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Production and performance of desulfurized rubber asphalt binder

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Abstract

Asphalt rubber binder typically exhibits disadvantages like segregation and high viscosity; however, this can be improved by the incorporation of desulfurized rubber powder. This study examined the swelling principle of desulfurized rubber asphalt (DRA). In addition, it evaluated the performance of DRA fabricated with various rubber powder contents under different shear conditions and development time. Superpave binders tests, including Brookfield viscosity, dynamic shear rheometer (DSR) and bending beam rheometer (BBR) tests, were applied on three control binders (i.e., neat, 20 mesh asphalt rubber binder, 40 mesh asphalt rubber binder) and a DRA binder. Binder testing results indicated that rubber powder swelled into the base binder and resulted in enhanced stability. Optimum performance of the DRA binder was achieved by adding 20% (by weight) of rubber powder into the base binder at shear rate, shear temperature, shear time and development time of 7000 r/min, 170 °C, 60 min and 45 min, respectively. Modified ranges of production conditions were also provided to widen the application of DRA in field construction. It appeared that DRA binder benefited from the recovered plasticity and viscosity of the rubber and consequently, exhibited superior performance over the neat and conventional asphalt rubber binders. Preliminary mixture evaluation was also conducted and the DRA binder was found to significantly improve the mixture resistance to permanent deformation and water damage. Overall, the DAR binder is encouraged to be used as a modified binder for flexible pavements.

Keywords: Desulfurized rubber asphalt; Swelling model; Production process; Asphalt performance; Rubber asphalt

1. Introduction

The asphalt industry has been searching and experimenting with sustainable alternatives since the 1970s which has led to the implementation of various recycling techniques that aimed at reducing energy consuming, construction waste and construction cost for highway pavement. The use of reclaimed asphalt pavement is a commonplace around the world, and another good example is recycling rubber tires into asphalt binders for pavement construction [1–3]. Recycled tire crumb rubber (CR) is produced from end-of-life tires. The disposal of these scrap tires has been a serious environmental concern for several reasons, such as lack of landfill space, and environmental issues. Using CR as a modifier in asphalt binder is one promising solution that not only protects the environment but also provides pavement performance benefits.

Mixtures with rubber modified binder have been reported with decreased traffic noise, reduced maintenance costs, and enhanced abrasive resistance, skid resistance, and rutting and cracking resistance [4–7]. Scanning electron microscope images of crumb rubber pre-blending demonstrated that the elastomeric properties of rubber

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could be partially recovered [8]. Due to these advantages, there has been an increased interest in using crumb-modified (CRM) binder in hot mix asphalt (HMA) mixtures and several studies have found that the performance of resultant mixtures can be significantly affected by the rubber content, particle size and types, blending conditions and modification processing technologies, and so on [9–14]. Research studies of CRM binder began in the 1980s in China and its first application in flexible pavement occurred in Jiangsu and Sichuan Provinces. In 2004, the Beijing Municipal Committee of Communication approved a provisional standard on the application of CRM binder, which spurred the adoption of CRM binders for many major highway projects.

Orthogonal experiments have been conducted on rubber asphalt binders and valuable experience/information has been gathered such as the appropriate content and production conditions [15]. However, it is difficult for a conventional rubber particle to swell in the base binder primarily due to its high molecular weight and a lack of chemical reaction with base binder. One way to promote the interaction between crumb rubber and base binder is to desulfurize the rubber particles creating desulfurized rubber powder/desulfurized rubber asphalt (DRA). However, limited studies have been conducted to compare the performance of DRA and CRM binders. It was only reported that the modification mechanisms of DRA and CRM were clearly different from each other, resulting in distinctive binder performance.

Therefore, this study investigated the effects of mixing techniques (i.e., shear time, temperature, time and development time) and desulfurized rubber powder content on rheological properties of DRA binders, with the goal of identifying optimized DRA production techniques for satisfactory binder performance. Empirical binder tests, including needle penetration (25 °C), softening point and ductility, were conducted to identify an appropriate combination of mixing techniques. Then, the performance of the DRA binder with optimized mixing procedures was evaluated using the Superpave binder tests (i.e., Brookfield revolving viscosity test, dynamic shear rheometer test, and bending beam rheometer test) and three control binders (i.e., neat, 20-mesh and 40-mesh rubber binder) were also included as references. Finally, mixture tests including the Marshall Stability, Marshall Immersion, and Wheel Tracking tests were conducted to evaluate the effect of desulfurized rubber powder on mixture resistance to permanent deformation and water damage.

2. Swelling principle of desulfurized rubber asphalt

The swelling mechanism of asphalt rubber is described as follows. The light oil in the base binder is absorbed by the rubber particles, making the rubber particles convert to a relatively loose flocculent structure from a dense structure, thereby partially recovers its un-vulcanized rubber property and viscosity. In addition, the reduced light oil in the base binder results in an increase in asphalt viscosity. Asphalt rubber not only retains the basic mechanical properties of base binder, but also partially recovers the plasticity and viscosity of rubber. Therefore, compared with base binder, asphalt rubber binder has enhanced physical properties, durability, temperature sensitivity, and viscosity.

Unlike regular rubber, desulfurized rubber powder has relatively low molecular weight and contains chemical bonders that potentially react with base binder. Of note, the desulfurized rubber powder has large particles but little debris remains at the end of the swell process. Also, desulfurized rubber powder swells into the base binder, accompanied by a considerable amount of air bubbles, at a much faster rate than regular rubber. Finally, DRA binder dissolves into the trichloroethylene at a slower rate compared to the convention asphalt rubber binder. These observations indicate that chemical reactions occur between desulfurized rubber powder and base binder such that the DRA binder yields better compatibility and higher stability than regular rubber. Yang [16] found that the DRA binder lacks of gel particle cores as compared to regular rubberized asphalt, as depicted in Fig. 1. This observation indicated that desulfurized rubber powder more thoroughly swell into base binder than regular rubberized asphalt.

3. Material and production process of desulfurized rubber asphalt

An unmodified binder, i.e., KLMY90# (Karamay), that has been regularly used in China was selected as the base binder. Table 1 shows the chemical constituents of the base binder. Fig. 2 shows the desulfurized rubber powder, which presented a honeycomb structure with approximately 6 mm in diameter. Its main technical specifications and solubility test results are listed in Tables 2 and 3. The production instruments mainly include a high-speed shearing machine, electric jacket, thermometer, and stirring rod. The high-speed shear machine has a speed range of 0∼12000 r/min and the electric jacket automatically adjusts the temperature. In the DRA mixture, desulfurized rubber powder is about 30 percent weight of the base binder. Basic binder tests, such as the penetration, softening point, and ductility were conducted to evaluate the swelling effect of desulfurized rubber powder on the base binder at different shear rates, shear temperatures, shear time and development time.

The asphalt penetration test is used to evaluate the asphalt's soft and hard levels and its shear resistance. The test reflects the asphalt's relative viscosity. The softening point test is used to determine the temperature at which the asphalt becomes soft and achieves a certain viscosity. Ductility is mainly about deformability of asphalt and indirectly reflects low-temperature anti-cracking property. It is an important index that can be used to evaluate asphalt plasticity such that the larger ductility value the better plasticity of the asphalt has. All these are the basic performance index to evaluate asphalt binder.