Construction and Building Materials 98 (2015) 530–536

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Evaluation of the diffusion and distribution of the rejuvenator for hot asphalt recycling

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HIGHLIGHTS

- Different rejuvenators have much different properties and recycling effects.
- Rejuvenator with lower viscosity has better diffusivity but worse thermal stability.
- It is difficult for rejuvenator to fully diffuse into RAP asphalt.
- Nonuniform distribution of rejuvenator negatively affect recycling performances.

ARTICLE INFO

Article history:
Received 11 December 2014
Received in revised form 13 July 2015
Accepted 26 August 2015
Available online 31 August 2015

Keywords:
Rejuvenator
Aged asphalt
Hot recycling
Diffusion
Distribution

ABSTRACT

This study focused on the diffusion and distribution of the rejuvenator in the aged asphalt of reclaimed asphalt pavement (RAP) materials during hot recycling. Diffusion tests were designed based on the penetration test and the dynamic shearing rheometer (DSR) test to evaluate the diffusivity of the rejuvenator in aged asphalt. The phased extraction and recovery test and the asphalt mortar transfer test were designed to determine the distribution of the rejuvenator during the recycling of asphalt and the distribution of the recycled asphalt within the asphalt mixture during recycling, respectively. Performance tests, including the wheel tracking test, low-temperature bending beam test and freeze-thaw splitting test, were conducted to evaluate the influences of the rejuvenator distribution on the performances of the asphalt mixture during recycling. The viscosity, components and rejuvenator thermal stability are found to have important influences on the diffusivity and distribution of the rejuvenator in aged asphalt. During the short blending process of recycling the asphalt mixture, it is difficult for the rejuvenator to fully diffuse into the aged asphalt. Therefore, the property and distribution of the recycled asphalt tends to be nonuniform in the asphalt mixture during recycling. This nonuniformity can lead to poor high-temperature anti-rutting performance, poor low-temperature cracking resistance and poor moisture stability of the recycled asphalt mixture.

1. Introduction

With the continuously increasing construction material costs and increasing awareness of environmental protection, the recycling technology of asphalt pavement has attracted increased attention in recent years [1]. Hot recycling of asphalt pavement has been proved to be one of the most promising approaches for asphalt pavement rehabilitation and maintenance. Hot recycling can produce new pavement with the required performance as well as provide considerable savings in material, money and energy [2–4]. To successfully conduct hot recycling for asphalt pavement, many research studies have been conducted on the mix design method and the mechanical properties of the hot recycling asphalt mixture [5–8]. Based on the findings, the use of recycled asphalt pavement (RAP) materials in hot-mix asphalt mixtures has evolved into routine practice in many areas around the world. A hot recycling asphalt mixture with controlled RAP content less than 30% as well as appropriate mix design and construction was proved to perform in a manner similar to virgin asphalt mixtures [9]. However, some serious problems, such as low early stiffness, cracking, raveling and short durability, were also commonly observed for hot recycling asphalt pavement during use in the field [10–13]. Thus, many agencies are reluctant to use a recycled asphalt mixture because of these problems. Many challenges and questions remain regarding the performances of recycled asphalt mixture.

Although there are many causes for the above-described problems, one of the most contentious issues is about the use of rejuve-

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http://dx.doi.org/10.1016/j.conbuildmat.2015.08.135
0950-0618/

nator. Based on previous studies, the aging of asphalt due to field usage is one of the most important reasons for the performance deterioration of an asphalt mixture and pavement [14,15]. Therefore, a rejuvenator has been used to recover the performance of the aged asphalt to meet the performance requirements of virgin asphalt [16,17]. The selection and content determination of the rejuvenator was usually based on performance tests of the recycled asphalt, which is composed of aged asphalt and the rejuvenator [18]. Aged asphalt was extracted and recovered from the RAP and then blended with the rejuvenator to obtain recycled asphalt. Performance tests were conducted on recycled asphalt to determine the proper type and content of rejuvenator. However, during actual production of the recycled asphalt mixture, the rejuvenator was added into the RAP and then blended with new aggregates and virgin asphalt to obtain the recycled asphalt mixture. The entire blending process lasted only 60–90 s. Studies found that when 10–50% of the rejuvenator by the weight of the aged asphalt in the RAP was poured into the RAP directly, it can take 48–144 h for the rejuvenator to fully diffuse into the RAP [19]. Compared to laboratory blending of the rejuvenator and the aged asphalt, the real blending status of the rejuvenator and the aged asphalt during the recycling process of the asphalt mixture could be much worse due to the short blending time and the poor flowability of the aged asphalt. If the actual blending status of the rejuvenator and aged asphalt is different from the laboratory blending status, then the rejuvenator may not play the same role as it does in the laboratory recycling process, which can lead to an improper mix design and performance deficiencies in the recycled asphalt mixture and the pavement during field usage.

Because there are currently no standard test procedures to evaluate the real blending status of the rejuvenator and aged asphalt in a recycled asphalt mixture, laboratory tests were designed in this study to reveal the diffusion and distribution of the rejuvenator in the aged asphalt of the RAP. The influences of the diffusion and distribution of the rejuvenator on the performance of the recycled asphalt mixture were also evaluated. The findings in this study can help evaluate and explain the performance problems of the recycled asphalt mixture during field usage.

2. Materials and methods

2.1. Materials

Four different rejuvenators, named A, B, C and D, were used in this study. The basic properties of the different rejuvenators are presented in Table 1. Rejuvenators A and B have much lower viscosity than rejuvenators C and D because rejuvenators A and B are mainly composed of light oils, whereas rejuvenators C and D are composed of light oils and tackifying resins. Clearly, after aging via the thin film oven test (TFOT), rejuvenators A and B have higher residual viscosity ratios and quality changing percentages than rejuvenators C and D. Therefore, the thermal stability and aging resistance of rejuvenators A and B are worse than those of rejuvenators C and D.

