Construction and Building Materials 126 (2016) 66–76

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Modification mechanism of asphalt binder with waste tire rubber and recycled polyethylene

Dongdong Ge [a,b], Kezhen Yan [a,*], Zhanping You [b], Hongbin Xu [c]

[a] College of Civil Engineering, Hunan University, Changsha, Hunan 410082, China
[b] Department of Civil and Environmental Engineering, Michigan Technological University, 1400 Townsend Drive, Houghton, MI 49931-1295, USA
[c] Architectural and Environmental Engineering, The University of Texas at Austin, TX 78712, USA

HIGHLIGHTS

- WTR and RPE were used to modify asphalt binders in combination.
- Morphological and rheological properties of modified asphalts were investigated.
- The modification effect greatly depends on the concentration of WTR and RPE.
- The interaction among WTR, RPE and light components guaranteed the performance.
- The high temperature performance grade was remarkably increased.
- The low temperature performance grade was not sacrificed after the modification.

ARTICLE INFO

Article history:
Received 10 March 2016
Received in revised form 27 July 2016
Accepted 6 September 2016
Available online 12 September 2016

Keywords:
Asphalt binder
Waste tire rubber
Recycled polyethylene
Rheology
Morphology

ABSTRACT

In this paper, the fundamental modification mechanism of asphalt binder modified with waste tire rubber (WTR) and recycled polyethylene (RPE) was studied through a comprehensive laboratory program. The base asphalt binder was mixed with 5% and 10% WTR of the mass of the asphalt binder, respectively. The modified asphalt binder is then prepared with additional 2% and 4% RPE of the mass of the base asphalt binder, respectively. Morphological analysis methods, which included Fourier transform infrared spectroscopy (FT-IR), fluorescence microscopy, thermogravimetric (TG) and differential scanning calorimetry (DSC), were employed to understand the modification mechanism. Conventional tests, dynamic shear rheometer and bending beam rheometer were used to assess the rheological characteristics under different temperatures. From the testing results, it is found that the deformation resistance, high-temperature stability, and flexibility of asphalt binder are all improved after WTR and RPE were added. The modification mechanism of WTR and RPE on asphalt binder is the combination of physical process and chemical process. With proper modifying agent content, the interaction among WTR, RPE and light component guaranteed the homogeneity of asphalt binders, the WTR and RPE distributed uniformly in modified asphalt binder and the thermal stability was enhanced. The penetration decreased and softening point increased, which means that the deformation resistant was enhanced and the high-temperature stability was improved. The complex shear modulus (G^*) increased and the phase angle (δ) decreased after modification. When WTR dispersed in the bitumen, it formed a continuous elastic network. Furthermore, the increment of $G^*/\sin\delta$ proved that high-temperature deformation resistance was enhanced. The decrease in creep stiffness after modification with WTR and RPE suggested that the flexibility of asphalt binder was improved. The capacity to relax the load induced stresses was weakened at −6 °C, −12 °C, and −18 °C but the ability increased at −24 °C. The performance was more stable after modification and the effect was better at lower temperatures. The high temperature performance grade changed and low temperature performance grade kept unchanged after modification, the PG 64-22 base asphalt binder changed into PG 76-22 for base asphalt binder with 5% WTR and 2% RPE and PG 82-22 for base asphalt binder with 10% WTR and 2% RPE.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

The overburden of road traffic and the delay of proper maintenance resulted in the premature damage of pavement structures

* Corresponding author.
E-mail address: yankz@hnu.edu.cn (K. Yan).

http://dx.doi.org/10.1016/j.conbuildmat.2016.09.014
0950-0618/© 2016 Elsevier Ltd. All rights reserved.

around the world. Thus high quality asphalt mixtures are required for the pavement design, construction and maintenance. The asphalt binder should be capable of enduring thermal stresses due to temperature changes and the resulting pavement shrinkage to withstand traffic loads without emerging fatigue failures under repeated loading and unloading processes and resist permanent deformation owing to heavy traffics [1]. However, asphalt binder is highly affected by temperature. Asphalt binder will be softer and less viscous at high temperatures, which may have a negative impact on the permanent deformation of the asphalt mixtures [2,3]. Therefore, asphalt binder modification is needed to enhance various engineering properties of asphalt binder. By decreasing the stiffness of hot mix asphalt at high temperatures, the compaction performance of the asphalt mixture can be improved. Furthermore, rutting may be reduced if the stiffness of hot mix asphalt increased at high temperatures. The service life of the pavement will be increased if the proper asphalt binder modifier was adopted [4–8].

