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Experimental study of stable crumb rubber asphalt and asphalt mixture

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HIGHLIGHTS

- Plant-produced rubber asphalt based on wet process shows good storage stability.
- Plant-produced rubber asphalt shows satisfied property compared to other binders.
- Asphalt mixture with plant-produced rubber asphalt shows satisfied performance.

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ABSTRACT

This study aims to analyze the road performance of plant-produced crumb rubber asphalt (PRA) based on wet process by comparing with base asphalt, styrene–butadienestyrene (SBS) modified asphalt, and field-produced rubber asphalt (FRA). Through infrared spectrum (IR) analysis and differential scanning calorimeter (DSC) tests, the microstructure of each binder were analyzed and compared. Dynamic Shearing Rheometer (DSR) with different test modes were utilized to analyze the rutting resistance and fatigue property of each binder while Bending Beam Rheometer (BBR) test was used to analyze the low-temperature properties of each binder. Asphalt mixtures were prepared with different binders and the road performances including high-temperature rutting resistance, low-temperature cracking resistance, moisture stability and fatigue failure resistance were evaluated. The findings indicate that the plant-produced crumb rubber asphalt shows good storage stability and satisfied road properties compared to other binders while the asphalt mixture prepared with plant-produced crumb rubber asphalt shows satisfied road performances. In general, the study indicates that the plant-produced crumb rubber asphalt could be a promising replacement for SBS modified asphalt based on the mixture type evaluated.

1. Introduction

The disposal of scrap tires has been a serious issue since it occupied large scale of landfill space and caused various environmental concerns such as soil and air pollution [1]. Several methods are now available to recycle those scrap tires and their utilization in asphalt pavement construction could be one of the most successful cases. For instance, the use of Crumb Rubber Modified asphalt (CRMA) started from 1980s [2] and the asphalt industry can recycle up to 40% scrap tires in each year with an increasing recycling rate [3]. The CRMA here refers to asphalt modified by crumb rubber. According to the ASTM D6114, crumb rubber modified asphalt (CRMA, also named as rubber asphalt) is defined as modified asphalt composed of virgin asphalt and no less than 15% crumb rubber by the weight of virgin asphalt. The scrap tires are used typically in two ways: produce rubber modified asphalt, or re-place part of the fine aggregates in gradation design.

Currently, the manufacture process of CRMA can be divided into two ways, wet process and dry process. For dry process, crumb rubber was mixed with aggregates before asphalt binder was inserted into the drum. In contrast, crumb rubber was pre-blended with asphalt binder and followed by mixing with aggregates for wet process. Wet process is generally considered as the more efficient way to improve performance of asphalt and asphalt mixtures with optimum rubber content of 15–25% by weight of original binder [2,4–6].

The benefits of using CRMA binder include three parts: decreased traffic noise, improved pavement performance, and reduced maintenance cost [7–10]. Previous studies have found that although complicated chemical reactions occur during mixing of crumb rubber and asphalt, physical reaction between asphalt absorbed by crumb rubber and swelling of crumb rubber is

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predominant [11–14]. It is also noted that although thermal dissociation of crumb rubber also happens, most of the crumb rubber particles still stay in asphalt as solid particles which formed a net structure in asphalt. Such composition change of asphalt and the existence of crumb rubber particles, have been proved to greatly improve the performance of base asphalt [15].

In summary, although the current rubber asphalt is mainly produced by wet process, the microstructure of rubber asphalt may not be stable at elevated temperature, which could lead to separation of crumb and asphalt during storage. Therefore, it is difficult to produce and store rubber modified asphalt similar to virgin asphalt or polymer modified asphalt. Thus, the storage of rubber asphalt usually needs special equipment which produces rubber asphalt right before the production of asphalt mixture for field construction. Such procedure results in difficulties for quality control and is one of the barriers preventing the wide application of rubber asphalt technology.

The objective of this study was to characterize the performance of a plant-produced stable crumb rubber asphalt and the stone matrix asphalt mixture (SMA) with the plant-produced stable crumb rubber asphalt. Research activities of this study involve four steps. The first is material preparation followed by performance test for both asphalt and asphalt mixture. The test results were analyzed and conclusions were presented. Details are described in the next sections.

2. Materials and Laboratory test

2.1. Materials

A plant-produced stable rubber asphalt which has similar producing processes and storability with the traditional SBS (styrene-butadiene-styrene) modified asphalt was developed and evaluated in this paper. While the common rubber asphalt is usually produced with -40 mesh crumb rubber based on high temperature stirring and conditioning processes, the plant-produced rubber asphalt used 80–100 mesh crumb rubber instead as well as stabilizing agents based on the combined processes of reaction kettle and colloid mill.

