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Estimating correlations between rheological and engineering properties of rubberized asphalt concrete mixtures containing warm mix asphalt additive

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ABSTRACT

In recent years, warm mix asphalt (WMA) is widely used for reducing energy requirements and emissions in hot mix asphalt (HMA) industry. In addition, the use of rubberized asphalt in the past has proven to be economical, environmentally sound and effective in improving the performance of pavements across the US and the world. The objective of this research was to investigate the mixture performance characteristics of rubberized warm asphalt mixtures, and their correlation with binder properties, through a series of laboratory tests (e.g., viscosity, dynamic shear rheometer (DSR), and bending beam rheometer (BBR)) conducted on the binders, and obtaining the indirect tensile strength, rutting resistance, and resilient modulus of various mixtures. The results of the experiments indicated that the use of crumb rubber and WMA additive in HMA can effectively improve the engineering properties of these mixes at lower mixing and compacting temperatures and some statistical correlations between rheological and/or engineering properties were developed successfully.

1. Introduction

In recent years, the "warm mix asphalt" (WMA) is widely being promoted and used in the hot mix asphalt (HMA) industry as a mean of reducing energy requirements and lowering emissions. WMA can significantly reduce the mixing and compacting temperatures of asphalt mixtures, by either lowering the viscosity of asphalt binders, or causing foaming in the binders. Reduced mixing and paving temperatures would decrease the energy required to produce HMA, reduce emissions and odors from plants, and make better working conditions at the plant and the paving site [1–9].

At the same time, recycling of scrap tires has also been of interest in the asphalt industry throughout the world for over 40 years. Currently, approximately 82% of scrap tires are utilized for such applications as tire-derived fuel, molded products, crumb rubber, and other applications [10]. The mixing of crumb rubber with conventional binders results in an improvement in the resistance to rutting, fatigue cracking and thermal cracking [11–15]. Many researchers have found that utilizing crumb rubber in pavement construction is effective and economical [16–19].

However, the influence of crumb rubber and WMA additives mixed with virgin mixtures together has not yet been identified clearly. The interaction of modified mixtures with WMA additives is not well understood from the standpoint of binder properties and field performance. It has been shown that the WMA additives reduce the mixing and compaction temperatures and achieve ideal workability of HMA without significantly affecting the engineering properties of the mixtures [1–4]. While the addition of crumb rubber increases the demand of asphalt binder and significantly increases the mixing and compacting temperatures, the modified binder is helpful in resisting the high temperature deformation and extending the long-term performance of HMA. Because of the complicated relationships of the crumb rubber and WMA in the modified mixtures, detailed information will be beneficial to help obtain an optimum balance in the use of these materials.

The objective of this study was to gain an improved understanding of the mixture performance characteristics and the correlation between the rubberized asphalt concrete mixtures containing WMA additives and rubberized asphalt binders containing the warm asphalt additives. Experiments were carried out to evaluate properties of modified binder (i.e., viscosity, $G^*/\sin\delta$, $G^*\sin\delta$, and stiffness) as well as properties of the mixtures (i.e., indirect tensile strength, resilient modulus, and rutting susceptibility).

2. Experimental program and procedures

2.1. Materials

One virgin binder (PG 64-22) and one crumb rubber modified (CRM) binder (PG 64-22 + 10% −40 mesh rubber) were used in this study (Table 1). The test results of these binders were performed in accordance with Superpave mix design specifications (SP-2). The PG 64-22 binder was a mixture of several sources that could not be identified by the supplier. One type of rubber, −40 mesh ambient rubber, was produced by mechanical shredding at ambient temperature. To ensure that the consistency of the rubber was maintained throughout the study, only one batch of crumb

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Table 1
Rheological properties of binders.

	Unaged binder				Aged binder (RTFO + PAV)			
	Viscosity	Std.	$G^*/\sin\delta$	Std.	$G^*\sin\delta$	Std.	Stiffness	Std.
	Pa S (135 °C)		kPa (64 °C)		kPa (25 °C)		MPa (−12 °C)	
PG 64-22	405.0	1.3	1.2	212.1	2970.0	572.8	221.0	20.5
PG 64-22^{A}	439.2	4.0	1.6	55.2	2855.0	35.4	243.7	4.9
PG 64-22^{S}	382.2	13.1	2.1	115.3	3315.0	318.2	244.7	4.7
PG 64-22$^{\#}$	1600.0	0.0	3.7	60.8	1705.6	66.1	128.5	2.5
PG 64-22$^{\#A}$	1477.8	78.2	4.7	631.9	2042.1	3.9	148.0	1.2
PG 64-22$^{\#S}$	1438.9	93.0	5.2	469.4	2160.3	170.2	150.5	0.6

Note: A: asphamin; B: Sasobit; # 10% −40 mesh rubber, Std.: Standard deviation.

rubber was used in this study. Previous research and field projects conducted in South Carolina indicated that the −40 mesh ambient rubber is effective in improving the engineering properties of rubberized mixtures [20]. Therefore, the −40 mesh rubber was employed in this study. To prepare the modified binders, a reaction time of 30 min was considered suitable based on previous studies indicating that the mixing time did not significantly influence the binder properties [19,21].

