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Laboratory study on performances of bimaleimide/unsaturated polyester resin modified asphalt

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HIGHLIGHTS

- Optimum formula of BDM/UPR modified asphalt is determined by tests.
- BDM/UPR modified asphalt has excellent tensile and high-temperature performance.
- In low-temperature performance, BDM/UPR modified asphalt is better than epoxy modified asphalt.
- Cost of BDM/UPR modified asphalt is 0.69 times of that of epoxy modified asphalt.

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ABSTRACT

Unsaturated polyester resin (UPR) modified asphalt mixture has excellent high-temperature stability, low-temperature crack resistance and water stability. However, there are still great gaps in Marshall stability and tensile strength between UPR modified asphalt mixture and epoxy modified asphalt mixture. Hence, UPR is modified by 4,4′-bismaleimi-dodiphenylmethane (BDM) and then it is used to prepare BDM/UPR modified asphalt in this paper. Then, the optimum formula of BDM/UPR modified asphalt is determined by tensile, viscosity, separation and fluorescence microscope tests. Finally, the performances of BDM/UPR modified asphalt are compared with those of epoxy modified asphalt and pure UPR modified asphalt. Results indicate that compared with pure UPR modified asphalt, the tensile strength of BDM/UPR modified asphalt is 27.2% higher, high-temperature performance is improved significantly and low-temperature performance is slightly worse, while the low-temperature performance of BDM/UPR modified asphalt is still better than that of epoxy modified asphalt. In economy, the cost of BDM/UPR modified asphalt is higher than that of pure UPR modified asphalt but it is only 0.69 times of that of epoxy modified asphalt.

1. Introduction

Epoxy asphalt mixture is one of the main materials used for bridge deck pavement. The previous studies show that epoxy modified asphalt deck pavement has excellent performance in strength, durability and rutting resistance [1–3]. S. Hayash et al. [4] put forward a kind of bicomponent epoxy modified asphalt composed of epoxy resin and asphalt with amine curing agent, which laid a foundation for the formulation of bicomponent epoxy modified asphalt. K.P. Gallagher et al. [5] proposed the concept of thermosetting asphalt and solved the problem of the inferior stability of epoxy resin modified asphalt by adding additives. Epoxy modified asphalt was first used for the steel bridge deck pavement in San Mateo-Hayward Bridge of America and showed good performance [6]. Subsequently, epoxy modified asphalt was gradually popularized for using in North American and Australia, and the corresponding technical specifications were proposed in the United States and Germany. In recent years, the research on epoxy asphalt has gone further. E. Bocci et al. [7,8] dealt with the three-dimensional viscoelastic characterization of epoxy modified asphalt mixture and proved that it had higher stiffness and thermal sensitivity compared with hot mix matrix asphalt mixture, as well as investigated the shear resistance of epoxy modified asphalt both as bonding coat and as binder of the upper asphalt layer and the results showed that epoxy asphalt guaranteed excellent performance.

Although epoxy modified asphalt has many excellent performances, it is expensive, which leads to the high cost of bridge deck pavement [9]. The relatively cheap gussasphalt concrete or stone

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matrix asphalt (SMA) is usually used for the deck pavement of ordinary cement concrete bridges. However, gussasphalt concrete has defects in high-temperature stability [10,11] and SMA has the defects in water resistance [12]. Therefore, considering the cost and performances of deck pavement, it is particularly important to develop a new material for bridge deck pavement with better performances than gussasphalt concrete and SMA and lower price than epoxy asphalt.

Unsaturated polyester resin (UPR) and epoxy resin, both belonging to thermosetting resins, have similar physical and chemical properties. Adding initiator can make UPR and epoxy resins to be gradually hardened through chemical reactions to form an insoluble and non-fusible solid [13–15]. H. Zhang [16] has studied the performances of UPR modified asphalt and asphalt mixture. The results showed that UPR modified asphalt mixture had advantages over gussasphalt concrete and SMA in strength, high-temperature property, water stability and anti-fatigue ability. However, the tensile strength of UPR modified asphalt mixture is lower than that of epoxy asphalt mixture. In addition, there is also a gap in high-temperature performance between UPR modified asphalt mixture and epoxy modified asphalt mixture.

