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Experimental assessment on engineering properties of aged bitumen incorporating a developed rejuvenator

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HIGHLIGHTS

- Self-design rejuvenator improved the elastic recovery of the rejuvenated bitumen.
- Self-design rejuvenator can restore the low-temperature properties of aged bitumen.
- Self-design rejuvenator has better aging resistance.

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ABSTRACT

Effectiveness of reuse of recycled asphalt pavement (RAP) to produce new asphalt mixtures for pavements not only leads to obvious environmental benefits but also significantly saves natural resources in terms of using RAP as aggregates and decreased need of using virgin bitumen. In this study, a new type of rejuvenator was developed and designed by using rubber oil, plasticizer and anti-aging agent. The experimental tests including softening point, penetration, ductility, dynamic shear rheometer (DSR), multiple stress creep recovery (MSCR), Bending-Beam Rheometer (BBR), Brookfield viscosity as well as Fourier Transformed Infrared Spectroscopy (FTIR) test were conducted to evaluate some engineering properties of the aged bitumen incorporating the developed rejuvenator and other two commercial ones. Analysis on physical and rheological properties of rejuvenated binders indicated that adopting the developed rejuvenator can restore the related properties of the aged bitumen and be able to improve the visco-elastic behavior of the rejuvenated bitumen. Meanwhile, using the developed rejuvenator can enhance thermal cracking resistance of the rejuvenated bitumen due to its improved low-temperature property. Furthermore, when assessing the aging level of the bituminous binders by FTIR, the developed rejuvenator had the potential of reducing the aging speed of the rejuvenated bitumen. Consequently, it can be concluded that the developed rejuvenator not only restored the performance of the aged bitumen to its original level, but also improved some paramount properties for pavements such as visco-elastic behavior, cracking resistance and aging resistance.

1. Introduction

The total length of China's expressway network reached to 136,000 km in which most of these roads were overlaid with asphalt layers by the end of 2017 [1]. With the nearly completion of such modern expressway network, China's transportation development strategy would change from a massive-rapid construction period to a conservation-and-management stage [2]. It can thus be predicted that more and more end-of-life asphalt layers need to be removed from the road and replaced by new asphalt materials. In China, there are about 2.5 billion tons of reclaimed asphalt pavement (RAP) generated annually. The improper disposal of RAP not only occupies a lot of landfill but also causes environmental pollutions [3]. However, if the RAP can be effectively used as aggregates in constructing new pavements, two main advantages can be presented. Firstly, reusing the RAP as recycled aggregates reduces the consumption of virgin aggregates as a result of the reduction in the pavement construction cost [4]. Secondly, reusing the RAP causes reduction in energy consumptions and greenhouse gas emissions, which offers obvious environmental benefits [5,6]. Therefore, recycling and reuse of RAP is becoming great significant and conforming to a sustainable highway development.

RAP, which mainly consists of aggregates and bituminous binder, is generally reclaimed from damaged roads as a result of removal, milling and crushing process [7]. Due to its long period

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of service time, the RAP bitumen has been aged and highly oxidized [8]. The oxidation of bitumen can be separated into two phases: short-term aging and long-term aging. The short-term aging is mainly referred to oxidation of binder and volatilization of light component because of high mixing temperature, transportation and laying processes [9]. The long-term aging is the oxidation, polymerization and photo-oxidation of bitumen because of the weathering and oxidation of pavements (Fig. 1) during service life [10]. During the aging process, the ratio of maltenes to asphaltenes changes and results in an increased viscosity (stiffness) and a decreased ductility of binder [11]. In this case, the RAP particle behaves as "black rock", where the aged binder is tightly bonded to the aggregate surface and makes it very difficult to harmonize with new virgin bitumen and aggregates, especially at high RAP content [12]. The recycled asphalt mixture prepared with RAP could then have adverse effect on the low-temperature cracking resistance and fatigue resistance [13]. Therefore, it is of paramount significance to restore the properties of the aged bituminous binder to a condition that resembles the virgin bitumen.

