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Investigation on physical and high temperature rheology properties of asphalt binder adding waste oil and polymers

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HIGHLIGHTS

- Asphalt binder containing waste oil and polymers is prepared.
- Physical and high temperature rheology properties of asphalt binder are analyzed by tests.
- The resistance aging ability of asphalt binder is improved by the waste oil and polymers.
- Asphalt binder containing waste oil and polymers has better high and low temperature performance.
- The waste oil can improve the compatibility of polymer modified asphalt binder.

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ABSTRACT

The asphalt binders containing polymer modifier are more and more widespread, which can effectively degrade the disable of asphalt pavement and improve the service life of the road. The waste oil is recycling resource required from natural oil, and it is harmful to the people healthy. The paper researched a new method of the polymer modified asphalt binder containing the waste oil and the relative properties were researched. Experimental results illustrated that the improvement of anti-aging property is noticeable when waste oil and polymer were added into asphalt. The results of dynamic shear rheometer (DSR) showed that the asphalt containing waste oil and polymers has the better high temperature property. Meanwhile, the repeated creep recovery test (RCRT) is employed to simulate the stress and deformation of asphalt binders in pavement. The results also showed that the asphalt binder containing the polymers and waste oil has lower deformation and better recovery. Finally, the storage stability of the asphalt binders is presented. The results proved that the effects of waste oil on storage stability of asphalt/waste oil/polymers blends are little and can be used in pavement after long time storage at high temperature.

1. Introduction

Waste oil generated from the edible oil repeated frying, and those are regarded as potential alternative binders used in flexible pavement. Some basic physical and chemical properties of waste oil have been researched in previous studies [1–3]. Usually, bio-oil such as waste oil has similar components as petroleum asphalt binder. The ingredients can be classified as saturates, aromatics, polar and asphaltenes [4]. Some researches indicated that waste oil can improve the low temperature performance of asphalt binder [5]. Asli found that waste cooking oil can significantly reduce the softening point and viscosity of the aged asphalt binder [6]. Zeng investigated the properties of asphalt binder containing castor oil-based bioasphalt using conventional tests [11]. The results indicated that the penetration increased, the softening point decreases slightly with increasing bioasphalt content. The mass change, the retained penetration, and the ductility after RTFOT test vary moderately with increasing bioasphalt content, indicated acceptable aging resistance of the bioasphalt. Chen et al. also referred the physical, chemical and rheological properties of waste edible vegetable oil rejuvenated asphalt binders [7]. The result showed that the waste oil can effectively soften aged asphalt. The rutting parameter, phase angles and complex modulus of asphalt binder can be improved to a certain level by adding a certain amount of waste edible vegetable oil. Wan Nur Aifa Wan Azahar researched the rheological performance of asphalt after adding the waste oil, and the results proved that waste oil can increase rutting resistance and reduce temperature susceptibility of asphalt binder [8]. Therefore, waste oil was identified as one of the alternative solutions to improve the physical and rheological performance of asphalt binder. At the same time, Sun conducted that the bio-oil

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derived from the waste cooking oil can reduce the deformation resistance and improves the stress relaxation property [9]. Xu investigated the high temperature performance evaluation of bio-oil modified asphalt binders [10]. The results showed that the addition of bio-oil can increased complex modulus and rutting potential index, and reduced the phase angle of asphalt binders, which indicated that the high temperature stability was improved by bio-oils. From the multiple stress creep recovery (MSCR) test, the addition of bio-oil reduced the non-recoverable creep compliance (J_{nr}) and increased recovery proportion, that also indicated the improvement of high temperature stability and elasticity. Thus, it is concluded that the bio-oil can improve asphalt's high temperature performance. Jia et al. claimed that both asphalt binder and waste engine oil consist of similar functional groups and molecular structures [12–14]. At the same time, the waste engine oil adding into the asphalt binder leads to a decreased rutting resistance of the asphalt binder. A significant similarity was identified between the previous studies, in which there is no denying that waste oil can be used to regenerate aged asphalts. Moreover, in previous studies, waste oil was not being at an optimum dosage. How to use the waste oil in asphalt and improve the low temperature performance, flexibility, elasticity and thermal stability are a significant research.

In this paper, the polymers containing styrene-butadiene-styrene (SBS) and polyethylene (PE), and waste oil were blended into the asphalt and the physical and high temperature rheological properties were studied. There is a little research about the polymers and waste oil was added into asphalt to improve the asphalt's performance. Therefore, the study aims to assess the influence of polymer and waste oil on the properties of asphalt, and the short term aging and long term aging, dynamic shear rheology, repeated creep properties, storage stability and physical properties of asphalt binders were investigated.

2. Materials and methods

2.1. Raw materials

The 80/100 pen grade asphalt (made in the Korea), with penetration of 88.4 dmm (decimillimetre, 25 °C, ASTM D5), softening point of 46.0 °C(ASTM D36), ductility of 6.4 cm(5 °C, ASTM D113) and viscosity of 0.338pa·s at 135 °C(ASTM D4402), was used to prepare modified asphalt binder. The physical properties of asphalt are listed in the Table 1. The polymers include SBS and PE used in the study. The SBS was manufactured by the Yanshan Petrochemical Co., Ltd., in China and it was a star-like material, containing 30% of styrene by weight with an-average molecular weight of 180,000 g/mol. The PE was made by China Petroleum and Chemical Corporation (Sinopec) and it was linear low density polyethylene with an-average molecular weight of 115,000 g/mol.

