Jordan Journal of Civil Engineering, Volume **4**, No. **3**, **2010**

Cracking Characteristic of Asphalt Rubber Mixtures

Mohammad Abojaradeh [1]***, Basim Jrew*** [2]***, Fawzi Ghragheer*** [3]***, Kamil E. Kaloush*** [4]
and Dua Abojaradeh [5]

[1] Assistant Professor, Al-Isra University, Amman, Jordan
[2] Professor, Al-Isra University, Amman, Jordan
[3] Assistant Professor, Al-Isra University, Amman, Jordan
[4] Assistant Professor, Arizona State University, USA
[5] Civil Engineer
E-mail: abojaradeh@yahoo.com

ABSTRACT

The Arizona Department of Transportation (ADOT) has used Asphalt Rubber (AR) modified binders since the early 1970's. The primary purpose for using AR is to reduce reflective cracking in Hot Mix Asphalt (HMA) rehabilitation overlays. The AR mixtures have also performed well in cold climate conditions. This research study had the primary objective of conducting a laboratory experimental program to obtain typical cracking properties for asphalt rubber mixtures used in Arizona and comparing the performance of these AR mixtures to other conventional asphalt mixtures. Gap and open graded mixtures were subjected to fatigue and indirect tensile cracking tests. All test specimens in this study were prepared using hot mix AR mixtures that were collected during construction. Fatigue testing of AR specimens was conducted at different test temperatures using the beam fatigue apparatus proposed by the Strategic Highway Research Program (SHRP). The indirect tensile strength and creep tests were carried out at three temperatures according to the procedures described in the draft indirect tensile test protocol developed for the new 2002 Design Guide.

The results from the fatigue tests indicated that the AR mixtures would have longer fatigue life compared with the ADOT conventional dense graded mixtures. For the indirect tensile strength tests, the analysis for strains measured at failure showed that the AR mixtures have higher values than the conventional mixes. AR mixtures exhibiting higher strains at failure would have higher resistance to thermal cracking. The fracture energy results indicated that the AR mixtures are not as greatly affected by the decrease in temperature as compared to the conventional mixes. This relative insensitivity for changes in temperature makes the AR mixtures better resisting to thermal cracking in the field.

KEYWORDS: Asphalt rubber, Fatigue cracking, Thermal cracking, Flexural beam fatigue tests, Indirect tensile strength and creep tests.

INTRODUCTION

The Arizona Department of Transportation (ADOT) has used Asphalt Rubber (AR) modified binders since the early 1970's. The primary purpose for using (AR) is to reduce reflective cracking in Hot Mix Asphalt (HMA) rehabilitation overlays (Sousa et al., 2001; Way, 1979). AR mixtures have also performed well in cold climate conditions and provided tough surface characteristics that stand up well to snow plows.

Accepted for Publication on 15/7/2010.

An on-going research work at Arizona State University (ASU) involves characterizing AR mixes in order to determine their properties for future use in the American Association of State Highway and Transportation Officials (AASHTO) 2002 Pavement Design Guide. This research paper presents findings from this first project (Lukanen et al., 2000). The plan is to characterize AR mixes from several projects in order to represent different grades of AR binders, aggregates and climate conditions in Arizona.

This study project's elevation is approximately 5,000 feet and the region is considered a dry freeze zone according to SHRP (Kaloush et al., 2002). Air temperatures of over 38^{o}C occur in the summer and temperatures below –28^{o}C occur in the winter. The interstate truck traffic is quite heavy and averages 2.2 million ESALs per year. The AR overlay construction took place in June of 2001. The project consisted of removing by milling off 63.5mm of the old cracked pavement full width and replacing it with 50mm of the AR gap graded mix followed by 13mm of AR open graded mix.

OBJECTIVES AND SCOPE

The main objective of this research study was to conduct a laboratory experimental program to obtain typical mix cracking properties for asphalt rubber mixtures used in Arizona.

To accomplish this work, hot mix for the two AR mixes was collected during construction. In addition, cores of the two AR compacted mixes were taken to determine the in-place air voids. Material characterization tests were conducted on the laboratory compacted mixtures. This included: triaxial shear strength, static and dynamic creep, complex modulus, flexural beam fatigue and indirect tensile strength and creep tests. When possible, the test results obtained were compared to results available at ASU for conventional dense graded mixtures.

