Technical Paper

ISSN 1997-1400 Int. J. Pavement Res. Technol. 5(2):69-74

Durability Assessment of Asphalt Rubber Mixtures

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Abstract: In this paper, a gap graded Asphalt Rubber Asphalt Concrete (ARAC) was studied to carefully assess durability aspects, such as moisture sensitivity, aging resistance, and abrasion resistance that contribute to establishing an important database of ARAC engineering performance. In particular, moisture sensitivity was investigated through indirect tensile and Cantabro tests on dry and wet conditioned specimens while the aging resistance was assessed in terms of change in the stiffness modulus, fatigue life, and Cantabro particle loss after the laboratory simulated long-term aging of the AR mixture. Finally, Cantabro test results on dry and un-aged samples were employed to evaluate the abrasion resistance of the studied material. Results were compared with those of reference materials tested in the laboratory or found in literature. The study provided evidence of the strong durability of the investigated Asphalt Rubber (AR) mixture.

***Key words**: Abrasion resistance; Aging resistance; Asphalt rubber; Gap graded; Moisture sensitivity.*

Introduction

Asphalt Rubber (AR) is a blend of plain bitumen and crumb rubber produced from reclaimed tires (ASTM D8). Many worldwide research studies have demonstrated that AR is able to enhance the mechanical performance of bituminous mixes [1-10] while simultaneously creating an environmental benefit by re-using a waste material that otherwise would be disposed or burned. Moreover, AR binder appears to reduce rolling noise thanks to the lower stiffness of the bituminous mix, thus positively influencing the mechanism of noise generation by a vibration source [10-12].

Moisture sensitivity of hot mix asphalts is of fundamental concern because the presence of water can affect both binder cohesion and adhesion between the bitumen and aggregate, causing accelerated distresses [13-16]. Given this background, it is interesting to note that the water sensitivity of AR mixtures has attracted little attention until today [6, 7, 17-19].

The aging of asphalt is principally caused by the loss of volatile components during the construction phase and by the progressive oxidation in the field. This results in the embrittlement of the mixture with consequent loss of durability in terms of wear and crack resistance [20-22]. When crumb rubber is blended at high temperatures with bitumen, the rubber particles are swollen by the absorption of the aromatic oils of the bitumen, thereby improving the aging resistance of the binder [20-22]. However, given the fact that only a small amount of information is available regarding the aging behavior of AR mixes [7, 20, 22, 23], further, more specific research is needed.

Finally, as far as durability concerns, abrasion resistance is also a fundamental issue to be investigated in addition to moisture susceptibility and the anti-aging properties as illustrated by several research studies [7, 24-26].

This paper summarizes the main results obtained from a laboratory test program conducted to assess aging resistance, moisture sensitivity and abrasion resistance of a gap graded AR mix produced at the asphalt plant. In particular, indirect tensile and Cantabro tests on dry and wet conditioned specimens were carried out to investigate moisture sensitivity of the AR mixture, whereas change in the stiffness modulus, fatigue life and Cantabro particle loss after laboratory simulated long-term aging was selected to assess aging resistance of such bituminous material. Moreover, the abrasion resistance of the studied mix was evaluated through Cantabro test results on dry and un-aged samples.

Laboratory Investigation

Materials

A gap graded Asphalt Rubber Asphalt Concrete (ARAC) for wearing course produced at the plant using basaltic coarse aggregates was selected to be investigated in this research project. The mixture composition is shown in Table 1 and Fig. 1. Air void content, voids in mineral aggregate (VMA), and VMA filled with binder (VFB) of ARAC, in accordance with EN 12697-8, were also calculated. The main AR binder characteristics are reported in Table 2.

For comparison purposes, a traditional dense graded asphalt concrete for wearing courses (AC 12 surf 70/100) prepared in the laboratory with calcareous aggregates characterized by a 12 mm maximum aggregate size and manufactured with a plain 70/100 bitumen was studied in terms of aging resistance. The mixture composition of AC 12 surf 70/100 is shown in Table 1 and Fig. 1. Air void content, voids in mineral aggregate (VMA), and VMA filled with binder (VFB) of AC 12 surf 70/100, in accordance with EN 12697-8, were also calculated. AC 12 surf 70/100 properties fit within the Italian specifications for this kind of material. This bituminous concrete was selected as the reference mixture because it is commonly applied in Italy as wearing course.

