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Influence of foaming effect, operation time and health preserving properties of foam epoxy asphalt mixtures

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HIGHLIGHTS

- New epoxy asphalt curing system and treatment process are proposed in foam epoxy asphalt (FEA).
- 3 key influence factors in FEA research have been proposed.
- The waiting time for compacting FEA mixture is extended to 6 h, which makes the construction easier.

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ABSTRACT

Epoxy asphalt is provided with excellent performance. However, its construction time is too short for the current situation in China, which therefore has brought about the issues with harsh conditions, high costs and risks. In order to solve this problem, this paper proposes a new foamed epoxy asphalt (FEA), and adopts a new curing system. To investigate the hardening system effect on foamed epoxy asphalt, 3 key points in FEA research have been proposed, namely foaming effect, influence of waiting time for compacting during construction, and strength grows in health preserving. Conventional Marshall method is used for the preparation of the testing specimens. The results obtained showed that the optimum foaming temperature is 120 °C, with the optimum water consumption being 2% relatively; the minimum compacting temperature of FEA mixt is 56 °C, and its longest waiting time for compacting is 6 h. At least 50 days of health preserving time is recommended after the completion of the construction of the FEA paving, which equals to 24 h at a constant temperature of 60 °C preserving for the future laboratory study due to the time-temperature equivalence rule.

1. Introduction

Epoxy asphalt is an extremely durable and fatigue resistant paving material for the steel bridge deck. The traditional epoxy asphalt requires that the mixing plant be close to the project site (best if the plant is within 50 min of bridge location) [1,2], or 66 min construction time range from mixing to compacting [3]. Therefore, if the construction organization is not good enough, there could be waste of materials, or even damage potential after the constructions [3–5]. For a long time, researchers and practitioners have made many efforts to extend the construction time range or reduce the construction difficulty [6–8]. Moreover, a new kind of epoxy asphalt Foamed Epoxy Asphalt (FEA), as a composite modified asphalt made by an improved curing system, is presented in the current paper; then it is foamed before mixing. Its mixture brings a significant improvement on prolonging the operating time, and lowering the construction temperature as well as asphalt content [9], which therefore incarnates good economy and construction convenience. However, FEA is still in its research and development stage, and the foaming effect, the waiting time for compacting and the subsequent health preserving condition are the key factors affecting the final performance of pavement [9–11].

As is known to all, the epoxy resin is a thermosetting material; therefore, a lower temperature could make the operation time longer for it. However, the low temperature will reduce the asphalt wrapping material adhering ability and getting hard to compact. In order to solve this contradiction, the epoxy asphalt will be foamed to thin membrane to reinforce the adhesion of asphalt and aggregate, and reduce the gap after forming the mixture ratio. As studied before, for foamed asphalt, water consumption and temperature determine the foaming effect, which is measured by two indicators, namely half life and expansion rate [12]. Half-Life characterizes dissipation speed of the asphalt foam, while expansion rate

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amplifies the multiples of the asphalt volume. Both could influence the wrapping effect of asphalt and aggregates [13], thus determining the quality of the mixture ultimately.

The strength formation of the cured epoxy resin needs time and a definite temperature; therefore, it also takes time for the health preserving after construction. The effect of health preserving is important for the ultimate strength growth of the FEA pavement, which is related to the time of opening to traffic and the needs of the environment. As a result of the replacement of the new curing system, health preserving process needs to be studied.

Therefore, several concerns have been raised in the development process. (1) The foaming effect; (2) compacting waiting for the operation time; (3) the health preserving condition for the pavement's strength growth. To provide reference for the future research, standards or construction reference, test designs in this study are based on these 3 key factors.