In order to generalize the application of UPR modified asphalt in bridge deck pavement, it is necessary to improve its strength. One of the ways is to modify UPR. At present, polyurethane, epoxy resin, nanoparticles, bismaleimide and fiber have been used to modify UPR, among which BDM is the most effective one [17–20]. B. Gwadzki et al. [21] used 4,4́-bismaleimidodiphenylmethane (BDM) to modify UPR and verified the performances of the cured BDM/UPR. The results showed that the addition of BDM increased the thermotolerance of BDM/UPR by 78% compared with that of pure UPR. E. Martuseclli et al. [22] also used BDM to modify UPR and investigated the mechanical property of BDM/UPR, and they found that 8% of BDM is the optimum proportion for the curing reaction of BDM and UPR. Under this proportion the tensile strength of BDM/UPR was 23% higher than that of pure UPR. At present, BDM/UPR has not been used to modify asphalt yet.

The objective of this paper is to evaluate the effect of BDM on the performances of UPR modified asphalt binder, especially strength. First, the best processing parameters of BDM/UPR modified asphalt are determined. Then, the performances of BDM/UPR modified asphalt, pure UPR modified asphalt and epoxy asphalt are tested and compared. Finally, their costs are compared also.

2. Materials

2.1. UPR

According to the researches on UPR modified asphalt [16], it is found that 197# bisphenol A UPR has excellent modified effects on asphalt and the modified asphalt has good performances. Therefore, 197# bisphenol A UPR is selected in this paper and its properties provided by manufacturer are shown in Table 1.

2.2. BDM and inhibitor

The properties of BDM provided by manufacturer are shown in Table 2. In order to prevent the crosslinking reaction of UPR with styrene at high temperature, it is necessary to add 1% inhibitor (hydroquinone) into BDM modified UPR [23].

Table 1
Properties of 197# bisphenol A UPR.

Properties	Requirements [16]	Results
Appearance	Light yellow liquid	Acceptable
Viscosity (25 °C/Pa·s)	0.30–0.50	0.38
Gelation-time (25 °C/min)	7.0–13.0	10′35″
Acid value (mgKOH/g)	11.0–19.0	14.3
Solid content (%)	57.0–63.0	61.3

Table 2
Properties of BDM.

Properties	Criteria	Results
Appearance	Light yellow crystal or powder	Certified
Initial melting-point	≥155 °C	155.8 °C
Heating loss	≤0.5%	0.23%
Ash content	≤0.5%	0.18%
Acid value	≤1%	0.08%
Content	≥99%	99.4%

2.3. Additives

Tert-Butyl peroxybenzoate, coupling agent KH560 and maleic anhydride are selected as the initiator, coupling agent and compatibilizer for UPR modified asphalt, respectively [16]. Furthermore, the addition of diluent can not only make the resin obtain excellent impregnability, hydrophilicity and fluidity, but also prolong the curing time of resin effectively, which can control the viscosity increase of resin [24]. Therefore, a diluent specially designed to regulate UPR viscosity is selected as the diluent for UPR modified asphalt, whose test properties provided by manufacturer are shown in Table 3.

2.4. Epoxy resin

Epoxy resin E51 made in China is used for the preparation of epoxy asphalt and its properties provided by manufacturer are shown in Table 4. Polyamide is selected as curing agent in epoxy modified asphalt.

2.5. Asphalt binder

This research is sponsored by the transportation department in the northern region of Shaanxi Province of China, where matrix asphalt PG 58-16 is often used in the construction of asphalt pavement, so matrix asphalt PG 58-16 is selected in this paper and its properties are shown in Table 5.

2.6. Asphalt binder preparation

UPR are modified by BDM through blending method and the modification procedures are as follows: add a certain amount of

Table 3
Properties of diluent.

Properties	Criteria	Results
Appearance	Colorless clear liquid	Certified
Polymer (mg/kg)	≤10	8
Hyperoxide (mg/kg)	≤50	47
Total aldehyde content (with benzaldehyde) (mg/kg)	≤100	98.4
Ethylbenzene (%)	≤0.08	0.04
Content (%)	≥99%	99.6

Table 4
Properties of epoxy resin.

Properties	Criteria	Results
Appearance	Light yellow or tan clear liquid	Certified
Viscosity (25 °C/Pa·s)	6–10	8.2
Epoxy equivalent (g/ep)	210–244	224
Softening point (°C)	14–23	19
Color and luster degree	<3	2