MIXTURE CHARACTERISTICS

Asphalt

An asphalt cement PG58-22 and 22% of crumb rubber were used to produce the ADOT asphalt binder type CRA-2. The same binder type was used for both mixtures: Asphalt Rubber Asphalt Concrete Friction Course (AR-ACFC) open graded mix and Asphalt Rubber Asphalt Concrete (ARAC) gap graded mix.

Mixture Properties

The hot mix asphalt mixtures were obtained as loose mix samples taken from the paver hopper during construction. The air void levels and binder contents in the laboratory-testing program simulated the properties of the field mixes as good as possible. The original mix designs were done using the Marshall mix design method. Because of the high air void content of the two mixes, the CoreLok device was used to accurately determine the air voids of the field and laboratory compacted mixes. Table 1 shows the volumetric properties of the two mixtures.

Table 1: Mixture Properties

Mixture	**ARAC**	**AR-ACFC**
Asphalt Type	PG 58-22	PG 58-22
Nominal Maximum Aggregate Size	19mm	9.5mm
Crumb Rubber %	22.7	22.7
Crumb Rubber Size	0.6 - 1.18mm	0.6 - 1.18mm
Asphalt Content %	6.8	8.8
Air Voids (Va) %	11.0	18.0
Rice G_{mm}, *	2.593	2.528

** Maximum theoretical specific gravity.*

Specimens Preparation

The AR mix was transported to ASU laboratories, where it was re-heated and compacted. For the indirect tensile strength and creep tests, the mixtures were compacted with a Servopac Gyratory compactor into 150mm diameter gyratory molds. The gyratory specimens height was approximately 160mm. Two disc specimens were sawed near the mid portion of the gyratory specimen and prepared according to the "Test Method for Indirect Tensile Creep Testing of Asphalt Mixtures for Thermal

Cracking" presented in NCHRP Report 465 (Witczak et al., 2002). For the fatigue tests, beam specimens were prepared according to the Strategic Highway Research Program (SHRP). The beams were tested according to the test protocol AASHTO TP8-94 and SHRP M-009 (AASHTO; SHRP).

FATIGUE CRACKING TESTS

Test Conditions

Constant strain fatigue tests were conducted at 6 levels in the range of 300 to 1750 μ strain and at a load frequency of 10 Hz. The test temperatures were: 4.4, 21.1 and 37.8°C. Initial flexural stiffness was measured at the 50th load cycle. Fatigue life or failure under control strain was defined as the number of cycles corresponding to a 50% reduction in the initial stiffness. The loading on most specimens was extended to reach a final stiffness of 30% of the initial stiffness instead of the 50% required by AASHTO TP8 and SHRP M-009 (AASHTO; SHRP).