Experimental Program

Cylindrical specimens with a nominal diameter of 100 mm and a

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Note: Submitted November 19, 2011; Revised March 28, 2011; Accepted May 23, 2011.

Table 1. Characteristics of Materials Studied.

Sieves (mm)	ARAC (%Passing)	AC 12 surf 70/100 (% Passing)
20	100.0	100.0
12	99.2	95.0
8	69.3	80.0
4	29.7	47.5
2	18.7	31.5
0.5	8.2	16.5
0.25	5.6	12.8
0.063	2.5	7.1
Binder Content (%)	7.9	5.3
Rubber Content (% on Bitumen)	20%	-
Target air Void Content (%)	6.0	7.0
VMA (%)	22.5	18.3
VFB (%)	73.3	61.8

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

thickness of 60 mm were prepared at 165°C compaction temperature with a shear gyratory compactor at a target air void content of 6%. A set of 12 ARAC specimens was prepared in order to assess the abrasion and water damage resistance of the mixture using indirect tensile tests and Cantabro tests. Another set of 15 specimens was used to identify the aging resistance of the studied ARAC mix by means of Cantabro tests, Indirect Tensile Stiffness Modulus (ITSM) and Indirect Tensile Fatigue (ITF) tests. Furthermore, 12 samples of the AC 12 surf 70/100 mixture were tested in terms of their stiffness modulus and fatigue resistance in un-aged and aged conditions. ARAC and AC 12 surf 70/100 mixes were compacted with a shear gyratory compactor at very similar target air void contents in order to make the comparison between the two materials appropriate. Table 3 summarizes the experimental program and shows the number of specimens used for each kind of test.

Table 3. Experimental Program.

Test Method	ARAC			AC 12 surf 70/100	
	Dry/Un-aged	Wet	Aged	Un-aged	Aged
Cantabro Test	3	3	3	-	-
Indirect Tensile Test	3	3	-	-	-
ITSM Test	12	-	6	6	6
ITF Test	6	-	6	6	6

Test Methods

Cantabro Test

Cantabro tests were carried out at 25°C in accordance with EN 12697-17 in order to determine the influence of water and aging on the abrasion resistance of the material studied. In particular, the Cantabro test consists of subjecting an asphalt concrete sample to 300 revolutions (at 30 revolutions/minute) inside the Los Angeles machine drum without any metal balls. Results are expressed in terms of the percentage mass loss after the test. This value, referred to hereafter as the particle loss (PL), is an indicator of the abrasion resistance of the investigated mixture. The increase in particle loss after aging process was selected to evaluate the aging resistance of the ARAC mix. Moreover, the increase in particle loss after water immersion was selected to evaluate the moisture susceptibility of the investigated material.

Indirect Tensile Test

The well-known indirect tensile test was carried out at 25°C in order to determine the moisture sensitivity of the material studied. In accordance with EN 12697-23, the testing apparatus applies a diametral line load by imposing a deformation of 50 mm/min until the maximum failure strength (Indirect Tensile Strength, ITS) is reached. The loss of ITS after the water immersion of the test specimens was selected as the key parameter to evaluate the moisture susceptibility of the ARAC mix.

Indirect Tensile Stiffness Modulus and Indirect Tensile Fatigue Tests

Indirect Tensile Stiffness Modulus (ITSM) and Indirect Tensile Fatigue (ITF) tests were carried out at 20°C by means of repeated load dynamic equipment in order to assess the ARAC aging resistance. ITSM tests were carried out in accordance with EN

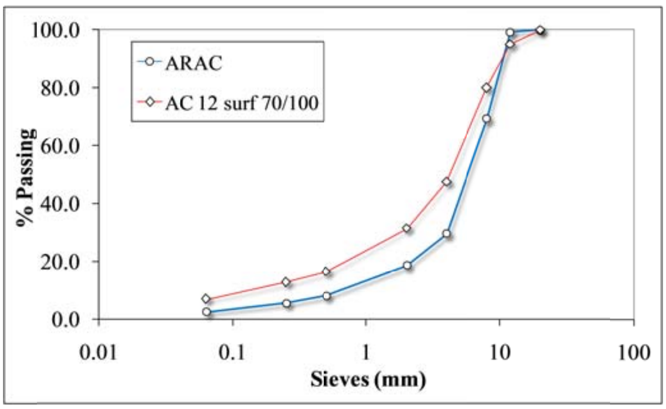

Fig. 1. Granulometric Distribution of Selected Mixtures

Table 4. Summary of Cantabro Test.