To control the variability of asphalt and obtain a sufficient amount of material for the tests, aged asphalt was prepared via a laboratory aging procedure involving a combination of the thin film oven test (TFOT) and the pressure aging test (PAV) on virgin asphalt, according to the Chinese Test Standard Methods of Bitumen and Bituminous Mixtures for Highway Engineering [20]. The basic properties of virgin asphalt and aged asphalt are presented in Table 2. Compared to the virgin asphalt, the aged asphalt has higher values of the viscosity and softening point as well as lower values of the penetration and ductility. This result indicates that the aged asphalt is much stiffer than the virgin asphalt due to aging.

Table 1
Basic properties of the different rejuvenators.

Indices		A	B	C	D
60-°C viscosity (mPa s)		4	15	190	215
Flash point (°C)		197	204	208	216
TFOT aged	Residual viscosity ratio	4.5	3.0	1.3	1.1
	Quality changing percent (%)	−6.7	−4.1	−1.6	−1.2

Table 2
Basic properties of virgin asphalt and aged asphalt.

Asphalt	Soften point (°C)	10-°C ductility (cm)	60-°C viscosity (Pa s)	25-°C penetration (0.1 mm)
Virgin	49.1	41.8	211.3	67.2
Aged	55.4	6.3	530.3	39.0

The virgin asphalt mixture was prepared using the virgin asphalt according to the mix design method by the Chinese Technical Specification for Construction of Highway Asphalt Pavement [21]. The asphalt content is 4%, and the gradation is shown in Fig. 1. Artificial RAP was prepared by blending aged asphalt with aggregates and then cured in an oven at 100 °C for 12 h. Two different types of artificial RAP were prepared. One type is artificial RAP with graded aggregates, which was prepared based on the previous mix design for a virgin asphalt mixture. Aged asphalt was used instead of virgin asphalt to mix with the graded aggregates to obtain the artificial RAP. The other type is artificial RAP with single-size aggregates, which was prepared by blending aged asphalt with 4.75-mm aggregates and mineral fillers. For each sample, 500 g of 4.75-mm aggregates, 10 g of mineral fillers and 9.6 g of aged asphalt were used to obtain the artificial RAP. Meanwhile, aggregates with size of 13.2 mm were prepared as new aggregates.

2.2. Testing procedures

Recycled asphalt was prepared by blending aged asphalt with the rejuvenator. Conventional performance tests, including the penetration test, the softening point test, the ductility test and the viscosity test, were conducted for virgin asphalt, aged asphalt and recycled asphalt according to the Chinese Test Standard Methods of Bitumen and Bituminous Mixtures for Highway Engineering [20].

To evaluate the diffusivity of the rejuvenator in the aged asphalt, diffusion tests, named the diffusion-penetration test and the diffusion-DSR test, were designed based on the penetration test and the dynamic shearing rheometer (DSR) test, respectively. During the diffusion-penetration test, the penetration test sample of aged asphalt was prepared. Next, 10% of the rejuvenator by weight of the aged asphalt sample was poured into the penetration mold to form a rejuvenator layer on the top surface of the aged asphalt sample. The penetration sample was cured in an oven at 100 °C for different times of 0.5, 1, 2, 3 and 4 h. After curing and cooling down the sample, the rejuvenator remaining on the top surface of the aged asphalt sample was rinsed. The penetration test was then conducted on the final sample at 25 °C. During the diffusion-DSR test, the DSR test sample of the aged asphalt was performed. Next, 10% of the rejuvenator by weight of the aged asphalt sample was dropped onto the top surface of the aged asphalt sample to form a rejuvenator film. The DSR sample was cured in oven at 100 °C for 4 h. After curing and cool down, the rejuvenator remaining on the top of the aged asphalt sample was rinsed. The DSR test was then conducted to measure the $G^*/\sin\delta$ of the final sample at 52 °C.

The phased extraction and recovery test was designed to evaluate the distribution of the rejuvenator in the aged asphalt of the RAP. For each test sample, 1.5 kg of artificial RAP with graded aggregates was prepared and then blended with the rejuvenator at 150 °C for 1 min to obtain the recycled asphalt mixture. After cooling down, the recycled asphalt mixture was placed into a net basket and immersed in 1500 ml of trichloroethylene solvent for 45 min. Based on the trial tests, approximately half of the recycled asphalt was dissolved in the trichloroethylene solvent; this dissolved asphalt is considered as the outer-layer asphalt surrounding the aggregates in the recycled asphalt mixture. Next, the recycling asphalt mixture was immersed again in a new trichloroethylene solvent for another 45 min to dis-

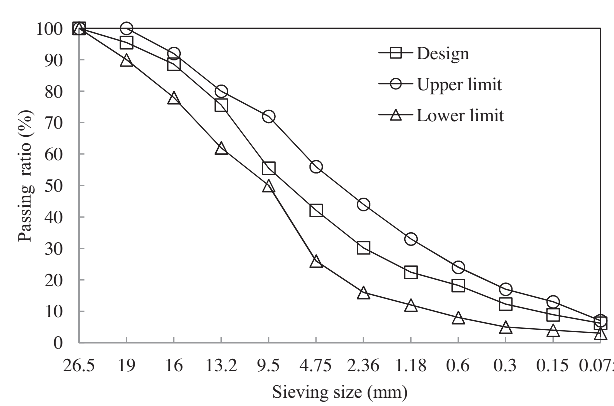

Fig. 1. Gradation for the virgin asphalt mixture.