggregate is shown in Fig. 1

3.3. Optimum binder-aggregate ratio

The optimum binder aggregate ratio was determined through Marshall asphalt mixture compaction and the subsequent performance testing. In Marshall asphalt mixture design, the Marshall stability and flow number are the two important factors. Because epoxy asphalt mixture is a thermosetting material and its property is sort of rigid, the optimum binder-aggregate ratio is determined by achieving the maximum Marshall stability, which is an indication of the indirect tensile strength. Five trial binder-aggregate ratios were selected for Marshall asphalt mixture compaction. The Marshall stability and flow value were obtained through standard tests AASHTO T245. The stability and flow value test was conducted after the compacted epoxy asphalt mixtures were cured at 20 °C for 24 h. Additionally, the air voids of the asphalt mixture under different binder-aggregate ratios were also obtained. Based on Fig. 2, the optimum binder-aggregate ratio was obtained as 7.1% (binder content is 6.6% by total weight), where the flow value and the air voids were about 2.7 mm and 2.4%, respectively.

3.4. Epoxy asphalt mixture beam

The epoxy asphalt mixture samples tested in this study were beams with a dimension of 380 mm × 63 mm × 50 mm, which were cut from compacted asphalt mixture slabs. The slabs were compacted using molds under a steel roller, as shown in Fig. 3. The dimension of the molds was 502 mm × 167 mm × 76 mm. A slope of 4:1 was set at the edge of the mold to help achieve the required compaction level. Before the compaction, the weight of the loose epoxy asphalt mixture to achieve the objective air void was calculated and placed into the mold. The loose samples were compacted for 50 cycles using a BOMAG compactor. The surface temperature should be no lower than 65 °C during the compaction. The compaction process was as follows: 10 cycles for the middle part, 10 cycles for the right part, 10 cycles for the middle part, 10 cycles for the left part, and 10 cycles for the middle part. Such a compaction process was to simulate the real field compaction. There are also some limitations for this compaction method, the boundary and the bottom of the mold are not exactly the same as that in the real condition. The compacted slabs were cured at 121 °C for 4 h after the compaction. Then the slabs were cooled down to room temperature to cut into beams. The curing process

Table 1
Requirements of physical properties of component A.

Physical properties	Testing value	Requirement	Testing method
Viscosity @23 °C, Pa·s	137	110 –150	ASTM D 445
Color, Gardner	2	≤4	ASTM D 1544
Water content, %	0.02	≤0.5	ASTM D1744
Flash point, °C	230	≥200	ASTM D 92
Specific gravity	1.17	1.16–1.17	ASTM D 1475
Appearance	Transparent	Transparent	Visual