To recover the oxidized bituminous binder and soften the RAP mixture, incorporating a rejuvenator is one of the most effective methods. The mechanism of rejuvenating RAP is to restore the original properties of the aged bitumen and replenish the volatiles and dispersing oils so that to promote its adhesion [15]. Based on this mechanism, rejuvenators should provide stable colloidal structure in which asphaltenes can be well dispersed in maltenes without precipitation or flocculation [16]. Previous researchers have found that materials containing a high amount of maltene constituents – naphthenic or polar aromatic fraction and low content of saturates can reach this aim [17]. The influence of rejuvenators on bitumen properties has been evaluated by many researchers and indicated their significant effects on lowering the stiffness and improving the low-temperature performance [18,19]. Due to the diffusing effect of rejuvenators in the hard binder, the recycled asphalt mixtures tend to result in lower air voids which in turn can mitigate the cracking sensitivity and moisture susceptibility of recycled asphalt mixtures [20]. However, because the chemical composition as well as the colloidal structure of the rejuvenated bitumen is significantly different from that of the virgin bitumen, the long-term performance of recycled asphalt mixture may be affected [21]. Previous researches have shown that the aging speed of the rejuvenated bitumen is quicker in comparison with the virgin bitumen [22]. So, reducing the aging speed of the rejuvenated bitumen is also one of the important issues for developing a rejuvenator.

The main aim of this study was to evaluate the properties of a developed composite rejuvenator by comparing with two commercial rejuvenators. Firstly, the feasibility of using this rejuvenator in the aged bitumen was preliminary evaluated by using conventional bitumen tests (softening point, penetration and ductility). Then, the rheological properties of the rejuvenated bitumen were comprehensively characterized by using Dynamic Shear Rheometer (DSR), Multiple Stress Creep Recovery (MSCR) and Bending-Beam Rheometer (BBR) tests. Furthermore, Brookfield viscosity of the rejuvenated bitumen was measured to evaluate its flowability at mixing and compaction temperatures. Finally, the aging influence on the functional groups of the rejuvenated bitumen were characterized using Fourier Transformed Infrared Spectroscopy (FTIR).

2. Experimental project

2.1. Materials

2.1.1. Bitumen

The 70# virgin bitumen produced from Sinopec Qilu Petrochemical Company was selected in this research to produce the aged binder. The properties of this bitumen were strictly evaluated in accordance with the Chinese standards JTG E20-2011 and the results are presented in Table 1 [23].

To evaluate the restorability of the self-designed rejuvenator for the aged bituminous binder, a type of RAP was collected from a fabricating yard and the recovered bitumen was obtained by using a rotary evaporator method complying with the Chinese standards JTG T0727-2011. The old asphalt pavement was constructed in 2002 with a new overlaying asphalt layer paved in 2011. The end-of-life asphalt pavement was first removed by using a pavement milling machine and transported to a storing yard, as shown in Fig. 2(a). Then, the RAP was placed into the extractor to conduce the bitumen leaching solution using Trichloroethylene, as shown in Fig. 2(b) and (c). Finally, the leachate was poured into a rotary evaporator to remove the Trichloroethylene and obtain the recovered bitumen, as shown in Fig. 2(d) and (e). The aging level of the recovered bitumen was evaluated and is shown in Table 2.

In comparison with the recovered bitumen, the aged bitumen was produced as well by simulating the aging process and accelerating the aging in the laboratory [24]. For this process, the virgin bitumen was heated using a Thin Film Oven Test (TFOT) and the aging level of bitumen was evaluated every two hours by using the penetration test. It has been found that the 70# reference bitumen subjected to a 10-hour TFOT can simulate the properties of the recovered RAP bitumen in the field, as shown in Table 2.

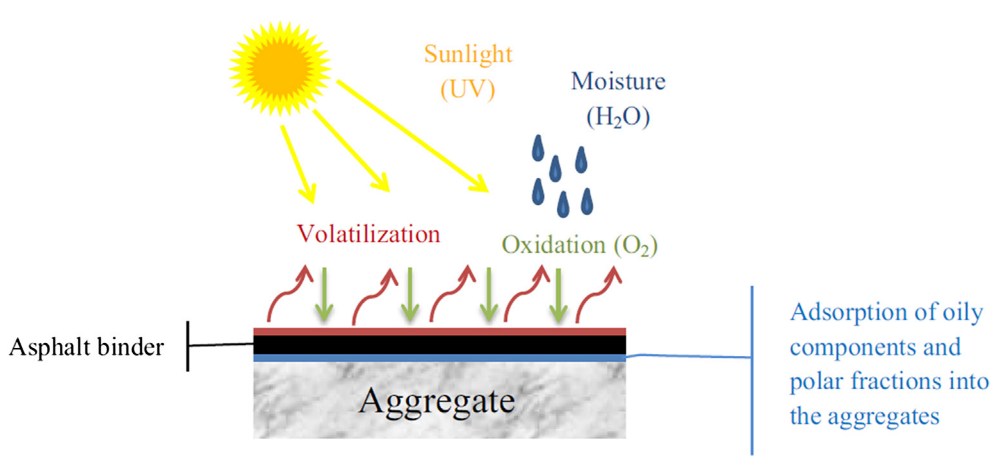

Fig. 1. Long-term aging phenomena of bituminous binder in asphalt pavement [14].