Mixture Type	Type of Binder	Air voids (%)	Average Particle Loss (%)
ARAC	Rubber Modified	6.6	1.8
Dense Graded Mixture [24]	Plain	5.7	10.2
50/60 Pen. Binder [26]	Plain	4.0	10.0
EVA Binder [26]	Polymer Modified	4.0	5.5
AR Mixtures [25]	Rubber Modified	3.3-5.7	4.0-9.0
SMA-LS-50pen [25]	Plain	3.6	15.0-19.0

Table 5. Moisture Sensitivity from Indirect Tensile Test.

Mixture	Binder	Dry test		Wet test		TSR
		Air Voids (%)	ITS (kPa)	Air Voids (%)	ITS (kPa)	(%)
ARAC	AR	5.9	993.0	5.7	957.0	96.4
DGAC [24]	Plain	5.7	804.0	5.7	793.7	98.7

12697-26 Annex C, while ITF tests were performed in a controlled stress condition following EN 12697-24 Annex E and applying different stress levels. Fatigue life was assumed to be the number of cycles corresponding to the physical failure of the test sample. Aging resistance of the materials studied was assessed by comparing the mechanical properties of unconditioned and age-conditioned specimens.

Mixture Conditioning

In regards to water conditioning, ARAC samples were tested in "unconditioned" and "conditioned" configurations to determine the indirect tensile strength and the particle loss at a temperature of 25°C. In accordance with ASTM D 4867, the conditioned specimens were partially saturated applying a partial vacuum of 370 to 410 mbar for 5 minutes using a vacuum chamber. Afterwards, specimens were immersed in a water bath for 24 hours at 60°C. On the contrary, unconditioned samples were stored at 25°C for 4 hours, prior to being tested.

As far as the aging resistance is concerned, particle loss, increase in indirect tensile stiffness modulus, and decrease in fatigue resistance were chosen as the material performance to be investigated. In regards to the aging procedure, short term mixture conditioning is used to simulate the effects of HMA aging and binder absorption that occurs during the pre-compaction phase (mixing and transportation) of the construction process. On the other hand, long-term mixture conditioning intends to simulate the effects of HMA aging that occurs over the service life of a pavement. Given this background, plant-mixed material (ARAC) does not need to be short-term aged, while laboratory prepared asphalt concrete (AC 12 surf 70/100) should be short-term conditioned prior to being subjected to a long-term aging procedure. Short-term aging (only for AC 12 surf 70/100 mix) and long-term aging were simulated in the laboratory in accordance with the AASHTO R30 specification. In particular, short-term aging requires the mixture to be placed in a pan and spread to an even thickness (25-50 mm). Then, the mixture should be conditioned and stirred every 60 minutes in a forced-draft oven for 4 hours at a temperature of 135°C. On the other hand, long-term laboratory aging consists of placing the compacted short-term aged specimens in a forced draft oven for 120 hours at 85°C in order to simulate the aging, which occurs over 7 to 10 years of pavement service life.

Test Results and Analysis

Abrasion Resistance

The abrasion resistance of the selected AR mix was assessed using the Cantabro test. The mean results obtained are shown in Table 4 where, for comparison purposes, results from other previously investigated mixes [24-26] are also presented.

It can be seen that the ARAC material results in this investigation returned very low particle loss values, clearly outperforming literature results. This implies that the mixture studied is expected to have excellent abrasion resistance. In agreement with previous studies [7, 24-26], the data collected in Table 4 indicate, as expected, that the use of more resilient crumb rubber modified or polymer modified binders leads to lower particle losses compared with mixes prepared using plain asphalt cements. Finally, no significant influence of air void content was observed between different materials having voids lower than 7%.