2.2. Preparation of modified asphalt binders

All the modified asphalt binders were prepared using a high shear mixer (made by Fluke Machine Co., Ltd., Germany). Asphalt was heated to 150 ± 5 °C in a heating iron container and the waste oil was mixed with asphalt. Then, The SBS and PE were added into asphalt slowly, keeping at 150 °C while swelling 30 min at 150 °C. The mixture was sheared and mixed under 4000 rpm rotation speed for 50 min at 170 °C to ensure the blend became essentially homogenous. The asphalt binders containing different dose polymers were also treated using the same process for the purpose of advisable comparison in the Table 2. For convenience, the five kinds of asphalt specimens SK90#, 5% waste oil + 5.5% SBS + 5% PE, 5.5% SBS + 5% PE, 5% waste oil + 3.5% SBS + 3% PE and SBS are sequentially denoted SK90#, Y5S5.5P5, S5.5P5, Y5S3.5P3 and SBS.

Table 1
Physical properties of original asphalt.

Property	Results	Test Method
Penetration (25 °C,0.1 mm)	88.4	ASTM D5
Softening point (°C)	46	ASTM D36
Viscosity at 135 °C (pa·s)	0.338	ASTM D 4402
Ductility at 5 °C (cm)	6.4	ASTM D113

2.3. Aging procedures

The Thin Film Oven (Model B1, CONTROL Co., Ltd., Italy) was employed to simulate short term aging according to ASTM D1754. In the test, the 50 g sample of asphalt is placed in a cylindrical flat-bottom pan transferred to a shelf in a ventilated oven maintained at 163 °C. The shelf rotates at 5 to 6 revolutions per minute. The sample is kept in the oven for 5 h.

The Pressure Aging Vessel (Model B1, CONTROL Co., Ltd., Italy) was employed to simulate long term aging according to ASTM D454 and ASTM D572. The PAV composed of stainless steel must be able to operate under the pressure (2070 KPa) and temperature conditions (90 °C, 100 °C, or 110 °C) of the test. The vessel accommodates a sample rack on which ten sample pans can be placed for aging. In the study, the temperature is designed at 100 °C. The PAV is placed in an oven for 20 h to maintain the desired temperature inside the vessel.

2.4. Conventional physical properties test

The conventional physical properties of asphalt binders, including softening point, penetration and ductility, viscosity were tested in accordance with ASTM D36, ASTM D5, ASTM D113-99 and ASTM D4402, respectively.

2.5. Dynamic shear rheological characteristic

The dynamic shear rheometer (DSR, MCR101, Anton Paar Co. Ltd of Austria) [15] is used to characterize the viscous and elastic behavior of asphalt binders at high and intermediate service temperatures in a parallel plate configuration with a gap width of 1 mm. The DSR measures the complex shear modulus (G^*) and phase angle (δ) of asphalt binders at the desired temperature and frequency of loading. Complex modulus consists of two components, storage modulus (G'), and loss modulus (G''). G^* can be considered as the total resistance of the binder to deformation when repeatedly sheared. The test procedure is given in AASHTO TP5. Temperature sweeps (from 30 °C to 85 °C) were applied at a fixed frequency of 10 rad/s. The plate used for temperature sweep test was 8 mm in diameter and the gap between the parallel plates was 2 mm. Frequency sweeps are showed at the frequency range 0.01 rad/s to 100 rad/s at the temperature (35 °C, 45 °C, 55 °C, 65 °C, 75 °C and 85 °C).

2.6. Repeated creep recovery test

Repeated creep recovery test was proposed by the Superpave draft of America NCHRP9-10. The test is designed by the repeated loading and unloading mode, which uses loading 1 s at a certain stress and unloading 9 s. In the study, the repeated creep recovery test was achieved by the dynamic shear rheometer.

2.7. Storage stability

Storage stability of modified asphalt is a rather important technical criterion of production. The hot storage test is used to evaluate the high temperature storage stability of modified asphalt binders. The storage stability of modified asphalt binders was tested as following procedure: the sample was poured into an aluminum tube (25 mm in diameter and 140 mm in height). The tube was sealed and stored vertically in an oven at 163 ± 5 °C for 48 h. Then the aluminum tube containing the modified asphalt binder was taken out of the oven and cooled in a refrigerator −7 °C ± 5°Cfor 4 h. Finally, the tubes were cut into three equal sections. The sections from the top and bottom were placed in separate dishes in an oven at 163 °C until the asphalt binder had well fluid to pour into softening point rings. If the difference of softening point (ΔS) between the top and the bottom sections of the tube was less than 2.2 °C, the sample could be regarded as a storage stable blend.

3. Results and discussion

3.1. Effect of aging on the conventional parameters

Softening point increment after aging can clearly reflect the susceptive degree of aging. It can be calculated by the following Eq. (1):

$$SPI = S_{aged} - S_{unaged} \quad (1)$$

Where: SPI is the softening point increment after aged. S_{unaged} and S_{aged} is softening point of asphalt binder before and after aged, respectively.