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Impact of rejuvenators on aging properties of bitumen

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HIGHLIGHTS

- Use of 100% RAP is a solution for reducing environmental impacts.
- It is possible to utilize 100% RAP in asphalt mixes using rejuvenators.
- The rejuvenator with the lowest viscosity has the highest softening efficiency.
- Long term aging has a significant effect on the stiffening of asphalt binder.
- Aging of the virgin bitumen is slower compared to that of the rejuvenated bitumen.

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ABSTRACT

Potential reductions in construction costs and environmental emissions have made the use of reclaimed asphalt pavement (RAP) as aggregates in hot bituminous mixes an attractive alternative to the highway agencies. Currently, there is a trend towards increasing the RAP content in asphalt pavements and recycle 100% RAP in asphalt mixes. However, RAP binder is already aged and stiffened, making the RAP containing mixes susceptible to fatigue and thermal cracking. Addition of rejuvenators may reduce the viscosity of the 100% RAP binder allowing restore some of the original characteristics of the aged binder in order to attain adequate performance of the mixture. This paper aimed to determine the aging behavior of rejuvenated 100% RAP binder and compare it with that of the virgin bitumen. Three types of rejuvenators were assessed in the study. The rheological tests conducted on the bitumen include softening point, penetration, and complex shear modulus. The tests were performed at 3 aging stages: no-aging, RTFOT (Rolling Thin Film Oven Test) aging, and combined RTFOT and PAV (Pressure Aging Vessel) aging. Aging of the bitumen was characterized using Fourier Transformed Infrared Spectroscopy (FTIR). It was shown that the aging of the virgin bitumen is slower than that of the rejuvenated bitumen. However, there was no significant difference between the aging behavior of the bitumen mixed with different types of rejuvenators.

1. Introduction

Environmental sustainability aims to make goods and services last longer and minimize their impact on the ecological system during their life cycle. One way of addressing sustainability in pavement industry is using recycled materials to replace a certain percentage of virgin materials used in the manufacturing process of hot mix asphalt (HMA), such as aggregates and asphalt binder. The use of reclaimed asphalt pavement (RAP) has been a viable alternative for transportation agencies and asphalt producers to make more efficient use of resources. RAP material is a reusable mixture of bitumen and aggregates generated from milling and/or crushing of old and damaged pavements for addition into new asphalt mixes.

There is a trend towards increasing the RAP content in HMA not only because it helps conserve non-renewable resources but also eliminates disposal problems because it reduces the need for landfills and diminishes the energy consumption and life cycle costs by reducing the requirement for virgin materials and fuel for material processing and hauling. However, including RAP in an asphalt mix raises concerns regarding the inherent asphalt binder that the mix receives from the RAP. The asphalt from RAP is age hardened due to oxidation during production and service. The blending of old, oxidized, and hence hardened asphalt binders from RAP with a virgin asphalt binder results in an asphalt binder that is stiffer than the virgin asphalt binder. In order to counteract the binder

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hardening and soften the recycled asphalt mix, a rejuvenator has to be used. Rejuvenators help replace the oils lost during age hardening and rebalance the composition of the recycled asphalt mix.

The stiffness of the RAP mix depends on the type of aggregate and its gradation, and the stiffness and amount of the aged binder in RAP, being the major factors [1,2]. Therefore, due to oxidative hardening of the RAP binder during aging, they may exhibit lower performance with respect to raveling, fatigue life, and durability. The construction of new asphalt concrete plants with special drums for the addition of high percentages of RAP makes it technically possible to recycle asphalt up to 100% with the addition of rejuvenators in the mix. However, the performance concerns of RAP mixes have imposed restrictions on the maximum RAP percentages in most of the countries. Currently, extended research activities have started all over the world to overcome the restrictions on the RAP content in the asphalt mix.

Many studies evaluated the effects of different rejuvenators on the engineering properties and the performance of the bitumen. It has been shown that the rejuvenators significantly lower the stiffness and improve the cracking resistance [3–5]. Hence, it is possible to obtain the same rheological properties of the target virgin binder by mixing the aged binder with a rejuvenator, however, the chemical composition, the ratio of asphaltenes to maltenes, of the rejuvenated binder is significantly different from that of the virgin bitumen [6–8] which may affect the long term performance of the RAP mix. The performance of the rejuvenated binder is also highly dependent on the rejuvenator content, therefore the optimum amounts for different rejuvenators should be determined for different binder types [3,6,7].