Three different modified asphalts were used including field-produced rubber asphalt (FRA), plant-produced rubber asphalt (PRA), and SBS modified asphalt. In this paper, field-produced rubber asphalt (FRA) refers to the rubber asphalt that was produced during pavement construction, which usually cannot be stored for a long time, whereas the plant-produced rubber asphalt (PRA) refers to the rubber asphalt that was produced and stored and can be used whenever in need. The contents of rubber used in FRA and PRA were both 20%, whereas the content of SBS was 4%. The SBS binder uses SBS as the primary modifier which was originally developed to increase the flow characteristics and improve the low-temperature flexibility and fatigue resistance. All the three modified binders were produced using same base asphalt and were directed obtained at asphalt plant during paving. The softening point test [15] results for the PRA, FRA and SBS modified asphalts are shown in Table 1. It can be seen that the storage stability of plant-produced rubber asphalt is worse than the SBS modified asphalt but much better than the field-produced rubber asphalt.

SMA mixture was also prepared in laboratory use the aforementioned binders with nominal maximum aggregate size of 13.2 mm (SMA13). The SMA13 is a typical used aggregate gradation type in China with nominal maximum aggregate size of 13.2 mm. Based on trial tests, the PRA and SBS used the same aggregate gradation and the FRA used slight different gradation, as shown in Fig. 1. The upper and lower limits of the gradation curve was also presented. The addition of rubber particles in the FRA makes it difficult for FRA to use the same aggregate gradation as SBS. Accordingly, the aggregate gradation was adjusted with lower percent passing of 4.75 mm and 0.075 mm sieves to provide more space for the rubber particles in the FRA to eliminate their interferences on the aggregate skeleton. Based on recommendations provided by a Chinese technical specification [16], the polyester fibers were used in the SMA13 prepared with SBS modified asphalt. However, due to the high viscosity of rubber asphalt, the SMA13 prepared with FRA and PRA didn't use polyester fibers. Marshall mix design method is utilized and the design parameters are shown in Table 2.

Table 1
Softening point test results of different asphalts.

Asphalt	PRA	FRA	SBS
Softening point difference /°C	2.2	6.7	0.9

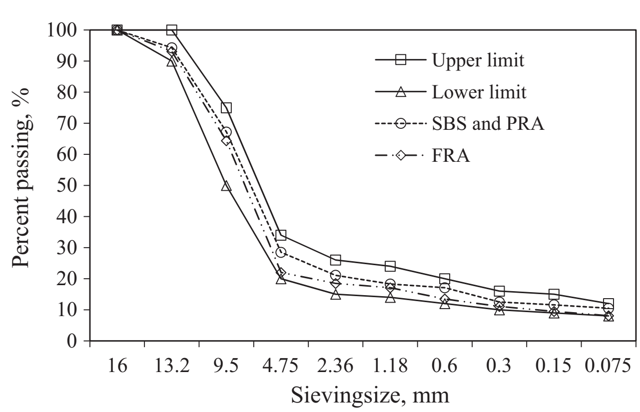

Fig. 1. Design aggregate gradation of SMA13 mix.

2.2. Laboratory test

Infrared spectrum (IR) analysis and differential scanning calorimeter (DSC) tests were used to analyze asphalt properties at micro-scale. The IR analysis was used to observe the microstructure of base, PRA, FRA and SBS asphalt. Since different chemical groups have its own absorption degree for the infrared radiation wavelengths, a single functional group can present a unique peak of infrared absorption during IR analysis. IR analysis, which is commonly used for asphalt materials, is an effective way to detect the main functional groups of materials [17,18]. The differential scanning calorimeter (DSC) test was used to evaluate how the macro-performance behavior varies under microstructure changing. When the material state converts from one to another as temperature changes, the endothermic or exothermic process will occur accordingly. The DSC test is adopted to monitor the heat flows changing within materials. In DSC curves, the peak temperature means that the composition state start to change and the endothermic peak area quantifies the amount of the changed composition. Fig. 2(a) and (b) show Fourier infrared spectrometer (TENSOR27 PMA50) produced by BRUKER company of Germany, and the differential scanning calorimetry (DSC8000) used in this study, respectively.

Asphalt properties of each binder were tested using dynamic shearing rheometer (DSR) test at high and medium temperatures at frequency of 1.5 Hz, and bending beam rheometer (BBR) test at low temperature [19–21]. Besides, the multiple stress creep and recovery (MSCR) test by using the DSR was also conducted at 64 °C to compare the rutting resistance [22]. DSR time sweep tests at different strain levels were also carried out to further compare the fatigue cracking resistance of different asphalt. In the time sweep test, the test stopped when the complex modulus decreased by half of its original value, and the fatigue life was characterized by the total loading cycles until the fatigue failure occurred.

Performance test for asphalt mixture including wheel tracking test, low temperature bending beam test, immersion Marshall test, freeze-thaw splitting test, and four-point bending beam fatigue test. These tests were conducted to evaluate material properties in resisting high temperature rutting, low temperature cracking, moisture damage, and fatigue failure, respectively [15]. Three replicates were used for all the asphalt and mixture performance tests except for BBR test in which two repetitions were included in accordance with AASHTO T313.

Table 2
Marshall mix design parameters of different asphalt mixtures.

SMA13	Asphalt content/%	Air voids/%	VMA/%	VFA/%	VCA/%	Stability/kN	Flow value/mm
With SBS	5.8	4.0	16.9	76.3	37.8	12.4	22.6
With PRA	5.7	4.2	17.0	75.1	37.8	13.1	25.3
With FRA	6.1	4.2	18.2	78.9	38.9	11.8	27.4