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Laboratory evaluation on high temperature viscosity and low temperature stiffness of asphalt binder with high percent scrap tire rubber

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ABSTRACT

The objective of this research is to utilize crumb rubber from scrap tires as an environmental friendly and sustainable additive for enhancing the high temperature and low temperature rheological properties of asphalt binders for asphalt pavements. Two different crumb rubber sources with different gradations – fine and coarse – were used in this project. The crumb rubber-modified (CRM) binder was produced by adding 10, 15, 20 and 25% crumb rubber particles by weight of a Superpave PG 64-22 asphalt binder. The CRM binders with and without Rolling Thin Film Oven (RTFO) aging were characterized by the AASHTO rotational viscosity test at 135, 140, 150, 160, 170, 177, and 190 °C (AASHTO T316). Furthermore, the low temperature cracking resistance of the binders was evaluated using the AASHTO Bending Beam Rheometer (BBR) test procedure at −12 and −18 °C (AASHTO T313). The statistical analysis of variance (ANOVA) was applied to quantify the effect of the influencing factors such as temperature, rubber particle size, and rubber concentration on the CRM binders' performance. From the laboratory tests and ANOVA results in this study, it is evident that the addition of crumb rubber into asphalt binder can both significantly improve the viscosity of binder at high temperature and lower the creep stiffness at low temperature, which is beneficial to better both high temperature stability and low temperature cracking resistance of asphalt pavements. After RTFO aging, the viscosity decreases with increasing rubber concentration. Finer crumb rubber attains higher viscosity at high temperature and lower creep stiffness at low temperature. Considering the viscosity–temperature relationship, RTFO aging effects, creep stiffness decreasing percentage, and economical factors, 15% to 20% rubber asphalt ratio is proposed for the production of CRM binder.

1. Introduction

With the motor industry developing and spreading at a higher pace in all parts of the world, high amount of scrap tires were produced every year, which makes the disposal of tires a serious environmental problem [1]. Crumb rubber, which is obtained from the grinding of scrap tires, has proved to be an efficient solution to the environmental concerns surrounding the accumulation of waste tires in recent years [2,3]. The beneficial use of crumb rubber into virgin asphalt binder and pavements provides an environmentally sustainable method of disposing of the millions of tires generated annually [4].

The American Society of Testing and Materials (ASTM) defines asphalt rubber (AR) as "a blend of asphalt cement, reclaimed tire rubber and certain additives, in which the rubber component is at least 15% by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles," [5]. Researchers have shown that the addition of crumb rubber into virgin asphalt can produce asphalt rubber binders with better resistance to rutting, fatigue cracking and thermal cracking as well as reducing the thickness of asphalt overlays and potential reflective cracking [6,7]. The asphalt rubber acts in slurry and chip seal materials as a stress absorbing membrane while demonstrating good anti-fatigue and durability performance in field applications [8,9].

The addition of crumb rubber into virgin asphalt induces a significant increase in binder viscosity. As the viscous property of asphalt rubber is critical to mixture compaction temperature and binder workability during storage and pumping process, the viscosity of asphalt rubber has been the central focus in previous research work [10,11]. Lougheed and Papagiannakis

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adopted the Brookfield viscometer to test the viscosity of three virgin and six rubber-modified asphalt binders [12]. Their samples contained crumb rubber concentrations of 3%, 5%, 7%, 12% and 18% by weight of the virgin binder. Notable among their conclusions was the introduction of the concept of "stabilized viscosity". Stabilized viscosity is the phenomenon whereby the viscosity of the rubber-modified asphalt will decrease to a stabilized value after approximately 45–75 min of blending; with the exact stabilized time dependent on the crumb rubber concentration. West et al. evaluated the effect of the tire rubber grinding method on AR binder properties and characteristics, and they found a good correlation between the grinding process of crumb rubber and the viscosity and storage settlement. Crumb rubber with greater specific surface areas and more irregular shapes can induce high viscosity conditions in asphalt rubber binder [13].

Lee et al. adopted the gel permeation chromatography (GPC), dynamic shear rheometer (DSR) and rotational viscosity (RV) to characterize control binder, SBS-modified binder and rubber-modified binder of two short-term aging method, rolling thin film oven (RTFO) aging and short-term oven aging (STOA) [14]. According to their tests, increased aging time will cause an increase in viscosity at high temperatures for the control and SBS-modified binders. It should be noted however that there was no clear trend in the viscosity change for the rubber-modified binder with and without aging. The scanning electron microscope (SEM) and differential scanning calorimeter (DSC) techniques have been used to evaluate the effect of crumb rubber characteristics, including rubber sources and rubber concentration, on crumb rubber-modified (CRM) binder viscosity [15]. Their tests proposed that the CRM type and sources plays an obvious role in influencing the viscous properties of the CRM binder. Statistical regression and neural network approaches have been applied to predict the viscosities of different rubber type CRM binders with different concentrations and proposed an efficient way to estimate the viscous properties of different variables such as asphalt binder grade, binder source, test temperature, rubber content and rubber source [16]. With the aid of the dynamic shear rheometer (DSR), rotational viscometer and the GPC, interaction effects such as blending time, temperature and rubber content of CRM binders were investigated in research conducted by Jeong et al. [17]. Their work proved that longer blending time and higher blending temperature result in a higher viscosity of CRM binders.

