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A lab study to develop a bridge deck pavement using bisphenol A unsaturated polyester resin modified asphalt mixture

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HIGHLIGHTS

- A new type of asphalt mixture, UPR modified asphalt mixture, is put forward.
- Optimum formula of UPR modified asphalt is determined by BBR and DSR tests, etc.
- Lab performances of SBS, epoxy and UPR modified asphalt mixtures are compared.
- Some lab performances of UPR modified asphalt mixtures are excellent.
- The cost of UPR modified asphalt is only 60% of that of epoxy modified asphalt.

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ABSTRACT

To improve the low-temperature and anti-fatigue performances of the bridge deck pavement and decrease its cost, an unsaturated polyester resin (UPR) modified asphalt mixture is put forward in this paper. First the optimum formula of UPR modified asphalt is determined through several tests. Second the ductility, bending beam rheometer (BBR), dynamic shear rheometer (DSR) and tensile tests are conducted for matrix asphalt, and SBS, epoxy and UPR modified asphalts. Finally, Marshall, rutting, low temperature bending, freeze-thaw splitting and fatigue tests are conducted for their mixtures. Test results show that the laboratory performances of UPR modified asphalt mixture are more excellent than those of SBS modified asphalt mixture and have advantages over those of epoxy modified asphalt mixture in low-temperature crack resistance, water stability and anti-fatigue ability. The maximum flexural-tensile strain, stripping inflection point and fatigue life of UPR modified asphalt mixture are 2.54, 1.25 and 1.08 times of those of epoxy modified asphalt mixture, respectively. Whereas the cost of UPR modified asphalt is only 62% of that of epoxy modified asphalt. Although the BPA will have a certain impact on the health of BPA unsaturated polyester resins production workers and construction workers, this impact can be controlled by limiting BPA concentrations within reasonable ranges and taking effective protective measures.

1. Introduction

Due to the deck pavement is a part of bridge structure directly bearing vehicle loads, girder deformation and effects of various environmental factors, the stress condition of asphalt deck pavement is more complex, and the climatic conditions, such as temperature, are more severe than those of ordinary asphalt pavement. In addition, due to bridge deck pavement cannot be compacted by large vibratory roller, its compactness is often insufficient, which will make the bridge deck pavement be prone to cracking, pit, rutting and other damages [1,2].

At present, stone mastic asphalt (SMA), epoxy modified asphalt mixture and gussasphalt concrete, are often used as bridge deck surfacing materials [3,4]. Wang et al. [5] found that compared to conventional gussasphalt, the high-temperature stability and fatigue performance of embedded gussasphalt concrete are remarkably improved. The researches of Chen et al. [6] showed that the addition of Trinidad Lake asphalt (TLA) to gussasphalt concrete increased the durability and stiffness of asphalt mixture, and the addition of mineral fillers could improve the anti-rutting ability of the gussasphalt concrete. Casey et al. [7] gotten that the addition

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of 4% recycled high-density polyethylene (HDPE) to SMA produced the excellent results. Ahmadinia et al. [8] found that waste plastic bottles (Polyethylene Terephthalate (PET)) as additive can significantly improve the properties of SMA. Hayashi et al. [9] proposed a kind of two-component epoxy modified asphalt comprising an epoxy resin, a maleinated asphaltic material and, if desired, a curing agent for the epoxy resin. Qian et al. [10] put forward a lightweight epoxy modified asphalt mixture (LEAM) for pavement on bascule bridges, and results showed that the LEAM had good performances for anti-water damage, resistance to permanent deformation and low-temperature anti-cracking. Cong et al. [11] proposed a kind of epoxy modified asphalt mixture with good heat resistance, low-temperature anti-cracking ability and aggregate scattering resistance for the long-span orthotropic steel deck bridges. The research groups of Professor Chen Z. and Professor Huang W. in Southeast University of China [12–15] made a type of high performance epoxy modified asphalt material by modifying the matrix asphalt with maleic anhydride and using the aliphatic dicarboxylic acid as curing agent, and applied it into Wuhan Tianxingzhou Bridge and Shanghai Hepu Bridge.

In general, gussasphalt concrete has good performances in low temperature and water stability, while its high-temperature performance is poor and construction process is complex. SMA has mature construction craft and low cost, but its low-temperature resistance and anti-fatigue capability are poor. Epoxy modified asphalt mixture have excellent performances in high temperature, anti-fatigue and anti-water damage due to the curing reaction of epoxy, modified asphalt mixture are denser, resulting in lower porosity. However, there are some restrictions for epoxy resin, for example, poor flexibility and high cost.