Aspha-min® and Sasobit® were used in this study as the two WMA additives. Aspha-min® is a sodium–aluminum–silicate zeolite, which is hydro thermally crystallized as a very fine powder. It contains approximately 21% crystalline water by weight. By adding it to an asphalt mix, the fine water spray is created as all the crystalline water is released, which results in volume expansion in the binder, therefore increasing the workability and compactability of the mix at lower temperatures [22]. Sasobit® is a long chain aliphatic hydrocarbon obtained from coal gasification using the Fischer–Tropsch process. After crystallization, it forms a lattice structure in the binder which is the basis of the structural stability of the binder containing Sasobit® [22]. More detail information regarding the two additives can be found in other studies [1–2,23].

Two aggregate sources (A and B) were used for preparing samples (Table 2). Aggregate A, granite source, is composed predominantly of quartz and potassium feldspar while aggregate B (schist) is a metamorphic rock. Hydrated lime, used as an anti-strip additive, was added at a rate of 1% by dry mass of aggregate. A total of eight mixtures were evaluated in this research.

2.2. Superpave mix design

The combined aggregate gradations for 12.5 mm mixtures were selected in accordance with the specification set by the South Carolina Department of Transportation (SCDOT). The combined gradations for each aggregate sources (A and B) are shown in Fig. 1, which shows that the design aggregate gradations for each aggregate source are the same when using different WMA additives (Asphmin and Sasobit) at the same percentages of rubber (0% or 10% rubber).

There are no previous specifications available regarding the mixing and compaction temperatures for rubberized mixtures containing WMA additives, however, some researchers have developed guidelines for mixing and compaction temperatures when using WMA or CRM binders [1–2,14,21,25,26]. The temperatures, shown in Table 3, were determined in accordance with previous research projects [24]. Both mixing and compacting temperatures increase as the percentage of crumb rubber increases, however, these temperatures could be reduced by adding Asphmin and Sasobit.

2.3. Sample fabrication and testing

For this study, the optimum binder content, during the mix design process, was defined as the amount required to achieve 4.0% air voids at a given number of design gyrations (N_{design} = 75). Six indirect tensile strength (ITS) specimens, compacted to 7 ± 1% air voids, were used to evaluate the moisture susceptibility of various mixtures as modified AASHTO T283 procedures (no freeze/thaw cycle) were followed.

Four specimens, one for destructive ITS test and three others for repeated loading, were also compacted to 7 ± 1% and 4 ± 1% air voids for no rubber and 10% rubber samples, respectively. Then all samples were tested for resilient modulus at three different temperatures (5 °C, 25 °C and 40 °C) as per ASTM D4123. All specimens had a height of 95 ± 1 mm and a diameter of 150 ± 1 mm.

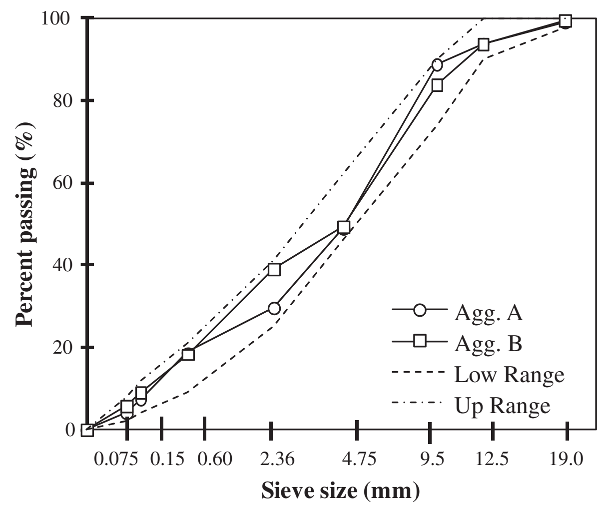

Fig. 1. Gradations of 12.5 mm aggregates.

Six cylindrical Asphalt Pavement Analyzer (APA) specimens, for each mix type, were compacted to 4.0 ± 0.5% air voids using a Superpave gyratory compactor. All testing with the APA samples were carried out to 8050 cycles to measure the rut depth of the HMA at 64 °C [27]. The testing temperature was based on the virgin binder's "performance grade" used in this study.

3. Analysis of test results

3.1. Binder analysis

Table 1 indicates that the viscosity of rubberized asphalt binder does not decrease significantly while the high temperature performance ($G^*/\sin\delta$) of binders increases with the addition of WMA additive. The unaged binder test result shows that the Asphamin and Sasobit can improve the workability (viscosity) and rutting resistance ($G^*/\sin\delta$) of mixtures. The aged rubberized binders show that the $G^*\sin\delta$ values decrease with the addition of rubber but these values increase slightly as the WMA additives are added. It can be noted that the stiffness values of binders have similar trends with $G^*\sin\delta$ values due to the addition of these materials. Aged binder properties show that the WMA additives do not noticeably affect the long-term performance of asphalt binder.

Table 2
Engineering properties of aggregates.

Aggregate source	LA abrasion loss (%)	Absorption (%)	Specific gravity			Soundness % loss at five cycles			Sand equivalent	Hardness
			Dry (BLK)	SSD (BLK)	Apparent	11/2 to 3/4	3/4 to 3/8	3/8 to #4		
A	51	0.80	2.740	2.770	2.800	0.2	0.1	0.1	–	5
B	34	0.60	2.780	2.800	2.830	0.4	0.6	0.9	35	5

Note: aggregate A: granite; aggregate B: schist.