A study was initiated at EMPA – Swiss Federal Laboratories for Materials Science and Technology in order to evaluate the effects of rejuvenators on the aging properties of 100% RAP and compare those with that of the virgin bitumen. Three different types of rejuvenators were assessed in this study. As a target virgin binder, standard penetration grade bitumen 70/100, which is widely used in Switzerland, was selected. The amount of rejuvenator to be added to the aged binder was determined in order to achieve the penetration of the target virgin binder, bitumen 70/100. Instead of extracting the aged binder from RAP, bitumen with a similar penetration grade to that of the RAP binder, bitumen 40/50, was used in the study. The rheological tests conducted on the bitumen include softening point, penetration, and complex shear modulus. The tests were performed at three aging stages: no-aging, Rolling Thin Film Oven Test (RTFOT) aging, and combined RTFOT and Pressure Aging Vessel (PAV) aging. Aging of the bitumen was characterized using Fourier Transformed Infrared Spectroscopy (FTIR). The aging properties of the target virgin binder and the bitumen 40/50 with different rejuvenators were compared.

2. Methodology

2.1. Materials

2.1.1. Rejuvenator properties

The three types of rejuvenators used in this study were designated as RJ1, RJ2, and RJ3. The dynamic viscosity, flash point, and properties of the rejuvenators are given in Table 1. The RJ1 and RJ2 have the same producer and similar viscosities. The RJ3 has lower viscosity and higher flash point than those of RJ1 and RJ2.

Due to the density difference between the virgin bitumen 40/50 and the rejuvenators, homogeneous mixing of the rejuvenators with the bitumen was not achieved by using a mechanical propeller mixer. Especially, RJ3 was hard to mix homogenously with the bitumen due to its lower viscosity. Therefore, the bitumen and the rejuvenators were mixed using the rotary evaporator, placing the 40/50 penetration grade bitumen with the rejuvenator in the evaporation flask and rotating it 65 ± 5 times/min for 5 min at ambient pressure in a bath heated at 145 °C. When the rejuvenators were mixed with the bitumen in the rotary evaporator, the repeatability of the bitumen performance tests stayed within the limits specified by the standards [9,10].

Table 1
The characteristics of the rejuvenators.

	Dynamic viscosity at 25 °C, Pa s	Flash point, °C	Remarks
RJ1	1.2	>100	Resin produced from cashew nut shells
RJ2	1.4	>100	Similar to RJ1, same producer
RJ3	0.03	>126	Composed of bitumen, vegetable oil, naphthenic oils, additives

2.1.2. Binder properties

For this study, virgin bitumen was used to simulate the properties of the aged binder in RAP. Initially, two types of RAP obtained from the field were evaluated in terms of their engineering properties: fine graded RAP 0/11 and coarse graded RAP 11/22. The RAP binder from the two mixes had an average penetration of 31 0.1 mm and average softening point of 59.2 °C. Hence, a 20-year old batch of bitumen 40/50, which was hardened in the mean time, and had a similar penetration to that of the RAP binder, 32 0.1 mm at 25 °C, was used to simulate the RAP characteristics.

In Switzerland, generally, standard penetration grade bitumen 50/70 or 70/100 is used. For this study, a penetration grade bitumen 70/100 was selected as the target virgin bitumen. The bitumen 40/50 was mixed with the rejuvenators in order to reproduce the engineering properties of the 70/100 bitumen. The amount of rejuvenator added to the bitumen 40/50 in order to get the same penetration value as the bitumen 70/100 was determined by adding different concentration of the rejuvenators. The aging behavior of the bitumen 40/50 with different rejuvenators was compared with the aging behavior of the virgin bitumen 70/100.

2.2. Test methods

2.2.1. Bitumen aging procedures

In this study, Rolling Thin Film Oven Test (RTFOT) in accordance with EN 12607-1 [11] was conducted to simulate short term aging of the bitumen. The long term aging of the bitumen was simulated using the Pressure Aging Vessel (PAV) in accordance with EN 14769 [12]. The short term aging was conducted at 163 °C for 85 min while long term aging was conducted at 100 °C for 20 h. After the bitumen was short term aged in RTFO, some of it was saved for the rheological tests and FTIR spectroscopy, and the rest was long term aged through PAV.

2.2.2. Bitumen performance testing

The performance of the virgin and the rejuvenated binder was assessed for three aging conditions of no-aged, RTFOT aged, and RTFOT + PAV aged. The performance tests conducted included Ring and Ball (R&B) softening point [9], penetration test at 25 °C [10], and the complex shear modulus (G^*) test [13]. The complex modulus test was performed with a Physica MCR 301 dynamic shear rheometer (Anton Paar, Austria) according to EN 14770 [13]. An approximately 1.5 mm thick sample of bitumen was prepared in a silicon mould and placed between two 25 mm parallel plates. The gap was adjusted to 1.00 mm and the complex modulus was measured at a temperature of 30 °C and frequencies of 1.25 Hz, 2.3 Hz, 3.35 Hz, and 4.4 Hz. However, only the complex