Unsaturated polyester resin (UPR) is one kind of linear polymer with ester bond and unsaturated double bond formed by the condensation polymerization reaction of unsaturated dibasic acid and glycol or saturated dicarboxylic acids and unsaturated diols. Fig. 1 shows the molecular structure of UPR.

UPR has excellent heat resistance (up to 120 °C), mechanical properties (high flexural, tensile and compressive strengths), chemical resistance and dielectric properties [16]. In addition, UPR is much cheaper than epoxy resin and has wide source. Thus, adding UPR into asphalt can make asphalt have excellent thermoplasticity and mechanical properties, especially in low-temperature crack resistance, rutting resistance, water stability and fatigue resistance. Moreover, UPR modified asphalt mixture has lower cost than epoxy resin modified asphalt mixture.

At present, the UPR is used extensively in coating, filler, patching materials or cement concrete [17–19], but there are only a few researches on its application in modified asphalt. Hashem et al. only studied the dynamic stability, flow value and deformation of UPR modified asphalt through the Marshall test and computer program named BISAR, which were compared with those of epoxy modified asphalt and UPR/epoxy resin modified asphalt [20]. Thus, in order to improve the low-temperature crack resistance, rutting resistance, water stability and fatigue resistance of bridge deck pavement and decrease its cost, the paper aims to develop the UPR modified asphalt mixture and compare its performances with matrix asphalt mixture, SBS modified asphalt mixture and epoxy modified asphalt mixture.

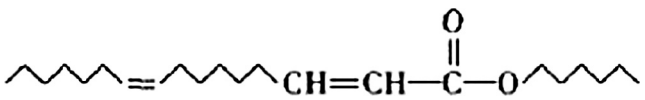

Fig. 1. Molecular structure of UPR.

2. Experimental parts

Experimental part is carried out in four steps. First, the main composition of UP modified asphalt was selected. Second, the optimum formula of UPR modified asphalt is determined by tests. Third, the high-temperature and low-temperature performances of UPR modified asphalt is examined and compared with those of matrix asphalt, and SBS, epoxy and UPR modified asphalts. Forth, the mechanical property, high-temperature stability, low-temperature cracking resistance, water stability, fatigue resistance and oil corrosion resistance of UPR modified asphalt mixture are tested and compared with other asphalt mixtures.

2.1. Selection of materials

The main components of UPR modified asphalt include resin, curing agent, accelerant, compatibilizer, coupling agent, diluent and asphalt.

2.1.1. Selection of the unsaturated polyester resins (UPR)

At present, the common UPR mainly include vinylite, halogenated, bisphenol A (BPA), terephthalic, or phthalic. Their performances and prices are shown in Table 1.

Bridge deck pavement materials need the excellent high-temperature resistance, water stability, corrosion resistance and mechanical properties as well as the low cost. Thus, BPA, phthalic and terephthalic unsaturated polyester resins are selected as the preliminary materials. The properties of BPA, phthalic and terephthalic unsaturated polyester resins are listed in Table 2.

2.1.2. Selection of curing agent and accelerant

Since the mixing temperature of asphalt mixture is generally higher than 130 °C, the high-temperature curing agents are selected. The main available high-temperature curing agents for UPR and their part properties are listed in Table 3.

The mixing temperature of ordinary hot mix asphalt mixture is preferably within a range of 130–160 °C and the mixing temperature of modified asphalt mixture is 10–20 °C higher, so the molding temperature should be within the range of 140–180 °C. According to the molding temperatures of curing agents in Table 3, only Tert-butyl Peroxybenzoate and Dicumyl Peroxide meet this requirement. Dicumyl Peroxide has toxicity, while Tert-butyl Peroxybenzoate is not only non-toxic but also more convenient to be purchased for its wide application, so Tert-butyl Peroxybenzoate is selected as the curing agent in this paper.

Because of the high mixing temperature, accelerant is not needed in the curing process.

Table 1
Performance and prices of UPR.

Type	Performance	Price
Vinylite	Good chemical resistance, water stability and toughness and high strength	Very high, even higher than that of epoxy resin
Halogenated unsaturated polyester resin	Good corrosion resistance, poor heat resistance	Moderate
BPA unsaturated polyester resin	Good corrosion resistance, water stability and high strength	Moderate
Terephthalic unsaturated polyester resin	Good corrosion and heat resistance	Moderate
Phthalic unsaturated polyester resin	Relatively poor, but it is wildly used and easy to be obtained	Low