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Rheological and microstructural properties of foamed epoxy asphalt

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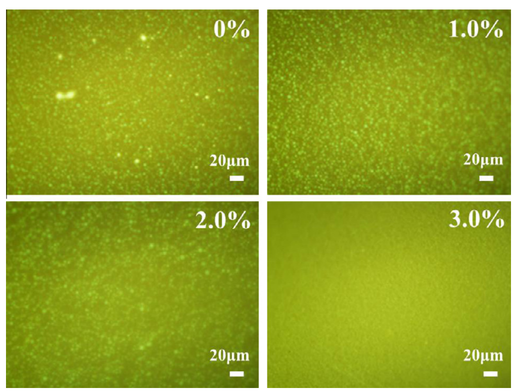
HIGHLIGHTS

- The foamed epoxy asphalt samples with different foaming water were prepared.
- Foaming process improves the workability and prolongs the allowable reserved time.
- The epoxy resin dispersion in the asphalt was enhanced by foaming water.
- The foaming water promotes the chemical reaction of system.

GRAPHICAL ABSTRACT



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ABSTRACT

Epoxy asphalt has been extensively used in the bridge deck pavement. The main concerns during the construction process of epoxy asphalt are including high construction temperature, high viscosity to deal with and limited construction time which finally affects the service performance of the pavement. In this study, foamed epoxy asphalt is proposed to solve these construction challenges. The foamed epoxy asphalt samples were prepared by foaming machine at different foaming water content in the laboratory. The viscosity-temperature performance, failure temperature, ZSV@60 °C, temperature sensitivity and storage stability were evaluated by rotational viscometer, temperature sweep, frequency sweep and storage tests. Fluorescence microscope and Infrared spectroscopy were utilized to characterize the morphology and chemical reaction change of non-foamed and foamed epoxy asphalt with different foaming water content. The results show that the addition of foaming water could improve the workability of foamed epoxy asphalt binder mixtures and prolong the allowable reserved time of construction process. Compared to non-foamed epoxy asphalt, foamed epoxy asphalt compromise failure temperature and viscosity@60 °C and improve the temperature sensitivity and storage stability. With the increase of foaming water content, the failure temperature, viscosity@60 °C and storage stability of foamed epoxy asphalt decrease at some extent, while the temperature sensitivity of foamed epoxy asphalt increases. According to the change of microstructure, the foaming water is beneficial to enhance the epoxy resin dispersion in the asphalt and promote the chemical reaction between epoxy resins and curing agent, which could improve the pavement performance of epoxy asphalt.

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1. Introduction

Epoxy asphalt mixtures have been shown to be excellent materials for steel bridge deck paving and have been widely used throughout the world [1,2]. In Year 2000, epoxy asphalt was first introduced to China on the Nanjing Second Yangze River Bridge to solve the premature pavement failure problem [2–4]. Then epoxy asphalt and its relevant technology has been spreading rapidly in China and becoming one of the most popular technologies in bridges deck pavement [5].

According to the component, epoxy asphalt is a two-phase chemical system in which a thermosetting acid epoxy (continuous phase) is blended with base asphalt (disperse phase) [6]. Before construction, there are typically two separate components: epoxy resin (Part A) and curing agent/asphalt blend mixture (Part B) [7]. Once the two components are mixed together, the curing agent will accelerate the crosslinking and curing reaction between part A and part B. And when the degree of cross linking reaction is complete, a three-dimensional network of epoxy resin and curing agent will be formed in the epoxy asphalt system [8,9], which will promote the stiffness and strength of the epoxy asphalt mixtures [10]. However, the application of epoxy asphalt technology also has some challenges. For example, the "breakout" time after the epoxy resin and the curing mixture are mixed together is normally very short, which is inconvenient to the construction process [11]. In addition, when the agent curing is different the workability of asphalt mixtures has great difference. Base on the curing temperature there are four kinds of curing agent including low-temperature curing agent [12], room-temperature curing agent [13], moderate-temperature curing agent [14] and high-temperature curing agent [15]. Especially for the high-temperature curing agent, the production and compaction temperature of asphalt mixtures reach more than 170 °C, and some of them reach up to 200 °C, which will consequently increase energy consumption and air emissions, and enhance the degree of aging for asphalt binders. So this is an effective way to decrease the work temperature of epoxy asphalt mixture by foaming method.

Compared to traditional hot mix asphalt (HMA), warm mix asphalt (WMA) pavement is an emerging technology. WMA can reduce the construction temperature by 30 ~ 50 °C and save energies. Recently, there are three types of WMA technologies commonly used: (a) organic additives which decrease the viscosity of asphalt [16,17], (b) chemical additives which decrease the interfacial friction between asphalt and aggregate [18], and water foaming process or water containing additives [19] which reduce the mixing temperature by foaming the liquid asphalt to expand. Among the above technologies, the foaming technology involves minimal cost for the additives and is the most widely used WMA technology in the US [20,21].

