

Laboratory Performance Evaluation of a Gap-Graded Asphalt-Rubber Mixture in Puerto Rico

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ABSTRACT. *Implementation of new technologies involving Asphalt-Rubber (AR) pavements can provide a challenge to designers and contractors especially in markets where traditional pavements are commonplace. In 2009, an AR gap-graded mixture was placed as a 0.5 kilometer pilot project test section on a highway in Ponce, Puerto Rico. The goal of this pilot project was to assess the performance of an AR pavement and the feasibility of AR implementation in Puerto Rico. The mixture was sampled in the field and was transported to Arizona State University (ASU) in the United States for further evaluation. The objective of this study was to obtain typical material characteristics of the AR mixture and assess its performance in the laboratory. Test results were compared to the ASU-Arizona Department of Transportation (ADOT) AR material characterization database developed at ASU over the past few years. The advanced material characterization tests included: dynamic complex modulus for stiffness evaluation, four-point bending beam for fatigue cracking assessment and repeated load permanent deformation (Flow Number) test for rutting evaluation. The materials characterization test results revealed that the pilot AR section would perform well and comparable to the Arizona AR mixtures.*

KEYWORDS: *Asphalt Rubber (AR) Gap Graded, Dynamic (Complex) Modulus, Flow Number, Fatigue.*

1. Introduction

In 2009, the Puerto Rico Highway and Transportation Authority (PRHTA) placed a 500-meter asphalt-rubber (AR) pavement section on highway PR-10 as part of a pilot study aimed at using AR pavements in Puerto Rico. In order to obtain typical engineering pavement materials properties of the in-place AR gap graded mixture, PRHTA entered into a research and testing plan with Arizona State University (ASU). The study involved laboratory characterization of the Puerto Rican AR gap graded mixtures, and further comparing the obtained engineering properties of those mixtures to the characteristics of the already in-service Arizona

Department of Transportation (ADOT) AR gap graded mixtures, which have similar mixture design parameters. All the ADOT mixtures presented in this paper were previously characterized at ASU using advanced pavement materials characterization tests. Figure 1 illustrates a pictorial representation of the PR-10 Highway outside of Ponce area in Puerto Rico where the AR gap-graded mixtures were placed.

The AR gap graded mixture contained approximately 20 percent ground tire rubber (crumb-rubber) very similar to the ADOT materials' mix specifications. The mixture was sent to ASU laboratories for testing and evaluation. This paper documents the various mechanical tests conducted on the Puerto Rican AR gap graded mix to evaluate the pavement material's performance characteristics in the laboratory at ASU facilities.

2. Objectives and Scope of the Work

The objective of this study was to conduct an advanced laboratory experimental program to obtain typical engineering material properties for the rubber-modified gap graded asphalt concrete mixture placed on the PR10 highway in the Ponce area of Puerto Rico. The laboratory testing program utilized current laboratory tests adopted by the pavement community. The results were compared / ranked with the already characterized ASU-ADOT AR gap graded mixtures.

At ASU, the mixtures were re-heated and compacted to cylindrical and beam specimen geometry. A Servopac gyratory compactor was used to compact the cylindrical specimens into 150 mm diameter and 170 mm in height gyratory plugs. One 100 mm diameter sample was cored from each gyratory plug. The sample ends were sawn to arrive at typical test specimens of 100 mm in diameter and 150 mm in height. These plugs were prepared to obtain Simple Performance Test (SPT) permanent deformation (rutting) values consistent with the procedures developed as part of the NCHRP 9-19 project [1]. Beam specimens were prepared according to the Strategic Highway Research Program [SHRP M-009] and the American Association of State Highway and Transportation Officials [AASHTO TP8-94] [2, 3]. Air voids, thickness and bulk specific gravities were measured for each test specimen and the samples were stored in plastic bags in preparation for the testing program.

Conventional binder consistency tests were performed on AR PG 64-22 binder, a modified binder with crumb-rubber additives. The same binder was used in the preparation of the AR gap graded mixtures. Furthermore, the advanced material characterization tests included: E^* dynamic (complex) modulus for stiffness evaluation; repeated load for permanent deformation characterization; and flexural beam fatigue for cracking evaluation.

