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Improving thermo-rheological behavior and compatibility of SBR modified asphalt by addition of polyphosphoric acid (PPA)

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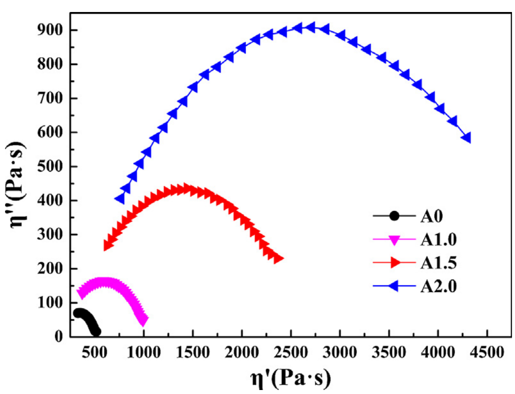
HIGHLIGHTS

- Addition of polyphosphoric acid (PPA) improves the thermal-rheological behavior of SBR modified asphalt.
- PPA reduces dispersed polymer phase size.
- The compatibility of SBR modified asphalt is improved by PPA.
- High asphaltene content is beneficial for the improving effect of PPA.

GRAPHICAL ABSTRACT



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ABSTRACT

With the aim of improving the compatibility, high and low temperature properties of SBR modified asphalt, polyphosphoric acid (PPA) was added to achieve a further modification in this study. The effects of PPA and asphalt composition on physical properties, viscoelastic behavior, creep and recovery behavior, cracking resistance, compatibility and morphology of PPA/SBR modified asphalt were characterized, respectively. It was demonstrated that PPA dramatically enhanced the adhesion ability, high temperature elasticity and anti-rutting ability of SBR modified asphalt through deflocculation effect. The resistance against low temperature cracking of PPA/SBR modified asphalt underwent a degradation after first improvement as PPA increased. PPA also improved the compatibility between SBR and asphalt and decreased the dispersed polymer phase size, thus a more desirable microstructure was formed. Furthermore, relatively high asphaltene content of base asphalt was beneficial to achieve desired rheological properties of PPA/SBR modified asphalt. As a consequence, chemical reaction with PPA is an effective way to comprehensively improve the compatibility and thermo-rheological behavior of SBR modified asphalt.

1. Introduction

Asphalts are currently the most eligible materials in paving technology as an adhesive to mineral aggregates [1]. Unfortunately, the extremely atmospheric conditions as well as increasing number of vehicles and traffic load result in a series of distresses in asphaltic pavements, such as low temperature cracking, fatigue

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and high temperature rutting [2,3]. These unfavorable distresses shorten the in-service life of pavements and increase risks to users, which are closely related to cohesive strength, mechanical properties, and viscoelastic behavior of asphalt binders [4]. In attempting to prevent the road network from deterioration, modified asphalts are extensively applied due to the enhanced durability, performance and adhesion to minerals [5–8].

Different types of additive have been used to modify asphalt such as polymers, acids and wax. Among them, styrene butadiene rubber (SBR) is an effective polymer to enhance the performance of asphalt binders such as the elastic recovery, low-temperature ductility, adhesive and cohesive properties, etc. [9,10], thereby allowing the pavements to have better flexibility and cracking resistance at low temperatures [11]. However, the limited effect of SBR on asphalt high temperature performance makes it difficult to meet the demand for applying in hot areas. In addition, the great discrepancy in structure and solubility parameter between SBR and asphalt lead to potential instability for blends. In order to solve these problems, it is necessary to further enhance the stability and performance of SBR modified asphalt, which can be achieved through the combination with other modifiers by either chemical reaction or physical mixing. Zhang and Su [12] studied the effect of nano-materials including nano-ZnO, nano-TiO_2 and nano-$CaCO_3$ on the performance of SBR modified asphalt. They founded that nano-$CaCO_3$ can improve the softening point and the dispersibility of polymer, but the ductility decreased observably and suggested dosage of nano-$CaCO_3$ reached 5.0 wt%, which resulted in the increase of the cost and the difficulty in preparation. Zhang et al. [13,14] reported that addition of sulfur improved the stability of SBR modified asphalts. However, the influence of sulfur on high temperature properties was very limited and asphalt became more sensitive to ageing and dynamic shear. Effect of clays including palygorskite clay, organomodified palygorskite clay, carbon black and montmorillonite on SBR modified asphalt were also evaluated by cited literatures [15–17]. The results reveled that addition of clays resulted in a negative influence on the elastic response and a significant increase in high temperature viscosity. Therefore, more effective additives, used together with SBR, need to be developed to satisfy the requirements of improving both the practical performance and the stability of SBR modified asphalt.