Polyethylene is one of the commonly used additives in terms of reducing the rutting, and the effect is more obvious under heavy loads [9]. Fang modified asphalt binder with both PE and OMMT. They found that the fundamental property of the modified asphalt binder improved remarkably. The high-temperature performance, low-temperature cracking resistance, and resistance to deformation increased remarkably [10]. Maharaj studied the impact of the PE particle dimension and contents on the performance of asphalt binder. It was concluded that the particle size and PE content have great relevance to the fatigue cracking resistance and rutting resistance [11]. Taher constructed a laboratory test to evaluate the impact of PE on the stiffness and permanent deformation of asphalt mixture. The results showed that the temperature variation, PET content and the stress level had great influence on the stiffness of the asphalt mixture. PE modification decreased permanent strain and the modified asphalt mixture has excellent resistance to permanent deformation [12,13]. Wang studied the combined modification of PE and rubber. The result indicated that the rheological properties of asphalt binder at different temperature ranges were enhanced after modification. In order to acquire stable modified asphalt binder, the density difference should be reduced and the interaction needs enhanced [14]. However, the compatibility between PE and asphalt binder is not good because of the crystalline property of PE when mixed with asphalt binder [15]. And there is no improvement in the low-temperature performance of asphalt binder when only mixing with PE particles [16]. What's more, PE particles will detach from asphalt binder if stored improperly, which restricts the use of PE modified asphalt binder [17].

Previous studies have demonstrated that the pavement performance and mechanical behavior of crumb rubber modified asphalt binder was good [18–22]. Huang studied the modification mechanism of rubber on asphalt binder. The result found that the rutting resistance was improved because at high temperatures the viscosity and elasticity increased. The fatigue resistance was improved at low temperatures because after aging, the viscosity decreased [23]. The addition of waste tire rubber (WTR) to base asphalt binder can enhance the property of asphalt binder, such as reduce construction and maintenance costs, improve resistance to permanent deformation, decrease fatigue damage and thermal cracking potential, reduce the thickness of the pavement structure and decrease the possibility of reflective cracking [24]. By adding WMA additive and rubber, the low-temperature performance of modified asphalt binder could be enhanced and the long-term performance of pavement can be extended slightly [25]. But the characteristic of asphalt binder is closely related to the additive types and the low-temperature property of the modified asphalt binder is enhanced when the rubber content is higher [26]. Abdelrahman studied the modification mechanism of crumb rubber modified asphalt binders, exchange of components played important role during the process, interaction conditions affected the crumb rubber modifier dissolution performance and the formation of network structure, in which interaction temperature is the main factor affecting the performance of crumb rubber modified asphalt binders [27,28]. However, rubber asphalt binder needs complex modification and construction technology, as it may result in energy waste and environmental problems, for example rubber asphalt binder needs higher construction temperatures compared to normal mixtures because of the higher viscosity of rubber asphalt binder [29,30]. What's more, many additives have been proven to improve the consistency and interaction between rubber and asphalt binder as well as improving the quality of rubber modified asphalt binder.

To overcome these problems and prolong the service life of asphalt binder, asphalt binder was mixed with WTR and recycled polyethylene (RPE). Hence, this study aims to investigate the modification mechanism of WTR and RPE on morphological and rheological characteristics of asphalt binder through laboratory tests. Infrared spectroscopic analysis, fluorescence microscopic image analysis, and thermogravimetric and differential scanning calorimetry analyses were carried out to explore the morphological characteristic of WTR and RPE modified asphalt binder. What's more, DSR and BBR tests were carried out to investigate the rheological behaviors of WTR and RPE modified asphalt binder in this study.

2. Materials and methods

2.1. Materials

In this study, AH-70 asphalt binder was used as the base asphalt binder. The basic performance index of asphalt binder are displayed in Table 1. The RPE was obtained from a petrochemical company in Xi'an (Shaanxi Province, China). The density of RPE was 0.92 g/cm^3 and the melting index was 0.8 g/10 min (190 °C, 2.16 kg). The WTR was manufactured by mechanical grinding at ambient temperature, and the diameter of the particles was smaller than 0.3 mm.

2.2. The procedure of asphalt binder modification

Two different contents of WTR (5% and 10% wt) and two different contents of RPE (2% and 4% wt) were mixed with base asphalt binder. The list of modified asphalt binder type and quantities are shown in Table 2. Firstly, the base asphalt binder was preheated in a container until it became liquid. After the temperature reached about 180 °C, the WTR and RPE of a certain amount were mixed with the asphalt binder in sequence and stirred for 20 min at a shearing ratio of 2000 rpm. Then, the asphalt binder was sheared at 180 °C with a speed of 5000 rpm for 1.5 h. Finally, the asphalt binder was stirred with a low shearing ratio (<100 rpm) for 30 min to eliminate the air introduced by the high speed shearing procedure.

Table 1
Basic performance index of asphalt binder.

Parameter measured	Results
Penetration at 25 °C (100 g, 5 s) (0.1 mm)	66.8
Penetration index (PI)	−1.18
Ductility at 15 °C (5 cm/min) (cm)	143.4
Softening point (R&B) (°C)	47.1
Viscosity (135 °C) (Pa·s)	0.39

Download English Version:

https://daneshyari.com/en/article/6480821

Download Persian Version:

https://daneshyari.com/article/6480821

Daneshyari.com