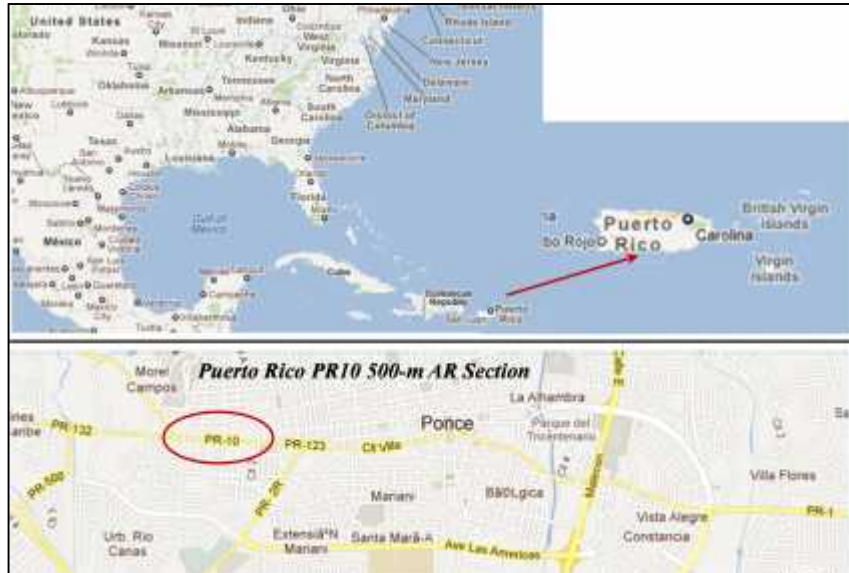


Figure 1. Location of PR10 Highway – Ponce Area, Puerto Rico (Google Maps).

3. Mixture Characteristics

The designated road section within the construction project had an asphalt-rubber gap graded (ARAC) mixture with an AR binder (designation: PG 64-22 AR) that contained approximately 20% ground tire rubber (crumb rubber). The Puerto Rico Highway and Transport Authority provided information that the field compaction / air voids for the three mixtures were 6.0%. The original mix designs were done using the Marshall Mix design method. The in-situ mixture properties of the PR10 highway project are reported in Table 1. Table 2 shows the reported average aggregate gradations for the AR-gap mixture. Figure 2 presents gradation chart for the PR10 AR mix and the two typical ADOT AR gap graded mixtures.

Mix Type	Binder Mix Design Data			
	Binder Type	Design AC (%)	Target AV (%)	G_{mm}
PR-10 ARAC	PG 64-22 AR	8.7	5.9	2.237

Table 1. AR Gap Graded Mixture Characteristics, Puerto Rican PR10 Highway

Aggregate Gradation	PR-10 ARAC w/ Admix	Spec. Control Points w/ Admix
19	100	100
12.5	96	80-100
9.5	80	65-80
6.35	53	-
4.75	40	29-43
2.36	17	15-23
2	15	-
1.18	11	-
0.6	8	-
0.425	7	-
0.3	6	-
0.15	4	-
0.075	3.2	0-3.5

