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Modification mechanism of asphalt modified with Sasobit and Polyphosphoric acid (PPA)

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HIGHLIGHTS

- Sasobit and PPA 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 PPA.
- The PPA content should be no more than 1.0% to guarantee the low-temperature property of asphalt.
- The interaction among Sasobit, PPA and asphalt guaranteed the performance.

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ABSTRACT

The laboratory performance and modification mechanism of asphalt modified with Sasobit and Polyphosphoric acid (PPA) were studied through a comprehensive laboratory program. The base asphalt was mixed with 3% Sasobit to produce Warm Mix Asphalt (WMA) and then modified with four different percentages of PPA (0.5%, 1.0%, 1.5% and 2.0%) by mass of base asphalt, respectively. The rolling thin film oven (RTFO) and the pressure aging vessel (PAV) procedures were conducted to simulate the aging of asphalt. Experiments were conducted for asphalts under different aging conditions. The rheological property of asphalt was measured by conventional tests, the Dynamic Shear Rheometer (DSR) and Bending Beam Rheometer (BBR). The morphological characteristic of asphalt was evaluated by Fourier Transform Infrared Spectroscopy (FT-IR), Fluorescence microscopy, Thermogravimetric (TG) and Differential Scanning Calorimetry (DSC). It is concluded that the rheological properties of asphalts were enhanced after Sasobit and PPA were added. The penetration of asphalts decreased and softening point increased, proving that deformation resistance was enhanced and high-temperature stability improved. The ductility decreased to an acceptable level when the PPA content was less than 1.0%. High-temperature deformation resistance and aging resistance were enhanced for asphalts under different aging conditions. In order to guarantee the low-temperature property of asphalt, PPA content in WMA should be no more than 1.5%. The modification effect of Sasobit and PPA on asphalt included chemical and physical processes. The compatibility between PPA, Sasobit and base asphalt is good and the microstructure of the modified asphalt is beneficial in improving the performance of asphalt. The addition of Sasobit restricted the decomposition process of the asphalt component, and the addition of PPA further alleviated the decomposition process and enhanced the stability of asphalt.

1. Introduction

By lowering the viscosity, Warm Mix Asphalt (WMA) technology reduced mixing and construction temperatures of asphalt mixtures compared with traditional hot-mix asphalt (HMA). The most significant benefit of WMA concerns the environment impact. Fossil fuel consumption and air contamination are decreased in the manufacturing process. The fuel cost may reduce by 40%, and the savings increased in countries where the price of fuel is more expensive [1]. The manufacturing temperature, the energy cost, the emission of gas, and organic compounds varied depending on the manufacturing method adopted in WMA technology. During

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the constructive process, the health of engineering works is highly related to the construction environment. With fewer harmful gasses generated in the construction of WMA mixtures, the health and safety of works are guaranteed [2,3]. However, some researchers found that the energy savings do not compensate the additional cost of additives used to manufacture WMA mixtures. What's more, in some production plants, machine modifications are required to produce WMA mixtures, which add extra cost to WMA pavement. Generally, the cost of WMA mixtures is higher than that of HMA mixtures, and the cost varied in line with the manufacturing method and the additives being adopted [4,5].

The viscosity of WMA mixtures is lower when Sasobit was mixed in asphalt as warm mix additive, thus the workability improves and the newly paved roads can open earlier. The lower compaction temperature makes it possible to pave WMA mixtures as thin asphalt layers and to pave in colder temperatures. The haul distances may be increased before mixtures are transported and compacted in the pavement [6–10]. Another benefit of WMA technology is producing WMA mixtures modified with reclaimed rubber and reclaimed asphalt pavement under lower construction and compaction temperatures without affecting the performance of mixtures significantly [11]. During the rejuvenation and softening process of aged asphalt from RAP, the workability improves, which allows higher RAP content for WMA mixtures. Doyle and Howard studied the rutting and moisture potential of WMA with different RAP content. The research found that the property of WMA with high RAP content was comparable with HMA with lower RAP content [12]. The short-term aging degree was decreased for WMA mixtures because the mixtures were manufactured and compacted under lower temperatures and the fatigue resistance and low-temperature cracking performance were almost the same when compared with HMA [13]. The adhesion between aggregate and asphalt was stronger for WMA mixtures when considering the short-term aging conditions. Nazzal studied the compaction effect of asphalt mixtures and found that the density of WMA mixture cores acquired in the field was higher than HMA mixture cores [14]. Estakhri used X-ray to evaluate the distribution of air voids for WMA and HMA mixtures; the air void distribution of WMA mixtures was more uniform, proving that WMA mixtures possess an even better field performance [15].

