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Performance evaluation of gap graded Asphalt Rubber mixtures

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ABSTRACT

In this research, an extensive laboratory test program was conducted in order to investigate the mechanical performance (stiffness, fatigue, permanent deformation and thermal cracking) of a gap graded Asphalt Rubber Asphalt Concrete (ARAC) establishing an important database of ARAC engineering performance. Additional tests were performed on Asphalt Rubber binder and ARAC mix in order to verify whether the new Mechanistic Empirical Pavement Design Guide (MEPDG) can be used effectively for AR materials. Results were compared with those of reference materials tested in laboratory or found in literature.

1. Introduction

Asphalt Rubber (AR) binder is a blend of plain bitumen and crumb rubber produced from reclaimed tires (ASTM D8). Many worldwide researches have demonstrated that AR is able to enhance the mechanical performance of bituminous mixes [1–9] simultaneously creating an environmental benefit by re-using a waste material that otherwise would be disposed or burned. Moreover, AR binder seems to reduce rolling noise due to the lower stiffness of the bituminous mix which positively influences the mechanism of noise generation from vibration source [9–11].

This paper summarizes results obtained from an extensive laboratory test program conducted to carefully assess the mechanical performance (stiffness, fatigue, permanent deformation and thermal cracking) of a gap graded AR mix produced at the plant. Moreover, additional tests were performed on AR binder and Asphalt Rubber Asphalt Concrete (ARAC) mix in order to verify whether the new Mechanistic Empirical Pavement Design Guide (MEPDG) [12] can be used effectively for AR materials. The MEPDG, developed under the NCHRP Project 1-37A, utilizes material properties to predict distresses in pavement structures. As far as asphalt pavements are concerned, the Design Guide utilizes three hierarchical levels of analysis in decreasing order of accuracy from Level 1 to Level 3. The input required for Hot Mix Asphalts will vary according to the selected level of analysis. In particular, at Level 1, the HMA dynamic modulus E^* is calculated from a master curve that is constructed from laboratory data concerning complex modulus measurements and binder tests; while, at Levels 2 and 3, E^* is predicted by using mixture volumetric and asphalt properties. As far as the asphalt binder is concerned, two alternatives for providing test data are available for Levels 1 and 2: Superpave (complex modulus G^* and phase angle at 10 rad/s) and conventional binder test data (softening point, penetration and viscosity). On the contrary, the binder input for Level 3 does not require laboratory test data, but they are estimated on the basis of typical temperature–viscosity relationships. However, the calibration process undertaken for the MEPDG did not include any AR mixes. Thus, collected results could be usefully employed as input data for MEPDG implementation.

2. ARAC characteristics

An ARAC mixture produced at the plant using basaltic coarse aggregates was selected to be investigated within this research project. The mixture composition is detailed in Table 1 while main binder characteristics are reported in Table 2. 50/70 penetration base asphalt was employed to prepare the AR binder at the asphalt plant. Air void content, voids in mineral aggregate (VMA) and VMA filled with binder (VFB) of ARAC, according to EN 12697-8, were also calculated as mean values of all tested samples. Specimens were prepared using shear gyratory or roller compactor in order to obtain a target air void content of 6%.

3. Test methods

3.1. AR binder characterization

MEPDG requires a viscosity–temperature relationship, given in Eq. (1), as binder properties input data needed for all design levels:

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Table 1
Characteristics of Asphalt Rubber Asphalt Concrete (ARAC).

Sieves (mm)	Granulometric composition (% passing)	Gradation limits (% passing)
20	100.0	100.0
12	99.2	85.0–100.0
8	69.3	57.0–71.0
4	29.7	24.0–35.0
2	18.7	12.0–20.0
0.5	8.2	8.0–14.0
0.25	5.6	5.0–9.0
0.063	2.5	2.0–5.0
AR binder content (%)	7.9	
Rubber content (% on bitumen)	20%	
Air void content (%)	5.8	
VMA (%)	22.0	
VFB (%)	73.6	

Table 2
AR binder characteristics.

Characteristic	Test method	Unit	Value
Maximum crumb rubber size	ASTM D5644	mm	0.85
Penetration at 25 °C	EN 1426	0.1 mm	48
Softening point	EN 1427	°C	59
Fraass breaking point	EN 12593	°C	−14
Dynamic viscosity at 175 °C	EN 13302	mPa s	1800
Elastic recovery at 25 °C	EN 13398	%	70
After RTFOT	EN 12607-1		
Change of mass	EN 12607-1	%	0.42
Retained penetration at 25 °C	EN 1426	%	46
Increase in softening point	EN 1427	°C	14
Elastic recovery at 25 °C	EN 13398	%	66

$$LogLog\,\eta = A + VTS Log\,T_R \tag{1}$$

where η is the binder viscosity (cP), T_R is the temperature (°R), A is the regression intercept and VTS is the regression slope of viscosity temperature susceptibility.