Table 2. AR Gap Graded Aggregate Gradations, Puerto Rican PR10 Highway

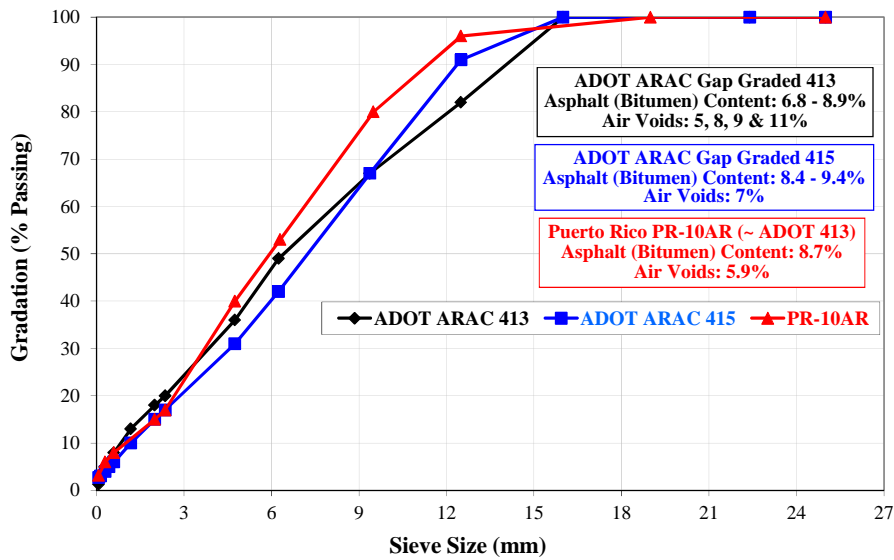


Figure 2. Gradation Chart of PR10 ARAC, ADOT ARAC 413, ADOT ARAC 415 Mix Designs

The project study also comprised of five 100mm diameter field cores were sampled during construction and sent to ASU with the loose AR mix. Using the ASU G_{mm} value of 2.237, the air voids of the un-trimmed field cores was determined to be 4.69%. To be consistent with laboratory standards, the ends of each field core were trimmed to produce a smooth surface. The air voids of these trimmed specimens were determined to be 3.96%. Air voids and bulk specific gravity of these specimens were computed according to AASHTO T166-93, "Bulk Specific Gravity of Bituminous Mixtures Using Saturated Surface Dry Method".

It is important to note that the target air voids value documented in the mix design was 5.9%. However, the air voids values of the compacted specimens obtained in the ASU laboratory may indicate the mix was slightly over compacted during construction. It is important to note that this may also be the result of the specimen and mixture aging during storage and transport from Puerto Rico to Tempe, Arizona.

4. Binder Characterization

The objective of binder testing was to compare the PR10 PG 64-22 AR binder with typical ADOT binders, namely, PG 64-16 AR, PG 64-16, and PG 58-22 AR. Conventional consistency tests, namely, penetration, softening point using ring & ball, and Brookfield viscosity tests were conducted on the PR AR binder.

Figure 3 shows a comparison of the viscosity-temperature relationship for the PR10 AR PG64-22 AR binder and the typical ADOT ARAC binders, which also includes a virgin binder and two binders with rubber-modification at tank condition. It was observed that the rubber modified binders have flatter slopes than the virgin binder PG 64-16 with increasing temperature, a behavior highly desirable for resistance to permanent deformation. In particular, the PR10 PG 64-22 AR binder had higher viscosities than all the other binders at higher temperatures indicative of its higher capacity to resist permanent deformation. However, the PR10 PG 64-22 AR binder had higher viscosity values than the other three binders at lower temperatures, which could lead the PR10 binder to be more susceptible to thermal cracking than the other binders. But, it must be noted that the Ponce area in Puerto Rico has an annual tropical climate with temperatures ranging from 20-35 °C, which means that low temperature characterization may not be very important. However, the above results provide some of the unique temperature susceptibility properties of the rubber-modified binders in contrast to the virgin binder.

Overall, it was observed that the rubber modified binders had flatter slopes than the virgin binder, indicating that rubber-modified binders would be least susceptible to viscosity changes across all ranges of low and high temperatures.

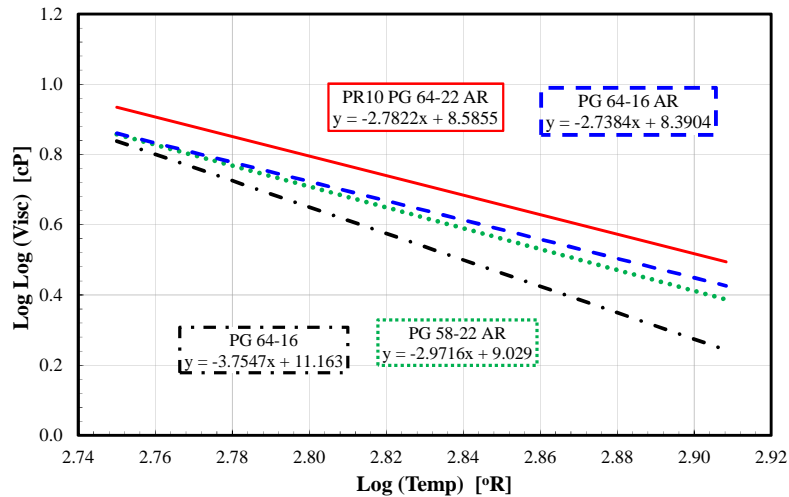


Figure 3. Viscosity – Temperature Relationship of PR10 Highway Binder in Comparison with the Typical Arizona Binders