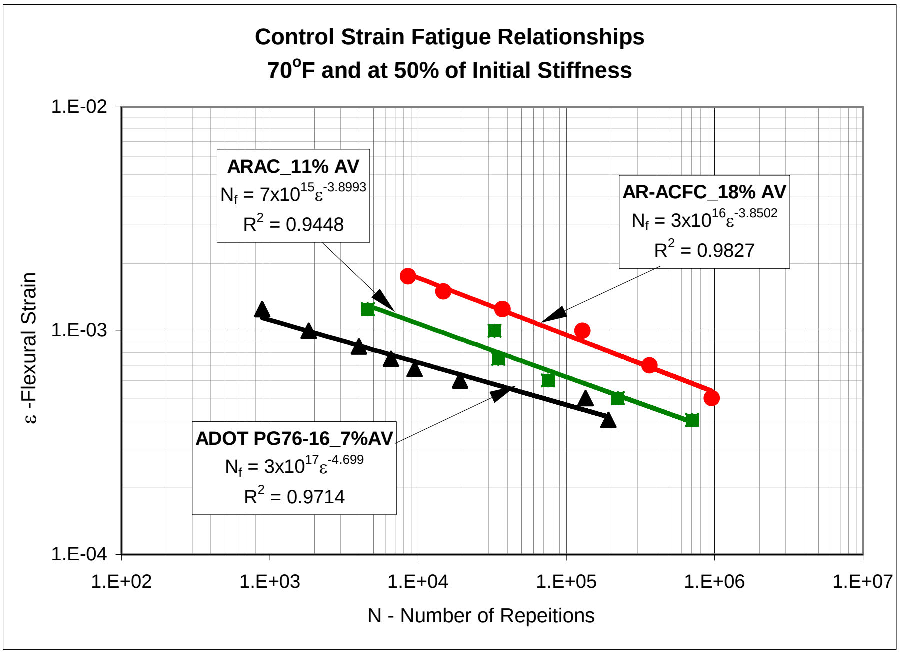

Figure 1: Controlled Strain Fatigue Relationships

Table 2: Summary of the Regression Coefficients for Generalized Fatigue Equation

MIX TYPE	50% OF INITIAL STIFFNESS, S_O @ N=50 Cycles				30% OF INITIAL STIFFNESS, S_O @ N=50 Cycles			
	K_1	K_2	K_3	R_2	K_1	K_2	K_3	R_2
ADOT PG 76-16	$1.32x10^{-3}$	4.954	1.531	0.97	$9.99x10^{-1}$	3.616	1.163	0.82
ARAC	$2.50x10^{-2}$	4.231	1.267	0.75	$3.52x10^{-5}$	3.921	0.520	0.95
AR-ACFC	$7.81x10^{3}$	2.997	1.530	0.99	$2.12x10^{8}$	1.998	1.705	0.97

$* N_f = K_1 * (1/\varepsilon_t)^{K2} * (1/S_o)^{K3}$.

Test Results for the Flexural Beam Fatigue Tests

Figure 1 shows a comparison of the two AR mixtures along with an ADOT conventional PG 76-16 dense graded mixture (asphalt content 4.2% and air voids of 7%). The relationships shown are for the test conducted at 21.1^{o}C and for a 50% reduction of initial stiffness. Tests conducted at other temperatures had similar trends to those shown in Figure 1.

The relationships obtained in Figure 1 have excellent measures of model accuracy as indicated by the coefficient of determination (R^2). The relationships are also rational in that higher binder content mixtures yielded higher fatigue life despite the air void content variations between the mixtures. Comparing fatigue curves for different mixes is not straightforward because of the different mixes' moduli. A look at the fatigue models coefficient may provide some guidance. In general, the ARAC mix would have approximately 3 times longer fatigue life, whereas, the AR-ACFC mix would have about 15 times longer fatigue life than the PG 76-16 mixture. Table 2 summarizes the K_1-K_3 coefficients of the generalized fatigue model for the three mixtures.

Both types of analysis yielded good to excellent measures of model accuracy. It is also noted that the models developed for the AR-ACFC mixture used only tests conducted at two temperatures (4.4 and 21.1^{o}C).

INDIRECT TENSILE TESTS

All test specimens were sawn from gyratory compacted specimens. The test specimen was approximately 38mm in thickness and 150mm in diameter. Vertical and horizontal LVDT's were used on the specimen for measuring the deformation using a gage length of 76.2mm for both directions. The tests were carried out at three temperatures: 0^{o}C, -10^{o}C and -15^{o}C.

Tests Results

Indirect Tensile Strength Test

Figure 2 presents a summary of the test results for the ARAC, AR-ACFC and a dense graded PG 64-22 mixture (also referred to as Salt River Base (SRB)). The test results include: tensile strength, strain at failure, energy until failure and fracture energy. The energy until failure is calculated as the area under the load-vertical deformation curve up to the peak load; whereas the fracture energy is calculated as the total area under the load-vertical deformation curve.

In Figure 2(a), the highest strength is observed for the SRB mix at all three test temperatures. Figure 2(b) on the other hand shows that higher tensile strains are obtained for the AR mixtures. It can be observed that the AR-ACFC mix has 140% larger strain than the SRB mix and 40% larger strain than the ARAC mix. This trend was consistent as the temperature decreased. The most interesting result was obtained from the fracture energy and energy until failure parameters (Figures 2(c and d)). Higher fracture energy and energy until failure were obtained for the AR mixes at –10^{o}C and –15^{o}C. Another important observation in Figures 2(c) and (d)) is the reduction in the energy levels measured as temperature decreases from 0^{o}C to –15^{o}C. It is observed that the AR mixes energy loss is in the range of 18% to 38%; whereas a significant loss for the SRB mix (70%) was obtained.