It could be concluded that several difficult pavement challenges have been solved by epoxy asphalt concrete due to its high temperature stability, improved fatigue resistance, superior durability and waterproofness [22]. On the other hand, the foaming process could be beneficial to asphalt as it can reduce the mixing temperature and improve the workability of mixture. Although a large number of studies have been conducted on epoxy asphalt and foamed asphalt respectively, few of them focused on the foamed epoxy asphalt. Especially, the effect of foaming water content on the performance of foamed epoxy asphalt has not been well investigated yet.

The objective of this paper is to investigate the influence of foaming water content on the rheological properties and microstructure of foamed epoxy asphalt. Experimental methods such as the rotational viscosity tests, temperature and frequency sweep tests, storage stability tests, temperature sensitivity tests, and Fluorescence microscope and Fourier Transform Infrared (FTIR) Spectroscopy tests are conducted and analyzed for this purpose.

2. Experiment and methods

2.1. Materials

The base asphalt with 60/80 penetration grade produced at the Ssangyong asphalt plant of South Korea was used. The properties of the base asphalt are listed in Table 1. The epoxy resins E-51 was supplied by ROK KUKDO Ltd., China, and its properties are presented in Table 2. The curing agent was prepared in the laboratory.

2.2. Preparation of non-foamed and foamed epoxy asphalt samples

Epoxy asphalt samples were prepared using a two-step shear method with a high shear mixer FM300-digital. The flow chart of sample preparation is drawn in Fig. 1.

The preparation of epoxy asphalt include: (1) the base asphalt was heated until it has become sufficiently fluid, and then poured into a 1000 mL spherical flask. And then 20% curing agent by weight of base asphalt was added to base asphalt and mixed for about 20 min at 120 °C, at a speed of 2000 rpm. (2) 12% epoxy resins by weight of base asphalt and curing agent was added to above mixture at 155 °C and mixed for about 5 min. The epoxy asphalt samples were then ready for further testing.

Then foamed epoxy asphalt was prepared using foaming machine produced by Wirtgen Group as illustrated in Fig. 2. The foaming water content used in this study was 1.0%, 2.0% and 3.0% by weight of epoxy asphalt, respectively. During the foaming process, the temperature of the epoxy asphalt and the water were controlled at 160 °C and 50 °C, respectively.

2.3. Rotational viscosity tests

Viscosity is an important property for evaluating the high temperature performance and workability of asphalt, so the viscosity must be appropriate during construction process. According to Biruk et al. [23], the expansion ratio of this system is up to about 10 after adding foaming water. The viscosity will decrease at a rapid rate, which can improve workability and allow production and compaction of mixture at lower temperature than conventional mixtures.

In this study, the Brookfield viscometer tests according to AASHTO T 316-04 [24] were performed for foamed and non-foamed epoxy asphalt samples at a variety temperatures (110 °C, 120 °C, 130 °C, 140 °C, 150 °C, 160 °C). And the viscosity of foamed and non-foamed epoxy asphalt samples was measured by the following procedure. Firstly, the samples should be immediately poured into the container at the set temperature for 60 s after the foamed epoxy asphalt samples prepared. Then, the samples were measured for 20 s and one data per two seconds was recorded during later 10 s, and the viscosity of this sample was obtained from the average value of the five data. Meanwhile, each sample was measured three times and the final data is the average value of every experiment.

2.4. Temperature sweep tests

Temperature sweep tests were conducted using a TA-AR1500EX dynamic shear rheometer (DSR) (25 mm diameter parallel plates, 1 mm gap) for foamed

Table 1
Properties of base asphalt.

Items		Results	Methods
Density @ 15 °C/g cm^{-3}		1.065	T0603
Penetration @25 °C/0.1 mm		63	T0604
Softening point/°C		45.3	T0606
Viscosity @60 °C/pa s		317.4	T0625
Ductility @15 °C/cm		>100	T0624
Flash point/°C		345	T0611
Components	Saturate/wt%	27.12	T0618
	Aromatic /wt%	43.25	
	Resin/wt%	29.34	
	Asphaltene /wt%	8.17	

Table 2
Properties of epoxy resins.

Items	Results
Epoxy equivalent/g mol^{-1}	183–190
Density @15 °C/g cm^{-3}	1.167
Viscosity @25 °C/mPa s	10000–14000
Color (Pt-Co)	⩽30
Hydrolysis of chlorine/mg kg^{-1}	⩽500