2. Materials

2.1. Binder

As with traditional epoxy asphalt, binder of FEA is divided into two parts: Part A and Part B. In general, the chemical polarities of epoxy resin and bitumen are different, and it is difficult to be compatible with each other. Therefore epoxy resin and asphalt should be stored separately. Part A is epoxy resin, and Bisphenol A epoxy resin typed E-51is chosen in this study, which is a product with good flow, large output and mature technology, relative to other grades of epoxy resin. Part B is a mixture of base bitumen and the curing system. The base bitumen is in 70 penetration grade produced in Caltex oil refinery. Table 1 presents the basic properties of this bitumen, with the Test method according to Chinese specification [14]. And the basic properties of E-51 epoxy resin are shown in Table 2. In addition, curing system in Part B comprises amine curing agent, compatibilizer and additives.

2.2. Aggregates and grades

All aggregates used in this study are basalt because such aggregates produced by most ore fields can exhibit a better shape and strength than other stones; the filler is limestone, and the vast majority of mineral fillers are made of limestone mainly because the limestone powder combines with asphalt strongly, which can produce an effect similar to that of asphalt mastic, thereby reducing the bleeding effectively. The test results of the basic properties of the aggregates are summarized in Tables 3 and 4. Each aggregate was studied separately to fulfill the requirements of the material specifications in China [15].

Table 5 presents the gradation Asphalt Concrete-13 (AC-13), which was referenced from the Technical Specifications for Construction of Highway Asphalt Pavements [15]. (See Table 6).

Table 1
Basic properties of 70 pen. grade bitumen.

Items		Technique index	Detecting result
Penetration (25 °C, 100 g, 5 s) (0.1 mm)		60–80	67
PI		−1.5 ~ +1.0	−1.04
Ductility 15 °C(cm)	≥	100	170+
Ductility 10 °C(cm)	≥	15	19.2
Softening point(°C)	≥	47	46.7
60°Cdynamic viscosity (Pa·s)	≥	180	183
Specific gravity		N/A	1.013

Table 2
Main chemical properties of E-51 type epoxy resin.

Chemical composition	Viscosity (mPa·s)	Epoxy equivalent (g/eq)	Density (23 °C) (g/cm^3)
2,2-bis(4-(2,3-epoxpropyloxy)phenyl) propane	11,000–14000	211–290	≤1.10

2.3. Materials and sample preparation

Air void, strength, and flow value are the main indices of steel bridge deck paving materials [16]. In this sense, the main laboratory program of this research consists of Marshall Tests. To achieve the consistency with the previous studies [5,6,9,11], Marshall compaction method, T0702-2011 of Chinese specification [14] was chosen to model specimens, as shown in Fig. 1.

3. Experimental design

3.1. Foaming effect research

Foaming effect of asphalt is directly affected by the water consumption and foaming temperature. In general, foam temperature ranges at 140–180 °C [10,11,13]. However, due to the low viscosity of foam epoxy asphalt Part B in the current research, the foaming temperature can be appropriately reduced. In this section, we set foaming temperature range at 100–160 °C, divided into the 100/120/140/160 °C for the evaluation. And its water consumption is about 1.5%; therefore five levels 0.5/1/1.5/2/2.5% were selected. Orthogonal experiment was carried out under the above two variables.

The test process can be described as follows:

1. Place Part B of foamed epoxy asphalt in Binder Tank, preserving it for 1 h to foaming temperature;
2. While conduct the Procedure 1, place Part A into an oven at 90 °C for 1 h;
3. Turn asphalt jet pump on and make it circulate for 15 min before foaming;
4. Adjust the water tank meter to a specific scale, and turn on the generator; start foaming, meanwhile, a particular foaming tube is injected to evaluate the foaming performance. Determine the optimum water consumption;
5. Keep on foaming at the optimum water consumption, weigh Part A and Part B, and put them into the mix pot together;
6. Mixing, followed by conventional Marshall specimen preparation method.

Fig. 2 shows the experimental machine used in this study, which can be employed for indoor test.

3.2. The influence of waiting time for compacting during construction

From mixing to compacting, the insulation measures for mixtures and waiting time for paving in the construction process, will be simulated during the properties evaluation of FEA for construction operation.

The experimental program was conducted as follows:

Prepare 52 Marshall specimens, and divide them into A, B, C three groups, to simulate the different conditions of thermal insulation way. The test Group A/B/C corresponds to the insulation measures Condition A/B/C respectively, the same below.