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Study on cohesion performance of waterborne epoxy resin emulsified asphalt as interlayer materials

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HIGHLIGHTS

- The cohesion of WEREA was investigated theoretically and experimentally.
- The curing agent A developed by the authors has good compatibility.
- Temperature and interlayer contact texture have significant effects on lateral cohesion.

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ABSTRACT

Interlayer of pavement overlays or bridge deck pavement using waterborne epoxy resin emulsified asphalt (WEREA) is proposed for the purpose of preventing pavement from shoving at bridge deck. This study consists of theoretical analysis on cohesion and simulation failure tests of cohesion and waterproof. The results show that the cohesion performance is affected by temperature and the choice of curing agent, and the shear strength performance is related to interlayer contact texture. The components and network microstructure of WEREA enhance the cohesion property of interlayer and improve the material viscoelasticity, and as a result it improves the shear strength and pullout strength performance. In addition, WEREA also has a strong waterproof performance on the bridge deck pavement as tack coat.

1. Introduction

Pavement distresses such as cracking and shoving, are mostly caused by heavy traffic, overweight vehicles and other environmental effects. Major pavement maintenances and reconstructions are required to maintain the required service quality [1]. Coating materials is one of the most important factors that can ensure the pavement service life, whether old roads with pavement overlays or bridge deck pavement [2,3]. Examples of tack coats are liquid asphalt, emulsified asphalt and modified emulsified asphalt. Literatures had shown that liquid asphalt is not commonly used due to poor performance [4]. When compared with emulsified asphalt, modified emulsified asphalt is better in terms of high and low temperature performances, fatigue resistance and water stability [5,6].

The main modifiers used to improve the quality of pavement include styrene–butadiene-styrene (SBS), styrene-butadiene rubber (SBR), polyethylene terephthalate (PET), epoxy resin (ER) and so on [7]. Of all these polymers, styrene–butadiene-styrene (SBS) is mostly used in asphalt modification because of its excellent performance, including favorable cohesion [8–10]. SBS exhibits crosslinked elastomer network behavior with a two-phase morphology, which consists of glassy polystyrene (PS) domains and rubber polybutadiene (PB) segments. This morphology has a positive effect on the asphalt cohesion [11]. However, past research found that the storage stability of SBS modified asphalt remains to be one of the most critical issues [11,12]. Xiao et al. indicated that epoxy resin may possibly react with the curing agent by a crosslinking effect and this effect could extend to an increased network structure in the asphalt phase. This would make it more effective in improving the cohesion properties for asphalt pavement. Hence, it can improve the pavement performance by reducing distresses, such as jostling, piling up, waving and rutting of "white + black" pavement overlay and steel bridge deck [13–15]. Besides, waterborne epoxy resin emulsified asphalt is without a storage problem as it is prepared by mixing the formulated emulsified asphalt and waterborne epoxy resin instantaneously during construction.

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Epoxy resin is commonly used in composite binder and coating materials due to its effective cohesion performance. However, it should be prepared as Waterborne Epoxy Resin (WER) in order to fit the ambient temperature construction of emulsified asphalt. WEREA obtained by blending the WER into emulsified asphalt through the physical or chemical methods achieves the benefits from both epoxy resin and emulsified asphalt [16]. The curing reaction can be carried out at normal room environment considering the temperature and humidity requirements. WER changes the asphalt's original thermoplastic properties to a new formation of thermosetting through the cross-linking function [17,18]. The composite materials have high strength, high stiffness, excellent high temperature and low temperature bonding properties, and good water stability [17,19,20].

The newly developed waterborne epoxy resin emulsified asphalt (WEREA) by Chang'an University has its advantages in emulsifying capacity, hydrophile lipophile balance and shorter curing time. This paper analyzed the composition, viscoelasticity and microstructure of WEREA theoretically by Fourier infrared spectrum tests, Dynamic shear rheometer (DSR) tests and Fluorescent microscope tests. It also simulated the stress condition of pavement interlayer by using shear tests and pullout tests. These tests were conducted to evaluate the WEREA cohesion properties in scenarios using different curing agents, epoxy resin dosages, temperatures and interlayer contact texture. In addition, the waterproof performance of WEREA tack coat was tested by using interlayer seepage tests.

