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Rheological properties of asphalts modified by waste tire rubber and reclaimed low density polyethylene

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HIGHLIGHTS

- Combinations of waste tire rubber and reclaimed low density polyethylene were used to modify asphalt binders.
- Rheological properties of the WTR/RPE modified asphalts were investigated.
- Much more enhanced rheological properties were observed for WTR/RPE modified asphalts.
- The compound modification effect greatly depends on the concentration of WTR and RPE.

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ABSTRACT

To identify the compound modification effect of waste tire rubber (WTR) and reclaimed low density polyethylene (RPE) on the asphalt binders' rheological properties, WTR/RPE modified asphalts with different contents of WTR and RPE were prepared this study. Their rheological characteristics were measured by conventional tests as well as dynamic mechanical methods using dynamic shear rheometer (DSR) and binding beam rheometer (BBR). After mixed with WTR and RPE, the asphalts show decreased penetration and phase angle, increased softening point, rotational viscosity and complex modulus, indicating that intermediate and high temperature rheological properties of the asphalts have been improved by the modification of WTR and RPE. However, the modification effect of WTR and RPE on the low temperature rheological properties of asphalts is controversial, as the addition of WTR and RPE introduces decrease both in creep stiffness and *m*-value. Rheological properties of the WTR or RPE modified asphalts are largely dependent on the WTR or RPE content, and much more enhanced mechanical properties can be achieved using a combination of both WTR and RPE. What's more, polymer network is developed in the WTR/RPE modified asphalts, and even though its formation is greatly influenced by the content of both WTR and RPE, WTR may have a predominant effect on it.

1. Introduction

Polymer modified bitumens (PMBs) are combinations of polymer and asphalt through mechanical mixing or chemical reactions [23]. Compared with virgin bitumen, they are often characterized by increased stiffness at high temperatures and improved flexibility at low temperatures, which can provide the corresponding asphalt mixture pavement with enhanced resistance to deformation under traffic load at high temperatures and increased resistance to cracking at low temperatures. Because of their performance, PMBs have been widely used in the constructions of road pavements. Currently, the most commonly used polymer is the styrene butadiene styrene (SBS), however, although it can improve binders' properties both at high and low temperatures, many researchers have reported that aging of SBS PMBs tends to result in a reduction of the molecular size of the SBS and a decrease in the elastic response of the modified bitumen [2], what's more, the pavement cost increases greatly due to SBS's high price. Considering this and many environmental problems caused by disposal of waste polymers, many researchers have studied the use of recycled polymers to act as alternatives [12,17,21], such as waste rubber and low density polyethylene.

The use of rubber as asphalt modifier in road constructions can date back to 1960, when Charles McDonald first added crumb rubber in asphalt mixtures to improve the pavement performance [7,11,15]. During the last decades, crumb rubber modified asphalt binder has been widely used as road paving materials worldwide [20]. As indicated in many studies [4,9,14,17], after adding rubber the asphalt exhibits increased viscosity and elastic properties at

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high temperatures, thus making it more capable of resisting permanent deformations. Moreover, it is also found that by adding rubber the low temperature stiffness of asphalt decreases endowing it improved flexibility to resist low temperature cracking [3,19,20].

Polyethylene is also a commonly used asphalt modifier, and it can bring a high rigidity to the bitumen, thus significantly reducing the deformations under traffic load at high temperatures [5]. However, even though it is discovered that adding polyethylene can minimize low-temperature cracking [6], the low temperature flexibility of bitumen can't be improved by adding PE alone [21], so polyethylene seems to be less effective in low-temperature range specially compared with rubber.

Considering the properties of rubber and polyethylene modified asphalt, it's promising to incorporate rubber with polyethylene in asphalt modification, which can not only reinforce the improvement of high-temperature performance, but also relieve the deterioration of low-temperature flexibility resulting from adding PE. There are already several studies concerning the compound modification of asphalt using the combination of rubber and PE in road and roofing applications [10,12,18]. In these studies, the effects of rubber and PE are combined, resulting in enhanced high temperature properties compared to single modified asphalts and improved low temperature properties compared to polyethylene modified asphalts. However, although impressive conclusions were made in these studies, the analysis of rheological properties was based on small range of concentrations or conventional tests that are unable to quantify the unique rheological characteristics of different PMBs. In this, research on the rheological properties of rubber/PE modified asphalt still needs supplement.

In this research, reclaimed low density polyethylene (RPE) and waste tire rubber (WTR) were incorporated to both enhance rubber's improvement on the high temperature performance of asphalt binders and complement LDPE's weakness in improving their low temperature performance. RPE/WTR modified bitumens with different RPE and WTR contents were produced using wet process and went through conventional tests, rotational viscosity test, dynamitic shear test, and low temperature creep test to assess their rheological responses.

(a) WTR

(b) RPE

Fig. 1. Waste tire rubber (WTR) and reclaimed low density polyethylene (RPE).

2. Materials and experimental

2.1. Materials

Base asphalt AH-70 was used in this study and its physical properties are listed in Table 1. The waste tire rubber (Fig. 1a) used here was derived from ambient grind, and the mean particle size of the particles, determined by screening, was 0.29 mm. The reclaimed low density polyethylene (Fig. 1b) was purchased from Laizhou (Shandong Province, China), with a density of 0.92 g cm^{-3} and a melting index of 0.8 g/10 min (190 °C, 2.16 kg).

2.2. Sample preparation

In this study, three WTR concentrations (5%, 10%, 15%) and four RPE concentrations (2%, 3%, 4%, 5%), with respect to the weight of base asphalt, were selected. Modified asphalts with different WTR and RPE concentrations were produced through a mechanical shearing process, and this process was conducted in an open cylindrical can (100 mm diameter) using a FLUKO FM-300 shearing machine (China). Firstly, the base asphalt was heated to 180 °C to make it fully melted, then the RPE and WTR were added to the asphalt in sequence, with a shearing speed of 2000 r/min for 20 min. After this, the mixtures were stirred at a speed of 5000 r/min for 1.5 h at 180 °C and followed by a 20 min low speed (<100 r/min) stirring to exclude the air introduced by the high speed shearing process.

Table 1
1 Physical properties of base asphalt.

Performance indexes	Test results
Penetration (25 °C, 100 g, 5 s) (0.1 mm)	66.8
Penetration index (*PI*)	−1.18
Softening point (*R&B*) (°C)	47.1
Ductility (15 °C, 5 cm/min) (cm)	143.4
Viscosity (135 °C) (Pa s)	0.39

2.3. Conventional tests

Penetration test at 25 °C, ductility test at 15 °C and softening point test were conducted to characterize the conventional physical properties of asphalts, according to ASTM D5, ASTM D113, ASTM D36, respectively. What's more, to identify the rotational viscosities of WTR/RPE modified asphalts, the Brookfield viscometer was used in this study in accordance with ASTM D4402.

2.4. Dynamic shear test

Although the conventional binder properties, such as softening point and high temperature viscosity, are able to indicate increases in stiffness and viscosity caused by polymer modification, they are generally unable to quantify the unique rheological characteristics of different PMB groups [2]. Considering this, WTR/RPE modified asphalts' intermediate and high temperature rheological properties were mainly measured by dynamic shear tests. The tests were conducted using a dynamic shear rheometer in a configuration of two parallel plates (diameter 25 mm) with a gap of 1 mm. The tests were performed under controlled strain conditions, and strains applied to the samples were defined through amplitude sweep. To