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Impact of recycled asphalt materials on asphalt binder properties and rutting and cracking performance of plant-produced mixtures

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HIGHLIGHTS

- Plant-produced asphalt mixtures were collected from various construction sites.
- Asphalt binder properties and rutting and fatigue performances were characterized.
- Most of the mixtures with RAP and RAS exhibiting relatively low Jnr values in the MSCR test.
- Mixtures passed the HWTT test while some had high rutting potential in the RLPD.
- All the mixtures with RAP and RAS exhibited low cracking resistance in the OT test.

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ABSTRACT

The use of recycled asphalt materials (RAM), such as Reclaimed Asphalt Pavement (RAP) and Reclaimed Asphalt Shingles (RAS), offers a great benefit in improving the rutting resistance of Hot Mix Asphalt (HMA) due to the changes in the rheological properties of the aged asphalt binder. To improve the HMA crack resistance, soft asphalt binders are typically blended with RAP and/or RAS to modify their rheological properties. However, soft asphalt binders could compromise the HMA rutting resistance, particularly in areas with high pavement temperatures and heavy traffic. Texas has implemented HMA mixtures with addition of RAM in many projects, and several premature field-rutting failures were observed with these mixtures. The addition of stiff aged asphalt binders of RAP and RAS can also decrease the HMA cracking resistance potential. Different from other previous studies, this study used plant-produced mixtures collected from various highway construction sites and projects to investigate the effects of RAM on the asphalt binder properties as well as the rutting and cracking performances of these plant-produced asphalt mixtures that represent actual in-service field applications. Through this study, designers, engineers, and the industry are able to gain a clearer understanding of pavement performance of mixtures with RAM. As theoretically expected, the corresponding results indicated that addition of RAP and RAS significantly improved the Dynamic Shear Rheometer (DSR) high temperature grade of all the extracted asphalt binders, with most of the HMA mixtures exhibiting relatively low J_{nr} values in the multiple stress creep recovery (MSCR) test. For the HMA rutting performance tests, all the mixtures passed the Hamburg Wheel Tracking Test (HWTT) while some exhibited relatively high permanent deformation in the Repeated Load Permanent Deformation (RLPD) test. By comparison, the MSCR (J_{nr})-RLPD correlation was found to be more definitive than the DSR-RLPD correlation. In general, the mixtures with RAP and RAS exhibited comparatively low cracking resistance in the Overlay Tester (OT).

1. Introduction

Recycled asphalt materials (RAM) including recycled asphalt pavement (RAP) and recycled asphalt shingles (RAS) have been gaining increasing attention in the past few years as sustainable

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road construction materials, with considerable savings in costs and environment protection [1,2]. The asphalt binder from RAP is generally an aged material that exhibits stiffer rheology properties than the virgin asphalt binder. Percentages of RAP used in hot-mixed asphalt (HMA) typically range from 20% to 50% [3]. RAS, on the other hand, is predominantly derived from two sources; namely manufacturing waste and tire tear-off. RAS contains asphalt binder with some amount of hard aggregates and fibers, with its quality varying as a function of its service life and sources among others [4]. The percentage of RAS added to HMA typically ranges from 3% to 5% by weight of the mixture, which are much smaller quantities than the percentages used for RAP dosage [5].

Permanent deformation (or rutting) is one of the major performance failures occurring in asphaltic pavements [6–8]. The use of RAP and/or RAS offers a great benefit towards improving the rutting resistance of HMA pavements due to changes in the rheological properties of the aged asphalt binder. However, such changes in the rheological properties of the aged stiff asphalt binder would often decrease the resistance of HMA pavements to fatigue and thermal cracking [4,5]. Thus, to improve the HMA crack resistance, a soft asphalt binder is generally blended with RAP and/or RAS to modify its rheological properties.

Due to blending with softer asphalt binders (e.g., PG 64-XX), HMA rutting resistance may be compromised and not be able to meet the design requirements. This is especially critical in areas with high summer temperatures and/or heavy traffic where high performance-graded (PG) asphalt binders (e.g., PG 70-XX or PG 76-XX) would otherwise be used. The current summer pavement temperatures can reach as high as 60 °C [9], and Texas has experienced recorded high summer pavement temperatures (>50 °C) in the recent years. For the cost savings and pavement sustainability, Texas has implemented HMA mixtures with addition of RAM in many projects, and several premature field-rutting failures were observed with these mixtures.