Previous research investigations have focused on viscous properties of CRM binders from different aspects and this was beneficial to understand the different influence factors and their effects on the performance of CRM binders. It must be emphasized that the aging effect on the viscosity of binders containing different CRM concentrations and at different temperatures still need a thorough study. Additionally, it is pertinent to focus on the low temperature stiffness of CRM binders to investigate the relationship between low temperature stiffness and thermal cracking of CRM mixture pavements. These areas of study have received less attention in past and current studies.

2. Objective and scope

The objective of this research is to utilize crumb rubber from scrap tires as an environmental friendly and sustainable additive for enhancing the rheological properties of asphalt binders. The focus was to investigate the viscous property of CRM binders with and without RTFO aging at different test temperatures, and also test the low temperature creep stiffness of CRM binders with different rubber concentrations.

3. Experimental program

3.1. Materials

Two particle size crumb rubber materials cryogenically produced from different sources in China were adopted in this paper. Fig. 1 shows the percent passing gradation of Crumb Rubber A (Rubber A) and Crumb Rubber B (Rubber B). Five rubber asphalt concentrations, 0%, 10%, 15%, 20% and 25% by weight of asphalt, were used in this study.

A Superpave PG 64–22 binder was used as the control binder in this study. This binder was obtained from a construction site near Detroit in Michigan and met the MDOT specification requirements. Table 1 shows the properties of control PG 64-22 binder.

Two sources of cryogenic fine crumb rubber were added to the virgin PG 64-22 binder to produce the CRM binders. The basic properties of the crumb rubber are shown in Table 2.

3.2. Experimental plan

The detailed experimental plan is indicated in Fig. 2. The plan sums up the material preparation, Superpave™ characterization and evaluation of the CRM binders.

3.3. Sample preparation

The crumb rubber was added gradually into the asphalt binder at a reaction temperature of 350 °F (177 °C), and mixed mechanically for about 45 min. The reaction time of 45 min was considered adequate based on some preliminary literature

Table 1
The properties of virgin asphalt.

Aging states	Test properties	Testing results
naged binder	Rotational viscosity @ 135 °C (Pa s)	0.435
	$G^*/\sin\delta$ @ 64 °C (kPa)	1.412
RTFO aged residue	$G^*/\sin\delta$ @ 64 °C (kPa)	3.69
RTFO + PAV aged residue	$G^*\cdot\sin\delta$ @25 °C (kPa)	1171
	Stiffness @ −12 °C (MPa)	189
	m-value @ −12 °C	0.314

Table 2
Properties of the crumb rubber materials.

Property	Rubber A	Rubber B
Specific gravity (g/m^3)	1.12	1.14
Moisture content (%)	0.56	0.65
Ash content (%)	3.6	4.3
Acetone to mention oil complex (%)	8.9	10.2
Fiber content (%)	0.1	0.05
Metal content (%)	0	0
Carbon black content (%)	32.7	35.4

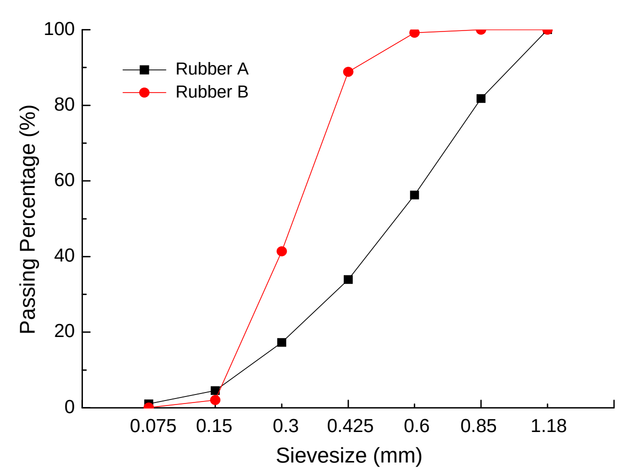

Fig. 1. The passing percent gradation of Crumb Rubbers A and B.