Indirect Tensile Creep Test

Figure 3 presents a summary of the test results for the ARAC and the AR-ACFC mixtures. No data was available for an ADOT conventional dense graded mixture. The test results include: strain and creep compliance at time=1000 seconds, slope and intercept of the compliance curve.

The results of strain at time 1000 sec (Figure 3(a)) show that the AR-ACFC mix has 12% higher strain at temperature 0^{o}C, 78% higher strain at –10^{o}C and 38% higher strain at –15^{o}C. The lowest strain that both mixtures had was at –10^{o}C.

At higher temperatures, the AR-ACFC mix has higher slopes and lower intercepts than the ARAC mix. The differences are significant: 2 times larger slope and almost 8 times smaller intercept. At –15^{o}C, the differences between the mixtures are increasing.

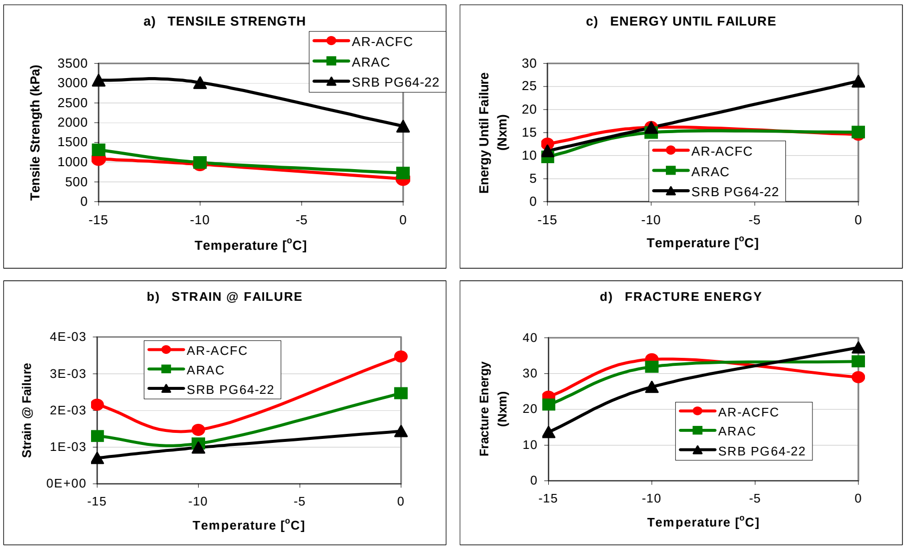

Figure 2: Summary Plots of the Indirect Tensile Strength Tests

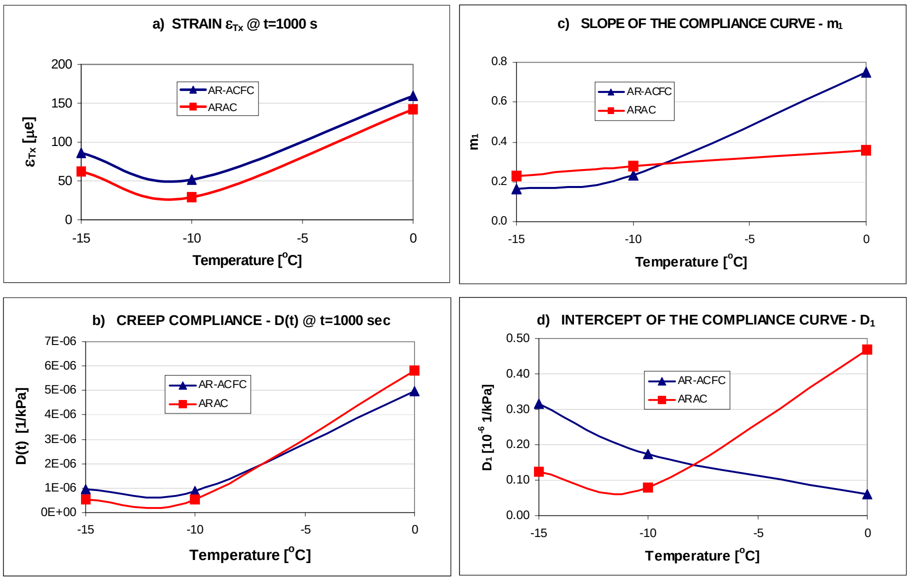

Figure 3: Summary Plots of the Indirect Tensile Creep Tests

SUMMARY AND CONCLUSIONS

Flexural Beam Fatigue Tests

The fatigue models developed for the AR mixtures in this study had excellent measures of accuracy and were rational in that lower fatigue life was obtained as the test temperature decreased. The fatigue life was found to be higher for asphalt rubber mixes compared to a conventional PG 76-16 mix. The comparison was carried out at 21.1°C and at a 50 percent reduction of the initial stiffness for all mixtures. The ARAC mix had approximately 3 times greater fatigue life than the conventional mix. The AR-ACFC mix had approximately 15 times greater fatigue life than the conventional mix. These orders of magnitude of fatigue life for the three mixtures were rational considering that the PG 76-16 mix had 4.20% binder content; whereas the ARAC and AR-ACFC mixtures had 6.8% and 8.8%, respectively.

Indirect Tensile Tests

Based on test results and analysis, the following conclusions are made:

The test results of the indirect tensile strength showed that the conventional PG64-22 dense graded mix had about 3 times higher strength compared to AR mixtures. This is not consistent with field observations, where the AR mixes show better performance compared to standard asphalt concrete mixtures when resistance to thermal cracking is considered.

The results of strain at failure showed that the AR-ACFC and ARAC mixes had higher values than the PG64-22 mix. Mixtures (i.e., AR mixes) with higher strain at failure have higher resistance to thermal cracking.