5. E* Dynamic (Complex) Modulus Test

The AASHTO TP 62-07 was followed for E* testing [4]. For each mix, three replicates were used. For each specimen, E* tests were conducted at -10, 4.4, 21.1, 37.8 and 54.4 °C and 25, 10, 5, 1, 0.5 and 0.1 Hz loading frequencies, and with a confinement of 138-kPa stress level to simulate the field conditions. A 60 second rest period was used between each frequency to allow some specimen recovery before applying the new loading at a lower frequency. The E* tests were done using a controlled sinusoidal stress that produced strains smaller than 150 micro-strains. This ensured, to the best possible degree, that the response of the material was linear across the temperatures used. The dynamic stress levels were 69 to 690 kPa for cold temperatures (-10 to 21.1 °C), and 14 to 69 kPa for high temperatures (37.8 to 54.4 °C). All E* tests were conducted in a temperature-controlled chamber capable of holding temperatures from -16 to 60 °C.

A master curve was constructed at a reference temperature of 21.1 °C using the principle of time-temperature superposition. Figure 4 shows the average E* master curves for the PR10 ARAC mix (confined condition) and two ADOT ARAC mixtures (one unconfined and the other confined). The figure can be used for general comparison of the mixtures, but specific temperature-frequency combination values need to be evaluated separately. That is, one cannot compare direct values on the vertical axis for a specific log reduced time values.

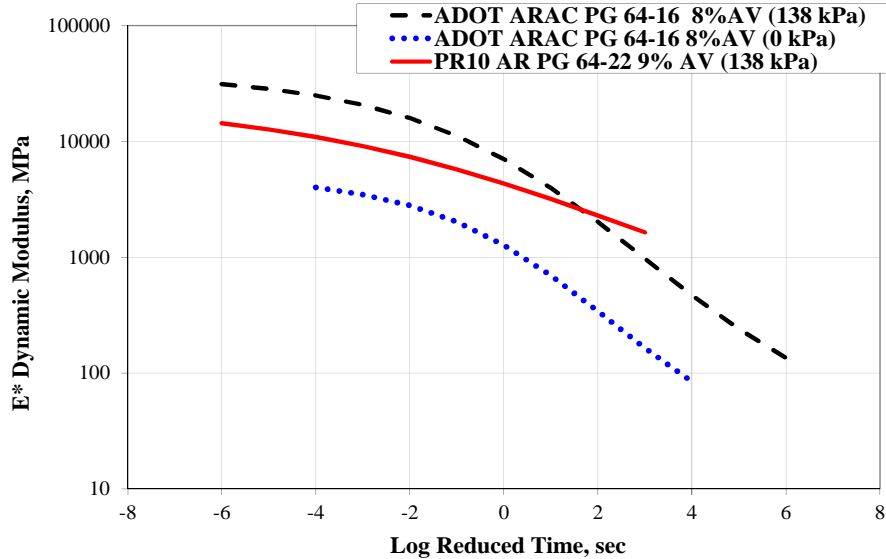


Figure 4. *E** Master Curves for the Puerto Rican PR10 ARAC (Confined), Arizona DOT ARAC Mixes at Confined and Unconfined Conditions

As shown in the figure, there is a significant difference between the E^* values run at confined and unconfined conditions. The E^* values of the confined ADOT ARAC mix were on average two times that of the unconfined ADOT ARAC mix. The PR10 ARAC confined mix also had higher E^* values than the unconfined ADOT mix at least by 50%. However, the PR10 ARAC mix also had lower moduli values at the lower temperatures compared to the ADOT mix. The results at the moderate temperature range were comparable. The increase in moduli values at mid and higher temperature ranges is an indication of the mix’s higher resistance to rutting potential.

6. Repeated Load Permanent Deformation Test

The repeated load permanent deformation or Flow Number (FN) test is a dynamic creep test used to determine the permanent deformation characteristics of paving materials [1]. In this test, a repeated dynamic load is applied for several thousand repetitions, and the cumulative permanent deformation, including the beginning of the tertiary stage (defined as FN) as a function of the number of loading cycles over the test period is recorded. FN tests were conducted unconfined using three replicate test specimens for the PR10 ARAC mix on cylindrical specimens, 100 mm in diameter and 150 mm in height. A haversine pulse load of 0.1 sec and 0.9 sec dwell (rest time) was applied. All tests were conducted at 37.8 °C at a dynamic stress level of 104 kPa within an environmentally controlled

chamber. Figure 5 shows a photograph of actual specimen's set-up for unconfined FN tests.



