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Performance of polyurethane modified asphalt and its mixtures

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HIGHLIGHTS

- Polyurethane modified asphalt is prepared with disk-based Serrated Mixer.
- Polyurethane modified asphalt has a greater high temperature performance, aging resistance and water stability.
- Polyurethane modified asphalt and its mixtures have a lower low-temperature performance than SBS modified asphalt.
- Polyurethane modified asphalt mixtures have excellent dynamic modulus, water resistance and high temperature resistance property.
- Polyurethane modified asphalt mixtures are a cost-effective material.

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ABSTRACT

Polymer modified asphalts are used to improve the performances of asphalt pavements. However, storage stability and aging performance need to be improved. Therefore, in this study, we focused on assessing the characteristics of polyurethane (PU), base or styrene-butadiene-styrene (SBS) modified asphalt and its mixtures. Polyurethane modified asphalt was prepared using a disk-based serrated mixer. The basic technical index tests of the selected asphalts were performed and bending beam rheometer (BBR), dynamic shear rheometer (DSR), Fourier transform infrared spectroscopy (FTIR) and dynamic mechanical analysis (DMA) were conducted. The property tests of the three asphalt mixtures were also performed. In addition, the approximate capital costs of PU modified asphalt mixtures were calculated. Results of this work demonstrated the high temperature and water resistance of PU modified asphalt. However, PU modified asphalt mixture had a lower low-temperature resistance than SBS modified asphalt, but greater than base asphalt. PU modified asphalt mixture performed excellent water stability and non-deformability. The optimal asphalt content of PU modified asphalt mixture was lower than other asphalt mixtures by 5%. The cost of PU modified asphalt mixtures was similar to that of SBS modified asphalt, indicating that it was a cost-effective material.

1. Introduction

1.1. Background

Pavements deteriorate with time due to traffic loading and environmental exposure. The modification of asphalts, by the utilization of polymers, is employed to improve pavement performance. However, those currently used in traditional polymer modified asphalt mixtures degrade as a result of heat, light, oxygen etc. [1–3]. Other than polymers, chemically modified asphalts have also been employed to enhance performance [4]. These asphalts are prepared by incorporating chemical modifiers under specific conditions to produce new functional groups and alter structures [5].

The use of synthetic polyurethane has grown in popularity in recent ten years. Polyurethane has excellent heat resistance and mechanical properties, and is widely applied to plastic foam to improve heat preservation in buildings, paints, coatings and synthetic leathers [6–8]. However, the using PU materials in pavement mixtures has not been extensively studied. Cong et al. [9] evaluated the performance of porous PU mixtures and open-graded friction course (OGFC). In addition, Wang et al. [10] and Li et al. [11] used a PU gravel mixture to produce a permeable pavement when used as a cement mixer. The proposed use of such porous PU gravel is in non-motor vehicle lanes and for landscape roads [12].

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Few studies have investigated the performance of PU modified asphalts. Behrokh Bazmara et al. [13] used a synthetic thermoplastic PU as an additive of asphalt. By subjecting this modified asphalt to five selected tests, including penetration grade, softening point, rolling thin film oven, pressure aging vessel, dynamic shear rheometer and bending beam rheometer, they demonstrated that PU based asphalt had an overall greater performance than SBS modified asphalts. Liu et al. [14] prepared PU modified asphalt using a disk-based serrated mixer under high temperature and compared its performance with that of Chinese standards [15]. They found that PU modified asphalt was resistant to high temperature and aging, and had good storage and water stability. Lei et al. [16] developed of castor oil-polyurethane (C-PU) modified asphalt, which was prepared using C-PU pre-polymer and base asphalt, and examined the classical and rheological properties of the asphalt. They also investigated the use of 10–30 wt% C-PU pre-polymer in base asphalt and characterized their properties using conventional experiments [17]. The results showed that the softening point, ductility and modulus of C-PU modified asphalt increased, while penetration and the phase angle slightly decreased. The performance of PU modified asphalts had not been well studied nor had their performance been systematically studied. In addition, the majority of studies related to PU modified asphalt had a high PU contents and therefore had high associated costs of production.