Polyphosphoric acid (PPA) is an oligomer of H_3PO_4 with more than 10 repeating units [18]. At the moment, PPA is the most significant acid applied in asphalt technology and it can be used not only alone but also in conjunction with other modifiers. Many literatures [19–22] have already proved that chemical modification with PPA remarkably enhances the high-temperature performance of asphalt without markedly affecting low-temperature grade, according to asphalt composition. The reaction between asphalt and PPA has been the subject of numerous researches aiming at revealing and understanding the detailed procedure. Nonetheless, since the reaction process is quite variable and complicated, the exact mechanism has yet been completely understood. Plenty of reactions were proposed by cited literatures [23,24] to give an interpretation such as neutralization of polar interactions between asphaltenes micelles, esterification, protonation of basic sites, crosslinking of neighboring asphalt segments, alkyl aromatization of saturates, formation of ionic clusters and any combination of these. Regardless of the reaction mechanism, It is well accepted that addition of PPA increases the solid mass fraction as well as the gel character of asphalt by altering the solvation constant of asphaltenes in maltene matrix, correspondingly the performance of asphalt is improved [1].

In addition to the positive effect of PPA on asphalt properties, Giavarini [25] and Moran et al. [26] pointed out that the storage stability of polymer modified asphalt was improved to some extent through adding PPA to the blends. Therefore, combination with PPA may constitute the solution for enhancing both the performance and stability of SBR modified asphalt. Nevertheless, scientific research that directly investigates the PPA/SBR composite modified asphalt is scarce and insufficient [27]. Furthermore, only few published articles completely studied the PPA effect on rheological behavior of asphalt at different thermal conditions, which is significant for researchers to describe and understand the mechanism between PPA and asphalt, whereas quite often empirical and fundamental properties are still characterized.

In view of above situations, in this study the objective is to improve the compatibility, thermo-rheological behavior of SBR modified asphalt through chemical reaction with PPA. The PPA-SBR composite modifier with various PPA contents and asphalt with different compositions were proposed to prepare high-performance PPA/SBR composite modified asphalt. The effect of PPA as well as asphalt composition on physical properties, linear viscoelastic behavior, failure temperature, creep and recovery behavior and low temperature cracking behavior of asphalt was evaluated. Meanwhile, the changes in compatibility and morphology of asphalt binders as a consequence of PPA addition were also studied, respectively.

2. Experiment and methods

2.1. Materials

Two base asphalts with 60/80 pen grade were selected for modification in this study, which were obtained from China (coded as A) and South Korea (coded as B), respectively. The chemical composition and oil source of them are different considering the aim of evaluating the influence of asphalt composition. Table 1 shows the conventional properties of both base asphalts. The chemical compositions are also presented. SBR powder with 27–33 wt% styrene content, was purchased from Shandong, China. Polyphosphoric acid, containing 80% P_2O_5, was supplied by Sinopharm Chemical Reagent CO., Ltd.

2.2. Sample preparation

PPA/SBR composite modified asphalt samples were prepared by mixing asphalt and modifiers under high shear. The base asphalt was first heated to 125 °C in an iron vessel and then blended with the SBR (3.0 wt% of base asphalt) and sheared at maintained temperature of 130 °C and the speed of 4000 rpm, for 50 min. Afterwards, a certain amount of PPA was added to above SBR-asphalt blends to reach a concentration of 0%, 0.5%, 1.0%, 1.5%, and 2.0% by weight, respectively. Then the blend was heated up to 160 °C, sheared at 4000 rpm for 40 min. Finally, the PPA/SBR-modified asphalts were obtained for the following tests. For comparing different samples easily, modified asphalt A with above-mentioned PPA content are coded as A0, A0.5, A1.0, A1.5 and A2.0 respectively and modified asphalt B are identified in the same way. In addition, the term binder, asphalt and asphalt binder are interchangeable in this paper.

2.3. Test methods

Rheological tests including temperature sweep test, multiple stress creep recovery (MSCR) test and frequency sweep test were performed using a rheometer (TA-AR2000EX, American) with parallel plates (25 mm in diameter, 1 mm gap) to measure the values of rheological parameters at different thermal situation. In addition, tests in all modes were performed on three replicates to guarantee the reliability of measured data.