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Viscoelasticity of Asphalt Modified With Packaging Waste Expended Polystyrene

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In view of environmental and economic aspect, asphalt was modified with recycled packaging waste expended polystyrene (WEPS) instead of common polymer. The differential scanning calorimetry (DSC), rotational viscometer and dynamic shear rheology (DSR) were used to analyze and evaluate the viscoelasticity of modified asphalt. Results indicate that the sensitivity of modified asphalt to temperature is decreased while the rut resistance of asphalt is increased. In addition, the viscoelasticity of asphalt is improved after the modification with WEPS. Besides, the modified asphalt has high viscosity at low temperature and low viscosity at high temperature, which is favorable for construction.

KEY WORDS: Waste plastics; Characterization; Viscosity

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1. Introduction

Asphalt plays an important role in modern road traffic, especially in highway. The quality of asphalt has an influence on the road life and safety. Asphalt is a seamless and continuous road material with many advantages, e.g. smooth driving, facilitating conservation, less dusty etc. With the sustained development of China, there are growing requirements for road construction than ever before. The addition of large vehicles brings about increased traffic loads and severe overloading; and the current road asphalt cannot meet today's transportation requirements. Besides, China has a vast territory with widely diverse environmental conditions; high temperature maintains all year in some regions, while a large temperature gradient exists in some other regions, where a favorable high/low temperature stability of asphalt is necessary.

Asphalt is a complex mixture consisting of four components, saturates, aromatics, resins and asphaltenes. The pavement performance of modified asphalt can be improved by adding modifier into the original asphalt to change the components, structure and the viscoelasticity of asphalt. Modified asphalt is one kind of typical viscoelastic materials, and its dynamic shear rheological properties are close to the actual viscoelastic behavior, indicating that it is more adapted to test the actual usability of asphalt[1].

Viscosity or elasticity, or a combination of both of asphalt may occur, which relies on the temperature and proportion of each component of asphalt [2]. In recent years, many experts and scholars have used different methods to study the viscosity of polymer modified asphalt. Zhan et al. [3] measured viscoelastic parameters of asphalt, such as storage modulus, loss modulus and phase angle. Li et al.[4] investigated the needle penetration, softening point and ductility according to T-0606-2000, T-0604-2000 and T-0605-1993, and confirmed the optimal ratio of coal tar pitch modified asphalt through viscosity testing. Dongre et al.[5] proposed high-temperature evaluation parameter using η' (kinetic viscosity) at 0.01 rad/s. In all these studies, only single/non-systematic method has been applied to evaluate the viscosity of modified asphalt.

As one of the commonly used packaging materials, waste expended polystyrene (EPS) offers shockproof packaging material in many fields, such as household appliances, instruments and electronic products[6]. However, the product is often disposable, resulting in serious threats to natural environment. Recovery of WEPS is a research hotspot all over the world. In this work, the asphalt base is modified with WEPS, and its viscoelastic property is analyzed.

2. Materials and Methods

2.1. Raw materials

The asphalt used in this study was conventional asphalt (90#), and its properties are shown in Table 1. WEPS was obtained

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Table 1 Properties of 90# asphalt

Penetration (25 °C, 100 g)/0.1 mm	Softening point (ring and ball method) (°C)	Ductility (cm)
86.13	51.25	>200

Table 2 Properties of recycled WEPS

Main components	Softening temperature (°C)	Antifreeze temperature (°C)	Compression degree (MPa)	Density (g/cm^2)
EPS	75	−40	107	0.15

from recycled TV's buffer packaging liner, and its properties are given in Table 2.

2.2. Preparation of modified asphalt

The WEPS was dried at room temperature after being cleaned, and then shaved into small particles with Komon knife (as shown in Fig. 1).

The asphalt was heated at 150 °C until it was fully melted and then a certain amount of WEPS (listed in Table 3) was slowly added. The mixture of asphalt with WEPS was heated to 190 °C, followed by manual stirring for 30 min and automatic stirring for 1.5 h with a JRJ 300-S digital shear emulsifying mixer (Shanghai Specimen Model Factory, China). The mixture was then cooled to 120 °C and kept for 30 min to disperse WEPS evenly in the asphalt.