Moisture Sensitivity

As mentioned, the moisture susceptibility of the ARAC mixture was evaluated in terms of Indirect Tensile Strength loss and in terms of percentage increase in particle loss (Cantabro test) after water conditioning. In particular, the ITS loss is expressed as the Tensile Strength Ratio (TSR); that is the percentage ratio between wet and dry ITS. Table 5 illustrates the mean results of the ITT experimental program compared with those of a previously studied reference mix [24] subjected to the same kind of water conditioning. It is possible to note that no significant differences were recorded between the wet series and dry series for both materials. This suggests that this kind of test, coupled with moderately aggressive water conditioning, is probably unable to detect the prospective water damage. As confirmation of this, it is worth mentioning that several recent research studies [6, 7, 17, 18, 25] that adopted even more aggressive water conditioning characterized by freeze-thaw cycles reported conflicting results, in terms of TSR, between materials prepared with plain or modified binders, including crumb rubber modified binders. Thus, it may be questionable to consider the TSR value as the only criterion for evaluating the moisture susceptibility of the selected material.

In this regard, the moisture sensitivity of the ARAC material was

Table 6. Moisture Sensitivity from Cantabro Test.

Mixture	Binder	Dry Test		Wet Test		Increase in PL
		Air Voids (%)	PL (%)	Air Voids (%)	PL (%)	(%)
ARAC	AR	6.6	1.8	6.7	2.1	13.5
DGAC [24]	Plain	5.7	10.2	5.7	13.3	30.9

Table 7. Summary of Cantabro Test for Aged Specimens.

Mixture Type	Type of Binder	Air Voids (%)	Aged PL (%)
ARAC	Rubber Modified	6.6	2.6
M10 [7]	Plain	14.5	11.0
M12 [7]	Plastomeric Polymer Modified	13.0	9.5
M14 [7]	Elastomeric Polymer Modified	14.0	5.0
M16 [7]	Rubber Modified	12.5	4.5

Table 8. Increase in ITSM after Long-term Laboratory Aging.

Mixture	Un-aged ITSM (MPa)	Aged ITSM (MPa)	Change in ITSM (%)
ARAC	3407	4053	+ 19.0
AC 12 Surf 70/100	4527	5860	+ 29.4

Table 9. ε_6 of Original and Aged Mixtures.

Mixture	Un-aged ε_6 (μ strain)	Aged ε_6 (μ strain)	Change in ε_6 (%)
ARAC	132	142	+ 7.9
AC 12 surf 70/100	124	86	- 30.7

also investigated through the Cantabro test, which considers the increase in average Particle Loss (PL) after water conditioning. Mean results, as reported in Table 6, demonstrate that water influenced resistance. In particular, the ARAC mix shows an excellent abrasion resistance in both dry and wet conditions. As a consequence, it can be asserted that, unlike the results for the reference Dense-Graded Asphalt Concrete (DGAC) mixture [24] and in agreement with previous studies [7, 9, 25, 27], the ARAC mix proved to be only slightly water sensitive. This is probably due to the enhanced properties of asphalt rubber binder coupled with the thicker bituminous film that covered the aggregates with respect to traditional hot mix asphalts.

Aging Resistance

The particle loss (PL) of laboratory-aged specimens was selected to assess the aging resistance of the ARAC material. In this regard, Table 7 shows the ARAC mean results compared with traditional reference mixtures [7]. ARAC abrasion resistance was 45% lower than that of the virgin mix (Table 4) due to the aging process. However, the particle loss proved to be extremely limited owing to the low air void content and the remarkable properties of the AR binder. The comparison with reference semi-porous mixtures [14] confirmed that the use of crumb rubber modified binders should guarantee appreciable anti-aging properties with respect to plain bitumens, whatever the void content is.

For a better comprehension of the anti-aging properties of the ARAC mixture, measurements of the stiffness modulus and fatigue resistance on un-aged and aged specimens were also performed. Due to the aging process, materials were expected to become stiffer, reducing their fatigue life. Thus, both the lower increase in stiffness and lower decrease in fatigue resistance mean a higher anti-aging performance.

