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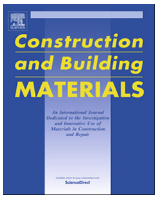

Asphalt rubber: Performance tests and pavement design issues

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HIGHLIGHTS

- Asphalt rubber mixtures have unique properties in terms of improved permanent deformation and fatigue cracking.
- Their use in new pavement designs and rehabilitation programs are intricate.
- Laboratory performance tests and models modifications are presented and discussed.
- Tests and models discussed are evaluated through field performance measures.

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ABSTRACT

Asphalt rubber mixtures continue to receive great attention from many transportation agencies worldwide because of their ability to improve pavement performance compared to conventional designs. A number of studies reported on the unique properties and characteristics of asphalt rubber mixtures in terms of improved permanent deformation and fatigue cracking. Several states in the US and countries around the world have used, or are in the process of using asphalt rubber mixtures in new pavement designs and rehabilitation programs. This paper summarizes findings from several research studies conducted at Arizona State University in the areas of binder and mixture performance. The unique engineering properties of asphalt rubber mixtures are discussed along with recommendation on how to use them in current pavement design procedures.

1. Introduction

There is no doubt that the use of Asphalt Rubber (AR) mixtures improves pavement performance with outstanding results. A number of studies reported on the unique properties and characteristics of AR mixtures in terms of improved environmental benefits, life cycle costs and pavement performance [1–9]. Several states in the US and countries around the world have used, or are in the process of using asphalt rubber mixtures in new pavement designs and rehabilitation programs.

The Mechanistic-Empirical Pavement Design Guide (name evolution: MEPDG, DARWin-ME, Pavement ME) developed by the National Cooperative Highway Research Program (NCHRP) utilizes material properties to predict distresses in the pavement structures [10]. This pavement design guide (referred to as “design guide” hereafter) was calibrated and validated with a global, national, performance distress approach. The design guide has been getting popularity and will soon be the mostly used procedure by DOT’s in the United States and some transportation agencies around the world. The national calibration process that was undertaken for the design guide did not include asphalt rubber mixtures. In fact, the use of design guide in current state will provide false predictions on the anticipated performance of asphalt rubber mixtures. It is very likely that such agencies without sufficient knowledge and proper tools will defer the use of asphalt rubber mixtures in their pavement design and rehabilitation practices.

Over the past decade, Arizona State University has developed a comprehensive material properties database for asphalt rubber mixtures. This database included binder and mixture material characterization. The conventional consistency binder tests included: penetration, ring and ball softening point, and rotational viscosities at selected temperature range. In recent years, additional tests included the dynamic shear and bending beam rheometers. The main mixture characterization tests included those that are most relevant to the design guide implementation. These include: dynamic (complex) modulus for stiffness evaluation, flexural beam test for fatigue cracking evaluation, repeated load for permanent deformation evaluation, and indirect tensile tests for thermal cracking evaluation. In addition, other recent advanced

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material characterization tests included fatigue evaluation using the continuum damage approach and crack propagation using the C^* fracture test.

Using the database and the experience developed over the years with asphalt rubber mixtures, different studies have been conducted to assess how asphalt rubber mixtures compare with conventional mixtures and what needs to be done in order to implement AR mixtures into the design guide [11,12]. It is noteworthy that the database included mixtures from Arizona, California, Texas, Canada, and Sweden. These studies have shown that because of the unique characteristics of asphalt rubber mixtures, it is difficult to group them together with conventional mixtures.

New models were developed to calibrate or replace existing models, and to properly predict the performance of asphalt rubber mixtures. Such efforts included a process to derive the equivalent PG grade of the crumb rubber modified binder, a revised predictive model for the dynamic modulus, a revised thermal cracking predictive model, and specific model coefficients for fatigue cracking analysis. While incorporating these new models in the existing design guide program is not straight forward, some of the development allows their input indirectly, where other models were developed as a stand-alone tool that mimic the current design guide program and analysis procedure.

2. Material input and implementation in the design guide

In the design guide, there are basically three input steps for the asphalt concrete layer: mixture, asphalt cement (binder or bitumen), and a general asphalt category. The information required in each of these fields will vary according to the level of analysis to be used, as briefly described below.