Figure 5. *Flow Number Test Setup, Unconfined Condition*

Figure 6 (a) and (b) present the Flow Number and total axial strain results, respectively, for the unconfined tests performed on the PR10 ARAC mix. The figure also shows values for four ADOT ARAC mixes tested previously at the same temperature and stress combination. Two ADOT mixtures used for comparison purposes had similar air voids as that of PR10 ARAC mix. Two other mixes from the ASU-ADOT database were also included as part of the comparison, which had 2% higher and lower air voids levels than the 9% laboratory air voids level of the PR10 ARAC mix.

The results showed that the PR10 ARAC mix had no flow (> 100000 cycles) when compared to the ADOT mixes that had flow number values reported at similar air voids (9% AV). It is interesting to note that ADOT ARAC mix with 7% air voids also did not have a flow even after 100000 cycles, and the mix with 11% air voids had the lowest FN value when compared to the other mixes. It is reasonable to say that the Puerto Rican ARAC mix has good laboratory performance in this test, and therefore would be less susceptible to permanent deformation in the field. In addition, the PR10 ARAC mix also had the lowest accumulated axial strain at no flow condition indicating that this mixture will have a high resistance to permanent deformation.

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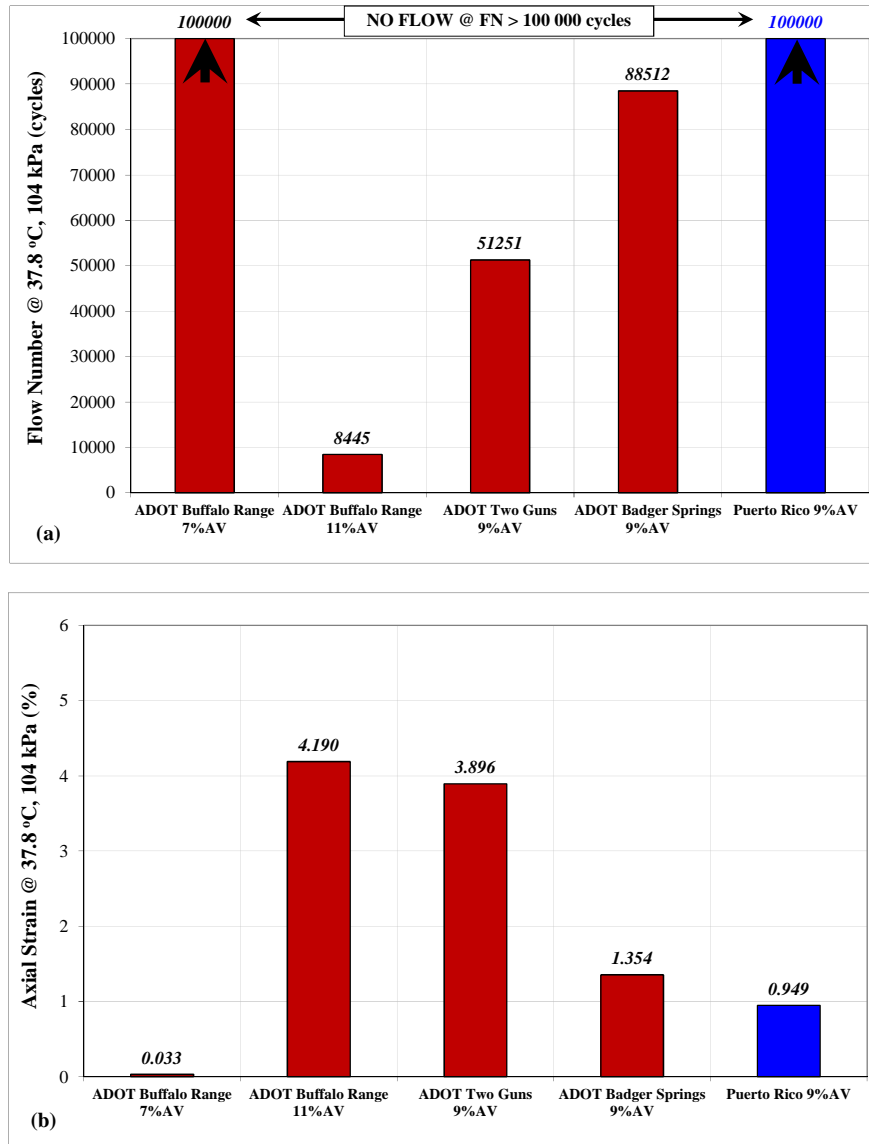