Table 8 illustrates the increase in the Indirect Tensile Stiffness Modulus as a result of long-term aging of the ARAC mixture in comparison with that of the dense-graded reference mixture (AC 12 surf 70/100) investigated in the same test conditions. In agreement with other research studies [20], the selected AR material shows a lower increase in stiffness after the aging process, suggesting a better aging resistance than that of the reference material.

These results are confirmed by the fatigue tests performed on original and aged materials. The fatigue behavior of both ARAC and AC 12 surf 70/100 in un-aged and aged conditions is illustrated in Fig. 2. This figure shows a higher fatigue resistance of the AR material in both the original and the aged condition, confirming the noteworthy properties of the AR binder. Moreover, test results clearly indicate that aging reduces the fatigue life of the materials in the test conditions used for this study. In order to rank the two mixtures in terms of aging resistance, the decrease in the microstrain corresponding to 10^6 cycles to failure (ε_6) due to the aging process was selected as the key parameter: the lower the decrease in ε6, the better the anti-aging properties of the material.

In Table 9, aging has no effect on the fatigue life of ARAC (it is reasonable to assume that the increase in ε6 was due to statistical variability among different experimental tests), whereas the reference mixture shows a decrease in the fatigue resistance of about 30%. These findings probably arose not only from the well-known properties of the AR binder in absorbing the aromatic oils of the bitumen but also from the higher binder dosage that produce a bituminous film around the aggregates, which was thicker

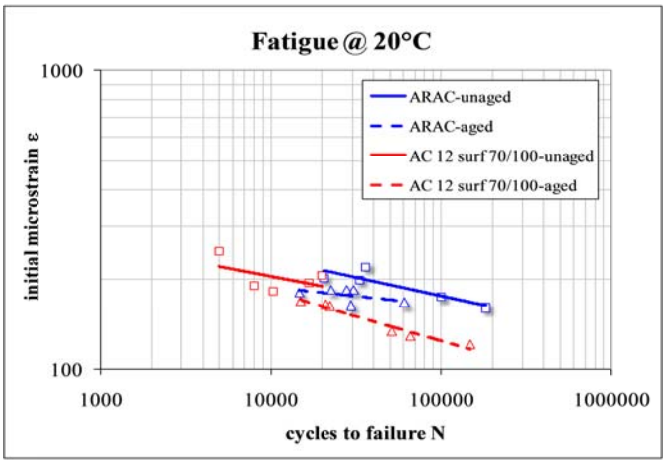

Fig. 2. Fatigue Life of Original and Aged Mixtures.

than in traditional hot mix asphalts. Once again, the results obtained are in agreement with previous studies [19, 20].

Conclusions

In this research study, a gap graded Asphalt Rubber mixture (ARAC) was laboratory tested to assess its durability in terms of abrasion resistance, moisture sensitivity and aging resistance. The abrasion resistance was evaluated by means of Cantabro tests, the moisture sensitivity was investigated through indirect tensile and Cantabro tests on dry and wet conditioned specimens, and the aging resistance was assessed in terms of Cantabro particle loss, indirect tensile stiffness modulus, and fatigue life after laboratory simulated long-term aging of the AR mixture.

Test results clearly depict a remarkable durability of the material studied with respect to traditional reference mixtures by virtue of the enhanced properties of the Asphalt Rubber binder. In particular, very limited particle losses were shown by the ARAC mix not only in its original condition but also for wet and aged specimens. This fact suggests not only a remarkable abrasion resistance of the material but also notable moisture resistance and anti-aging properties. On the contrary, the indirect tensile test did not appear to discriminate the water resistance of the different mixtures. Finally, as far as aging resistance is concerned, the increase in ARAC stiffness after laboratory aging of the material was lower than that of the reference mixture. Moreover, the fatigue analysis shows that, unlike the results obtained with the traditional reference mixture, there was no decrease in fatigue performance of the AR mixture in terms of microstrain corresponding to 10^6 cycles to failure (ε_6). These results clearly demonstrate the noteworthy aging resistance of the selected gap graded Asphalt Rubber mixture.

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