2. Materials

Esso 90# asphalt was used as matrix asphalt. The properties of a self-made emulsifier, waterborne epoxy resin and curing agent are shown in Table 1. To overcome the lack of polyamide and polyethylene polyamides, a waterborne epoxy curing agent A was equipped with suitable curing time, strong compatibility and less irritating odor. Triethylenetetramine (curing agent B) was regarded as the control material. Hydrochloric acid and polyvinyl alcohol (PVA) were selected as pH regulator and stabilizer respectively.

3. Experiments

3.1. WEREA preparation

To begin with, the matrix asphalt was heated to about 150 °C so that it was in a flowing state. At the same time, water was heated to 80 °C, the pH value of which was controlled to be between 2 and 3 by adding hydrochloric acid. The next stage of the process involved the preparation of emulsions. This was obtained by adding 1.2% of the emulsifier to the heated water and then stirred sufficiently to ensure uniform dispersion. In the following stage, matrix asphalt was slowly added to the colloid mill and then stirred for 4 min, after the emulsions were poured into a preheated colloid mill and stirred for 30 s. The ratio of water and oil was 6:4. The final WEREA was prepared by mixing the matrix emulsified asphalt, epoxy resin and curing agent according to the test required formula, when the interlayer materials were used.

3.2. Sample fabrication

The research consists of two parts, the theoretical analysis on cohesion and simulation failure tests of cohesion and waterproof. Part A: The Fourier infrared spectrum samples of matrix asphalt and curing agent A WEREA were put on ART crystal, and were not given strict demands of size and volume. The diameter and thickness of DSR samples were 25 mm and 1 mm. Based on the Fluorescent microscope test samples, the 160 °C WEREA cured resin was dripped on a glass slide, and then the cover glass was gently pushed from one end to the other. During the process, no air bubbles were generated in the WEREA film and the thickness was uniform.

Part B: As shown in Fig. 1, both in the shear tests, pullout tests and interlayer seepage tests, composite slabs of the "5 cm Portland cement concrete slab (coarse surface) + interlayer material + 5 cm AC-10 asphalt mixture slab" and "5 cm Portland cement concrete slab (smooth surface) + interlayer material + 2 cm UTFL-13 asphalt mixture slab" were chosen to simulate the overlay of the new road and polished old pavement respectively [21,22]. The BPN of coarse surface was 80.3 and of smooth surface was 69.8, and MTD of both were 0.56 mm and 0.14 mm respectively. In Fig. 2, the optimum amount of 1.0 kg/m^2 in the interlayer material was determined in order to study the effect of WER on tack coat using a single variable of different WER contents. After the mixtures were paved, wheel loading of 14 rounds were rolled on the composite slabs. After maintenance over 3 days at room temperature, core samples of shear tests and pullout tests were drilled, the diameter of which was 95 mm. The specimens of interlayer seepage tests were cut into slabs of the size 140 mm in width and 140 mm in length.

Table 1
Parameters of materials.

Measured properties		Results
Emulsified asphalt		
Particle charge		Cationic (+)
Demulsification rate		Moderate
Amount remaining on the 1.18 mm sieve (%)		0.04
Storage stability	1 day (%)	0.4
	5 days (%)	2.7
Evaporated residue	Solid content (%)	61.2
	15 °C Ductility (mm)	980
	Softening point (°C)	50
	100 g, 25 °C, 5 s Penetration (0.1 mm)	78
Waterborne epoxy resin		
Solid content (%)		48–52
pH		6–8
Density (g/cm^3)		1.06–1.08
Appearance		Milk-white fluid
Curing agent		
	Curing agent A	Curing agent B
Curing time (h)	4	8
Appearance	Yellow liquid	White liquid