Figure 6. Repeated Load Permanent Deformation Test Results, Puerto Rican PR10 ARAC, and ADOTARAC Mixes, (a) Flow Number (cycles); (b) Axial Strain (%)

7. Fatigue Cracking Test

The most common model form used to predict the number of load repetitions to fatigue cracking is a function of the tensile strain and mix stiffness (modulus) as follows [5].

$$N_f = K_1 \left(\frac{1}{\epsilon_t}\right)^{K_2} \left(\frac{1}{E}\right)^{K_3} = K_1 (\epsilon_t)^{-K_2} (E)^{-K_3} \quad (1)$$

Where:

- N_f = number of repetitions to fatigue cracking
- ϵ_t = tensile strain at the critical location
- E = stiffness of the material
- K_1, K_2, K_3 = laboratory calibration parameters

Flexural fatigue tests were conducted according to the AASHTO T321 and SHRP M-009 [2,3]. The flexural fatigue test has been used by various researchers to evaluate the fatigue performance of pavements [6,7,8]. Beams are saw-cut from compacted specimens to the required dimensions of 63.5 mm wide, 50.8 mm high, and 381 mm long.

The air voids for the PR10 ARAC mix was about 9.7%. The tests were conducted at 10 Hz and at a constant strain level loading conditions between 450 and 1200 μ strain (7 levels of the strain range was used). The test temperature was 21.1 °C for the PR10 AR gap graded mix. Initial flexural stiffness was measured at the 50th load cycle. Fatigue life or failure under controlled strain was defined as the number of cycles corresponding to a 50% reduction in the initial stiffness. The loading was also extended to reach a final stiffness of 30%. The control and acquisition software reported load and deformation data at predefined cycles spaced at logarithmic intervals.

Figure 7 shows comparisons of predicted number of cycles to failure, N_f for a range of applied microstrains using 50 and 30% of initial stiffness for the PR10 ARAC, and three ASU-ADOT ARAC mixtures at 21.1 °C. A comparison of fatigue life of the mixes was made at 500 $\mu\epsilon$. As observed, the PR10 ARAC mix had the greatest fatigue life trend (~ 4 million cycles), followed by the three ADOT mixes. However, it is noteworthy that all the ARAC mixes, including the PR10 mix and the three ADOT mixes had higher fatigue lives, which are typically higher for the AR mixes than the conventional mixes. Note that the initial stiffness values were not similar across all mix specimens and thus the relationships can be used to compare fatigue data as general trend lines.

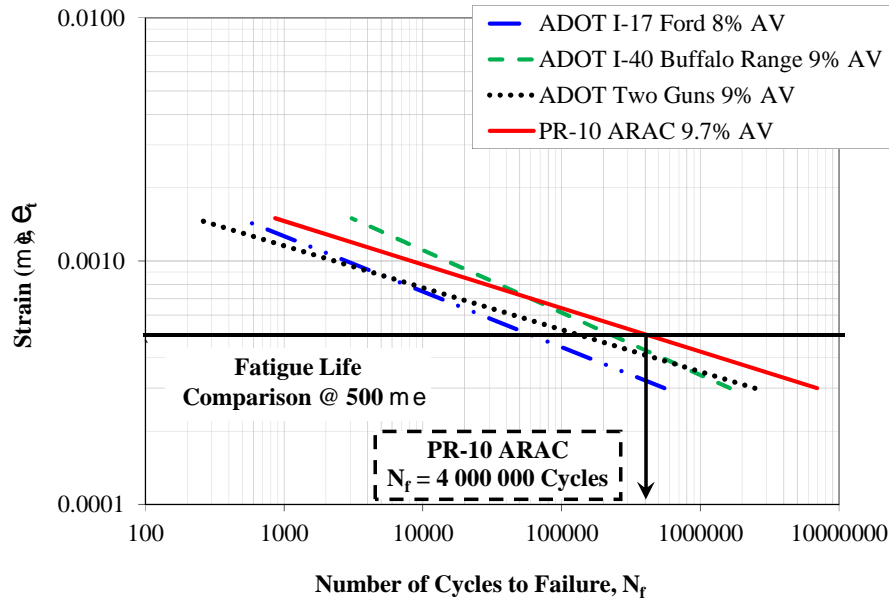


Figure 7. Comparison of Fatigue Relationships for the Different Mixtures at 50% of Initial Stiffness, 21.1 °C