2.3. Performance test

The differential scanning calorimetry (DSC) curves were obtained on a 2910 differential scanning calorimeter (US Ta Model) in the temperature range from −40 °C to 180 °C at a heating rate of 10 °C/min.

Rheological characteristics were examined with an AR1500ex dynamic rheological shear apparatus provided by Ta company, US.

Complex shear modulus (G^*), storage modulus (G'), loss modulus (G''), phase angle (δ) were measured by a dynamic shear theometer. G^* and δ can be used to characterize the viscosity and elasticity of modified asphalt[7,8].

Viscosity was measured by using a Brookfield DV-II type rotary viscometer made in Middleboro of USA.

3. Results and Discussion

3.1. DSC results

The DSC peak area forms direct ratio to all heat of reaction. It provides a chemical method to study the endothermic behavior of asphalt quantitatively because of high-precision and good reproducibility[9]. From a thermodynamic perspective, during the heating process three states are presented in asphalt, which are glassy, viscoelastic, and viscosity fluid state. The glass transition of asphalt, which is not a real thermodynamic second order transition, but a relaxation process of polymer or macromolecular chains, and viscous flow transition have a wide temperature range. As seen in Fig. 2, base asphalt has one absorption peak and the modified asphalt has two endothermic peaks. Zhang et al.[10,11] demonstrated that the endothermic peak reflects the extent of transformation in the aggregation, the ratio of solid to liquid and the viscoelasticity of asphalt. As WEPS is added, the absorption firstly goes down and then slightly goes up. Weaker absorption usually suggests better plasticity and thermal stability of asphalt[12]. The bigger absorption peak becomes, the microscopic properties of the asphalt components in this temperature range change more, and state interval occurs in more components, which include the crystalline component of the molten, the non-crystalline component of phase change and have an immense impact on macroscopic. The reason is that the high-speed mixing leads to the uniform disperse of WEPS in asphalt, as shown in Fig. 3. The WEPS can effectively absorb the wax in asphalt and remove the adverse effects of wax on the susceptibility of temperature and plasticity at low temperature.

3.2. DSR analysis

3.2.1. Viscoelasticity of modified asphalt. As shown in Figs. 4–6, the G^*, G', G'' of modified asphalt and asphalt decrease dramatically as the temperature increases from 64 °C to 70 °C, which is due to the sliding motion of chain molecules induced by the thermal absorption of asphalt. The G^* in

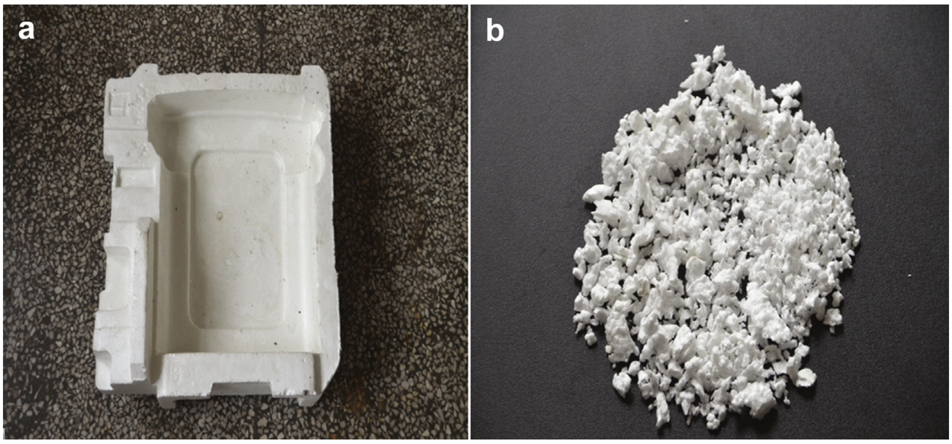

Fig. 1 Optical images of recycled EPS (a) and (b) EPS small particles obtained by cutting.