The results of energy until failure and fracture energy from the indirect tensile strength test, as well as the results of the creep compliance from the indirect tensile creep test, indicated that AR mixtures, and especially the AR-ACFC mix, are not affected by decrease in temperature. On the contrary, the PG64-22 mixture was more affected by the decrease in temperature.

Higher energy values are indicative of more resistant to thermal cracking. At 0^oC, the PG64-22 mix performed better than the AR mixtures, but when the temperature dropped to a level between 0^oC and -10^oC, the PG64-22 mix rapidly lost its “good properties (performance)”, while the AR-ACFC and ARAC mixes kept their “good performance” as higher energy is necessary to fracture the specimen. This relative insensitivity for changes in temperature makes the AR mixtures, and especially the AR-ACFC mix, better resistant to thermal cracking in the field.

In summary, while the indirect tensile strength test parameter did not provide good explanation to the cracking potential behavior of the AR mixes, the strain at failure and energy parameters from the same test provided better indications for the observed field behavior of the mixes.

REFERENCES

AASHTO Designation: TP8-94. Standard Test Method for Determining the Fatigue Life of Compacted Hot Mix Asphalt (HMA) Subjected to Repeated Flexural Bending.

Kaloush, K.E. et al. 2002. Performance Evaluation of Arizona Asphalt Rubber Mixtures Using Advanced Dynamic Material Characterization Tests. Final Report, Department of Civil and Environmental Engineering, Arizona State University, Tempe, Arizona, July.

Lukanen, E.O., Stubstad, R.N. and Briggs, R.C. 2000. Temperature Predictions and Adjustment Factors for Asphalt Pavement, Federal Highway Administration, Publication No. FHWA-RD-98-085, Washington, DC, June.

SHRP Designation: M-009 Standard Method of Test for Determining the Fatigue Life of Compacted Bituminous Mixtures Subjected to Repeated Flexural Bending.

Sousa, J.B., Pais, J.C., Saim, R., Way, G.B. and Stubstad, R.N. 2001. Development of a Mechanistic Overlay Design Method Based on Reflective Cracking Concepts, Rubber Pavement Association, Tempe, Arizona, August.

Way, G.B. 1979. Prevention of Reflection Cracking Minnetonka-East, Arizona Department of Transportation, Report Number 1979GWI, Phoenix, Arizona, August.

Witczak, M.W., Kaloush, K.E., Pellinen, T., El-Basyouny, M. and Von Quintus, H. 2002. Simple Performance Test for Superpave Mix Design. NCHRP Report 465. National Cooperative Highway Research Program, Transportation Research Board, Washington D.C.