Herein, the performance metrics related to storage stability, segregation and aging of low content PU modified asphalts are investigated. Preparation equipment and processes of PU modified asphalt are recommended and the performances of PU, SBS or base asphalts and its mixtures are compared. In addition, the cost associated with PU and SBS modified asphalt mixtures are calculated and compared.

1.2. Objective

This study examines the preparation, evaluation and cost of PU modified asphalt. The objectives of this article are summarized as follows:

(1) Identify an effective method for the preparation of PU modified asphalt using a disk-based serrated mixer.
(2) Evaluate the performances of PU modified asphalt and its mixtures.
(3) Compare the cost of PU and SBS modified asphalt mixtures.

2. Experimental

2.1. Materials

2.1.1. Polyurethane

Polymers containing –NHCOO– macromolecular structures are termed polyurethane. PU is a synthetic material with many purposes. By varying the number and type of functional groups, various PU products, differing in properties and appearances, can be prepared [8,18,19]. Hence, PU can be used to prepare modified asphalts with desirable characteristics. The reaction of isocyanate and polyol with PU is used to determine the desired product. 4,4′-diphenylmethane diisocyanate (MDI) is used as the source of isocyanate. MDI is obtained from Wanhua Polyurethane Specialties (China) Company Ltd. The basic properties of MDI are as shown in Table 1. The performance indexes of PU used in this study are presented in Table 2.

2.1.2. Asphalt

The base asphalt used in this work is Shuanglong 70#, and its basic technical indexes are presented in Table 3.

Table 1
The basic properties of MDI.

Parameter	Results	Standard
Appearance	Pale yellow	Visual inspection
-NCO Mass fraction/%	33.5	Gravimetric method
Flash point/°C	213	ASTM D92
Density at 50 °C/g·cm^{-3}	1.182	ASTM D4052
Viscosity at 5 °C/mPa.s	5	ASTM D445

Table 2
The basic properties of PU.

Project	Appearance	Viscosity/mPa.s	Density/g·cm^{-3}
Test results	Yellow liquid	2400–3100	1.07–1.11

Table 3
Technical indexes of Shuanglong 70#.

Parameter	Results	Standard in China (JTG E20-2011)
Penetration/0.1 mm	71	T0604
15 °C Ductility/cm	>100	T0605
Softening point/°C	48.2	T0606
Dynamic viscosity at 60 °C/Pa.s	158.7	T0620
Elongation/%	5.7	T0629
Rupture strength/MPa	0.25	T0629

Table 4
The basic properties of SBS.

Parameter	Results	Standards
Melt flow index/g·10 min^{-1}	9	ASTM D1238
Proportion/g·cm^{-3}	0.94	ISO 2781
Tensile strength/MPa	190	ASTM D412
Elongation/%	900	ASTM D412

2.1.3. Styrene-butadiene-styrene

The ratio of styrene/butadiene of SBS is 60/40, the basic properties are presented in Table 4.

2.1.4. Accessory ingredient

In addition, polymer polyhydric alcohols, chain extender, stabilizer and organo-metallic catalyst are used in the test. Polyether polyol (PPG) is chosen as the polymer polyhydric alcohol, DC2517 as the chain extender, pentaerythritol as the stabilizer and dibutyl tin dilaurate as the catalyst. The ingredients are obtained from Wanhua Polyurethane Specialties (China) Company Ltd.

2.2. Preparation of PU modified asphalt

PU modified asphalt possesses reactive functional groups, which may be exposed using a disk-based serrated mixer, due to its high shear force that is applied to the surrounding medium (Fig. 1) [20]. As the performance of PU modified asphalt is drastically influenced by the preparation process, including the mixing rotation speed, time, temperature and the amount of modifier, they are investigated using a three-level and four-factor orthogonal test. Previous studies have found that the softening point of the modified asphalt has a good relationship with the gel time [14]. A higher softening point results in a shorter gel time. Therefore, the optimum preparation scheme is determined corresponding to the appropriate softening point.

The determined preparation process is as follows: 500 g Shuanglong70# base asphalt was heated to 170 °C and sheared using a