8. Summary and Conclusions

The objective of this study was to conduct an advanced laboratory experimental program to obtain typical engineering material properties for the rubber-modified gap graded asphalt concrete mixture placed on the PR10 highway in the Ponce area of Puerto Rico. The pilot AR field test project consisted of placement of a 500-meter asphalt-rubber pavement section that had similar mix design properties to the Arizona Department of Transportation's typical asphalt-rubber gap graded mix.

The material characterization tests results in this study showed that the PR10 AR gap graded mix provided improved or similar performance to comparable ADOT AR gap graded mixtures. Crumb-rubber modified binders are known to have less susceptibility to viscosity changes across a wide range of temperatures. The Puerto Rican AR binder had higher viscosities than all of the other binders at higher temperatures indicating higher capacity to resist permanent deformation. However, it also had higher viscosity values at lower temperatures, which indicate higher susceptibility to thermal cracking than the other binders. The Ponce area in Puerto Rico has an annual moderate tropical climate with temperatures ranging from 20-35 °C; thermal cracking is not of a concern in this area.

The E^* dynamic modulus tests indicated that the moduli (stiffness) values of the Puerto Rican AR gap graded mix had similar values to the that of the ADOT AR

mixes at mid temperature range, but lower moduli values a lower temperature ranges. In general, the moduli values indicated good resistance to rutting potential in the field. The Flow Number (FN) and accumulated axial strain results in the permanent deformation test confirmed such findings; the Puerto Rican AR gap graded mix had no flow (did not fail) during the test.

A comparison of fatigue life between the Puerto Rican AR gap graded mixes and the three ADOT gap graded mixtures revealed that the Puerto Rican mix had a very good fatigue life trend.

Overall, the permanent deformation and fatigue characteristics of the Puerto Rican AR gap graded mixture were very good and comparable to the previously characterized in-service AR mixtures from the ASU-ADOT database. The advanced materials characterization tests conducted on the Puerto Rican AR gap graded mixtures revealed that the pilot AR section would perform as good as and similar to Arizona AR mixtures.

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12. Bibliography

- [1] Witczak, M.W., Kaloush, K.E., Pellinen, T., El-Basyouny, M., & Von Quintus, H. (2002). *Simple performance test for superpave mix design. NCHRP report 465*. Transportation Research Board, National Research Council. Washington D.C.
- [2] SHRP Designation: M-009. *Standard method of test for determining the fatigue life of compacted bituminous mixtures subjected to repeated flexural bending*.
- [3] AASHTO T321-03. (2003). *Determining the fatigue life of compacted hot-mix asphalt (HMA) subjected to repeated flexural bending*. AASHTO, Washington, D.C.
- [4] AASHTO TP 62-07. (2007). *Standard method of test for determining dynamic modulus of hot-mix asphalt concrete mixtures*, AASHTO, Washington, D.C.
- [5] Strategic Highway Research Program, (1994). *SHRP-A-404, Fatigue response of asphalt-aggregate mixes*. Asphalt Research Program, Institute Of Transportation Studies, University Of California, Berkeley.

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- [6] Witczak, M.W., Mamlouk, M., & Abojaradeh, M. (2001). *Flexural fatigue tests, NCHRP 9-19, subtask F6 evaluation tests, task F advanced mixture characterization - interim report*, Arizona State University, Tempe, Arizona.
- [7] Harvey, J., & Monismith, C.L. (1993). Effect of laboratory asphalt concrete specimen preparation variables on fatigue and permanent deformation test results using SHRP A-003A proposed testing equipment. *Transportation Research Record, Journal of the Transportation Research Board*, 1417, 38-48.
- [8] Tayebali, A.A., Deacon, J.A., & Monismith, C.L. (1995). Development and evaluation of surrogate fatigue models for SHRP-A-003A, abridged mix design procedure. *Journal of the Association of Asphalt Paving Technologists*, 64, 340-366.