Rutting and moisture damage are two main problems for WMA mixtures. Lower stiffening occurred for WMA under lower manufacturing and compaction temperatures and lower short-term aging conditions. WMA mixtures are hard to be fully compacted and are prone to accumulate permanent deformation and rutting [16,17]. Water in the mixture weakens the interface between aggregate and asphalt, decreases the strength of asphalt mixtures, increases the probability of permanent deformation accumulation and results in the damage of asphalt mixtures [18]. The water in aggregate cannot be excluded completely under lower heating temperatures, which results in the loss of adhesion between aggregates and asphalt [19]. In coping with this kind of moisture damage, researchers tried a variety of methods to guarantee sufficient bonding between aggregate and asphalt, such as adding lime or anti-stripping additives into asphalt mixtures, using aggregate with good performance, optimizing aggregate grading, and increasing the construction quality [20,21].

According to the different type of additives used, three technologies can be adopted to produce WMA, which includes organic additives, chemical additives, and foaming processes [22–24]. The mechanical properties of WMA highly depend on the type of WMA technology adopted and the amount of additives and the performance of WMA varies in large ranges [25]. One of the most commonly used organic additives is Sasobit, which is a synthetic wax fabricated from the coal gasification process. The melting point of Sasobit is around 100 °C. When Sasobit is mixed with asphalt and when the temperature reaches above 116 °C, it is fully miscible in asphalt [26]. The viscosity of asphalt reduced significantly when Sasobit was added, allowing asphalt mixture construction temperatures to be decreased by 20–30 °C. Energy consumption and carbon emissions were also decreased during this process [14,27]. When temperatures dropped below the melting point of Sasobit, a lattice structure was formed in the asphalt and the molecules movement was restricted in the modified binder, then the stiffness of asphalt at low and intermediate temperatures increased, and improved the permanent deformation of WMA mixtures produced with Sasobit [28,29].

Different kinds of Polymer modifiers were adopted to increase the performance and durability of asphalt by mechanically dispersing polymers in melted asphalt with high shear force. There were many factors should be considered when producing polymer modified asphalt, which including required mechanical property, high-temperature viscosity, storage stability, and related cost. The modifiers can be divided into three categories: elastomers, plastomers, and reactive polymers [30]. SBS is mostly used and studied elastomeric modifiers in pavement industry. Many researchers concentrated into their research focus on the interaction and compatibility between SBS and asphalt, and the influence of SBS structure on the performance of SBS modified asphalt [25,31–33]. Plastomeric modifiers were widely used due to less expensive and the asphalt was more stable after modification compared with SBS modified asphalt. Polyethylene (PE) and polypropylene (PP) were two main plastomers adopted due to their availability as waste materials and the environment influence promoted their application [34]. The rigidity was improved and the rutting resistance was enhanced under heavy traffic load after asphalt was modified [35]. Some reactive polymers were adopted to modify asphalt because the nature that they can react with asphalt to improve the compatibility of modified asphalt. Sometimes reactive polymers were treated as compatibilizers and mixed with other polymers to modify asphalt. However, the high cost of reactive polymers restricted the application as only limited amount were used for asphalt modification [36,37].

There is an increasing trend in the application of PPA in asphalt modification due to the lower price of PPA compared with normal polymer modifiers. The PPA modifier can notably increase the stiffness of asphalt in an easy manner. The addition of PPA can increase the initial stiffness and thus decrease the early rutting potential of the pavement. The service life of pavement can be extended due to the improvement in the low-temperature flow property. Fatigue cracking and low-temperature cracking of asphalt can be reduced by modification with PPA [38–40]. Some laboratory studies indicated that the stiffening effect of PPA on binders highly depends on the crude source [41].

2. Objectives and scopes

The primary objective of this study is to determine the modification mechanism of PPA in WMA containing Sasobit through a comprehensive experimental procedure. The asphalt was manufactured with Sasobit and PPA, and aged using the rolling thin film oven (RTFO) to simulate short-term aging and aged using the pressure aging vessel (PAV) to simulate long-term aging. Conventional tests, as well as, the dynamic shear rheometer (DSR) and binding beam rheometer (BBR) were used to determine the influence of PPA on warm mix asphalt. Microanalysis methods, which included Fourier transform infrared spectroscopy (FTIR), differential scanning calorimetry (DSC) and thermo-gravimetric (TG), were adopted to analyze the modification mechanism.