Level 1: laboratory test data are required to develop the Dynamic Modulus master curve and shift factors. Dynamic modulus test results (AASHTO TP62-07) at different temperatures and frequencies must be input. Binder data at short term aging is also required. This can be either Superpave or conventional binder consistency tests. For the superpave binder test data, complex modulus and phase angle data are needed over a range of temperatures and loading rate of 1.59 Hz. For conventional binder test data, softening point, penetration, and viscosities are needed as input. These test results are used to determine the viscosity-temperature susceptibility parameters (A_i–VTS_i) of the binder [13]. The information required for the asphalt mixtures are the volumetric properties, which are also the same information required for Levels 2 and 3.
Level 2: the Witczak Dynamic Modulus predictive equation shown below is used. The same binder test data is needed as in the Level 1 analysis.

$$\begin{aligned}\log E^* = {} & 3.750063 + 0.02932\rho_{200} - 0.001767(\rho_{200})^2 - 0.002841\rho_4 \\ & - 0.058097V_a - 0.802208\left(\frac{V_{eff}}{V_{eff}+V_a}\right) + \\ & \frac{3.871977 - 0.0021\rho_4 + 0.003958\rho_{38} - 0.000017(\rho_{38})^2 + 0.005470\rho_{34}}{1 + e^{(-0.603313 - 0.313351\log(f) - 0.393532\log(\eta))}}\end{aligned} \tag{1}$$

where E^* = dynamic modulus, psi; η = bitumen viscosity, 106 poise; f = loading frequency, Hz; Va = air voids content, %; V_{eff} = effective bitumen content, % by volume; ρ_{34} = cumulative % retained on the 3/4 in sieve; ρ_{38} = cumulative % retained on the 3/8 in sieve; ρ_4 = cumulative % retained on the # 4 sieve; ρ_{200} = % passing the # 200 sieve.
Level 3: the Dynamic Modulus predictive equation is also used to estimate the dynamic modulus. The binder information for Level 3 does not require laboratory test data. The binder viscosity information is estimated from typical temperature-viscosity relationships after the Rolling Thin Film Oven (RTFO) test results are established for different asphalt grades derived from various grading systems.

3. Binder characteristics

Table 1 shows a summary of typical viscosity-temperature susceptibility parameters (A_i–VTS_i) data for two binders with and without rubber. These results include original and RTFO aging levels. It is observed that the AR binders improve the performance grade of the virgin binder especially at high temperatures (lower VTSi values).

Table 1
Typical A_i and VTS_i parameters for binders with and without asphalt rubber.

Binder type	Aging	A_i	VTS_i
PG58-22	Original	11.164	−3.764
	RTFO	11.076	−3.722
PG58-22 AR	Original	8.3595	−2.726
	RTFO	8.0475	−2.598
PG64-16	Original	11.163	−3.755
	RTFO	11.116	−3.728
PG64-16 AR	Original	8.39	−2.738
	RTFO	8.543	−2.781

By using asphalt rubber as a binder, the film thickness is increased to a value of 19–36 μm compared to the typical dense-graded Hot Mix Asphalt (HMA) film thickness of about 9 μm [Way 2000]. In Arizona, the grade of asphalt binder used as a base to make AR is a PG58-22 (AC-10, Pen 85-100), in contrast to the typically stiffer grade of PG 64-16 (AC-20, Pen 60-70) used in the mountains. In the desert the AR base asphalt grade is PG 64-16 (AC-20, Pen 60-70) compared to the PG 70-10 (AC-40, Pen 40-50) typically used for dense graded mixes. The 20% ground tire crumb rubber particles change the AR temperature susceptibility, the VTSi of the rubber modified binders is better (flatter, lower slope) than the conventional (virgin) binder, both at high and low temperature conditions. At lower temperature conditions, the AR binders are softer than the virgin binder. Higher binder viscosities at high temperatures and lower viscosities at lower temperature are indicative of good overall mix performance characteristics. These characteristics also agree with observed field performance, where AR mixes are known to have better response against permanent deformation, and low-temperature cracking.

The results in Table 1 were used to provide approximate PG grading of the AR binders. Since no PG grading are established for AR binder in the MEPDG, one approach would be to find the PG grading that best match the A_i and VTS_i values obtained in Table 1. This approximate matching is demonstrated in Table 2. For example, a PG 70-40 is the PG grading that best represents the A_i and VTS_i values for the PG 58-22AR binder. Similarly, a PG 76-34 is the one that best matches the PG 64-16 AR binder. By using this approach, Levels 2 and 3 of the MEPDG can be implemented.

4. Dynamic modulus characteristics

The Dynamic Modulus testing program follows AASHTO TP 62-07, which basically is a test protocol for unconfined laboratory testing. However, unconfined and confined stress state conditions were conducted for AR mixtures at ASU over the past several years. The confined Dynamic Modulus E^* test is especially important for the open and gap graded mixes because it represents the true state of stress in the field (upper layers with high confinement stress under loading). The effect of confinement is clearly shown in Fig. 1, where typical master curves for a gap graded mixture (ARAC) are presented for unconfined and three levels of confinements: 69, 138, and 207 kPa. The confined test results yield much higher moduli and the difference among the level of confinements continue at high temperatures.

Table 2
Approximate PG grading for AR binders.

Binder type	A_i	VTS_i
PG 58-22 AR	8.048	−2.598
PG 70-40	8.129	−2.648
PG 64-6 AR	8.543	−2.781
PG 76-34	8.532	−2.785

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