In particular, this relationship can be extrapolated from laboratory test results for both Levels 1 and 2, while binder viscosity information (A and VTS) for Level 3 is estimated from typical temperature–viscosity relationships [12].

As far as laboratory data are concerned, two alternatives are possible: Superpave (complex modulus G^* and phase angle at 10 rad/s) or consistency test data (softening point, penetration and viscosity).

In this study, direct measurements of AR binder complex modulus G^* by means of a dynamic shear rheometer, according to SHRP specifications [13], were performed at different temperatures (40, 46, 52, 58, 64, 70, 76, 82 °C). Next, asphalt stiffness (G^* in Pa) and phase angle (δ) data for a loading rate of 1.59 Hz were converted to viscosity units (Pa s) using Eq. (2) [12]. This allowed the viscosity–temperature susceptibility parameters A and VTS to be obtained according to the above mentioned Eq. (1):

$$\eta = \frac{G^*}{10}\left(\frac{1}{\sin\delta}\right)^{4.8628} \tag{2}$$

As an alternative, penetration at 25 °C (EN 1426) and softening point (EN 1427) together with dynamic viscosity determinations using the Brookfield Viscometer (EN 13302) at different temperatures (60, 100, 135, 150, 160, 175 °C) were also performed on the selected AR binder. The results allowed to determine the viscosity–temperature susceptibility of crumb rubber modified asphalt binder also taking into account the conversion of penetration and softening point measurements into viscosity units [12]. In particular, it is assumed that all asphalts at their softening point will yield a penetration of approximately 800 dmm and a viscosity (η) of 1.3×10^6 centipoises (cP), while penetration data (Pen) are converted to viscosity units (in Poise) according to the following equation:

$$Log\,\eta = 10.5012 - 2.2601 Log(Pen) + 0.00389 Log(Pen)^2 \tag{3}$$

Next, dynamic viscosity data together with converted penetration and softening point results allowed to obtain the viscosity–temperature susceptibility parameters A and VTS according to the above mentioned Eq. (1).

3.2. ARAC stiffness modulus and fatigue resistance

In order to assess the bearing capacity and fatigue cracking resistance of the studied bituminous mixture, Indirect Tensile Stiffness Modulus (ITSM) and Indirect Tensile Fatigue (ITF) tests were carried out on six cylindrical samples at 20 °C by means of repeated load dynamic equipment. Moreover, stiffness data were also collected at 0, 10 and 30 °C. ITSM values could be used as the modulus of the bituminous layer when designing pavement using multi-layered elastic theory.

ITSM tests were carried out according to EN 12697-26 Annex C while ITF tests were performed in controlled stress conditions according to British Standards BS DD ABF applying three different stress levels with two repetitions for each stress value. Fatigue life was assumed as the number of cycles corresponding to physical failure of the test sample.

The specimens were prepared with a shear gyratory compactor at 165 °C compaction temperature. The final dimensions of specimens corresponded to a nominal diameter of 100 mm and to a thickness of 60 mm in order to obtain a target air void content of 6%.

The fatigue test results were also employed to verify the suitability of the MEPDG predictive fatigue model given in Eq. (4) [12] to also describe the behaviour of the selected AR gap graded material:

$$N_f = k_1\left(\frac{1}{\varepsilon_t}\right)^{k_2}\left(\frac{1}{E}\right)^{k_3} \tag{4}$$

where N_f is the number of repetitions to fatigue cracking, ε_t is the tensile strain at the critical location, E is the stiffness of the material and k_1, k_2 and k_3 are laboratory calibration coefficients. In this damage model k_1 can be expressed as a function of the total thickness of the asphalt layers h_{ac} (inches), the effective binder content V_b (%) and the air void content V_a (%) as illustrated in Eq. (5):

$$k_1 = 0.00432 \times \frac{1}{0.000398 + \frac{0.003602}{1+e^{(11.02-3.49h_{ac})}}} \times 10^{4.84\left(\frac{V_b}{V_a+V_b}-0.69\right)} \tag{5}$$

3.3. ARAC dynamic complex modulus

The MEPDG uses the dynamic modulus E^* as the primary material property of HMA mixtures in predicting pavement distresses [12]. E^* data of an HMA provide very important information about the linear viscoelastic behaviour of the material. Thus, cyclic uniaxial unconfined compression tests were also conducted on ARAC in order to determine the dynamic complex modulus E^*. The cylindrical specimens (diameter $\varnothing$ = 100 mm; height h = 150 mm) were compacted using a shear gyratory compactor to obtain a target air void content of 6%. A set of 6 replicates were tested at four temperatures (0, 10, 20 and 30 °C) and six frequencies (20, 10, 5, 2, 1 and 0.5 Hz). Each sample was tested in an increasing order of temperatures and decreasing order of frequency to cause the minimum damage to the specimen. To account for the effect of temperature