In addition, a survey conducted by Texas Department of Transportation (TxDOT) indicated that the percentages of the lane miles contained shallow rutting and deep rutting increased from 23.0% in 2011 to 41.7% in 2014 and 4.0% in 2011 to 6.7% in 2014, respectively, while there was no significant increase for the cracking distress [10]. Thus, the rutting distress is a critical issue in the pavements across the State of Texas. Evaluation of effectiveness of the RAM for the improvement of rutting resistance is important and necessary. On the other hand, the recycled asphalt is less strain-tolerant due to its stiff aged asphalt, which could be more susceptible to cracking [11,12]. Thus, evaluation of rutting and cracking performance of such plant-produced mixtures with addition of RAM is meaningful and essential for the designers and the industry.

In this study, all the mixtures evaluated were plant-produced mixes that were collected from various highway construction sites and projects across the State of Texas. The objective of this study was to evaluate the effects of RAM (i.e., RAP and RAS) on the asphalt binder properties as well as the rutting and cracking resistance of plant-produced mixtures that represent actual in-service field applications. Through this study, designers, engineers, and the industry are able to gain clearer understanding of pavement performances of mixtures with RAM.

In order to achieve the objective, three asphalt binder tests, namely the dynamic shear rheometer (DSR) high temperature grade, multiple stress creep and recovery (MSCR), and viscosity tests, were utilized to characterize the rheological properties of the extracted asphalt binder from plant-produced mixtures. MSCR is a relatively new creep and recovery performance test used for asphalt binders to measure non-recovery compliances as well as recovery properties of the asphalt binders. The MSCR test has been drawing increasing attention in the past few years, with various studies showing that it is a performance-related test and its non-recovery compliance property (J_{nr}) has a better correlation with HMA rutting performance than the traditional DSR high temperature properties [13–15]. Additionally, the recovery properties of extracted asphalt binders can reveal some information related to cracking performance [16,17]. For the pavement performance tests, the Repeated Loading Permanent Deformation (RLPD) and the Hamburg Wheel Tracking Test (HWTT), and the Overlay Tester (OT) test were used to evaluate rutting and cracking resistance of HMA mixtures, respectively.

In the subsequent sections, the experimental framework and the laboratory test methods are described, followed by the materials used including the asphalt binders and HMA mixtures. The laboratory test results are subsequently presented and include an analysis and corresponding discussions. The paper then concludes with a synthesis and summary of the key findings and recommendations.

2. Experimental framework

This section presents the laboratory test methods used to characterize asphalt binder properties as well as rutting and cracking performance of asphalt mixtures (as shown in Fig. 1). It should be mentioned that the DSR test at intermediate temperatures and BBR test was not included in the experimental plan since all the asphalt binders used in this study were extracted from plant-produced mixtures and not feasible to obtain sufficient PAV-aged asphalt binder. The asphalt binders were extracted and recovered from the plant-produced mixtures according to the Tex-210-F [18] and ASTM D5404 [19] test procedures for solvent-based binder extraction and recovery methods.

2.1. The DSR high temperature grade test

The DSR high temperature grade test is a standard test that to measure the viscoelastic properties of asphalt binders at high temperatures according to AASHTO M 320 [20]. Two parameters, namely the shear modulus ($|G^*|$) and phase angle (δ), are the output results. The high temperature PG grade parameter is designated to indicate the properties of the asphalt binder relative to HMA rutting resistance [13].

2.2. The MSCR test

The MSCR test is used to characterize the creep and recovery behavior of asphalt binders with the use of the DSR machine setup as per AASHTO TP 70–10 [21]. The test is typically conducted at high temperatures such as 64, 70, and 76 °C, respectively. An example of the MSCR test results are illustrated in Fig. 1. It can be seen that two stress levels of 0.1 and 3.2 kPa with a total of ten cycles for each stress level are applied on an asphalt binder sample [13]. The output results of percent recovery (R%) and non-recoverable creep compliance (J_{nr}) are expressed in Eqs. (1) and (2), respectively [13]:

$$J_{nr} = \frac{Non\text{-}recoverable\ strain}{Stress\ level} \tag{1}$$

$$R\% = \frac{Recoverable\ strain}{Total\ shears\ train} \tag{2}$$

2.3. The viscosity test

The viscosity test is a standard test method used to measure the viscosity of asphalt binders at a specified temperature using a Rotational Viscometer (Fig. 1) in accordance with ASTM D4402