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COMPARISON OF LABORATORY TEST PERFORMANCE BETWEEN ASPHALT-RUBBER HOT MIX AND DENSE GRADED ASPHALT CONCRETE

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Abstract

Asphalt-Rubber Hot-Mix (ARHM) has shown a higher resistance to flexural and reflective fatigue cracking, and also to permanent deformation, than conventional Dense Graded Asphalt Concrete (DGAC). Experience has demonstrated that with ARHM, a significant reduction in overlay thickness is possible, especially in cases where the existing pavement is cracked.

This paper reports the efforts done on behalf of the Rubber Pavement Association (RPA) to develop a mechanistic design method to quantify the rehabilitation performance of ARHM and DGAC mixes. Based on the results of widely available performance related tests, such as flexural fatigue, repetitive simple shear, wheel track, and permanent deformation tests, combined with traditionally adopted mechanistic-empirical modeling tools, equivalency factors in terms of required overlay thickness have been derived.

The results show that to reach the observed overlay thickness equivalency factor of 0.5, a more appropriate modeling tool based on the test results of an appropriate laboratory test done on properly aged specimens is needed. It appears that new modeling tools and test procedures will need to directly consider the phenomenon of reflective cracking.

1. Introduction

The results reported in this paper were based on three series of tests performed by *"CONSULPAV – Consultores e Projectistas de Pavimentos, Lda."*, the *"Universidade do Minho"*, and the *"Laboratório Nacional de Engenharia Civil"* in Portugal. Tests were executed on two bituminous mixtures: one with gap-graded asphalt rubber hot mix (ARHM) and one with conventional dense graded asphalt concrete (DGAC).

California and Arizona specifications allow up to a 50% reduction of the bituminous layer thickness if ARHM is used to inhibit reflective cracking. In the present study, some of these differences were quantified based on behavioral performance tests conducted in the laboratory.

The addition of properly graded crumb rubber to the binder used in the bituminous mixture gives it more resilience, such that it slows down the crack propagation mechanisms. This increase in resistance has been broadly proven by the vast experience in the American Southwest, especially in Arizona.

2. Materials

The material used in this study was crushed granite to which a small percentage of lime was added. *Figure 1* shows a comparison of the aggregate gradation used in the ARHM and DGAC mixes used.

The bitumen used was a PEN 35/50, which graded as a PG64-16 from a light Arabian crude source. In the ARHM case, the bitumen was modified through the addition of 20% tire crumb rubber.

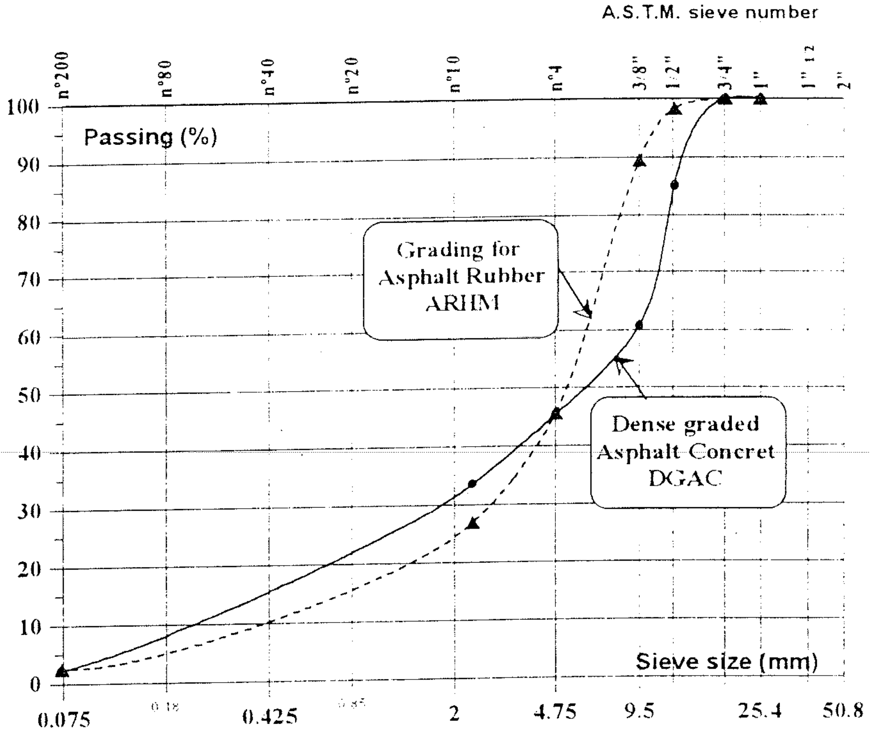

Figure 1. ARHM and DGAC Gradation Comparison

The addition of rubber was achieved through a rotational mixer, at a 180°C temperature and approximately 60 minutes reaction time.

The rubber used for the modification of the bitumen is supplied as crumb (ambient grind); the grading of the rubber is shown in *Figure 2*.

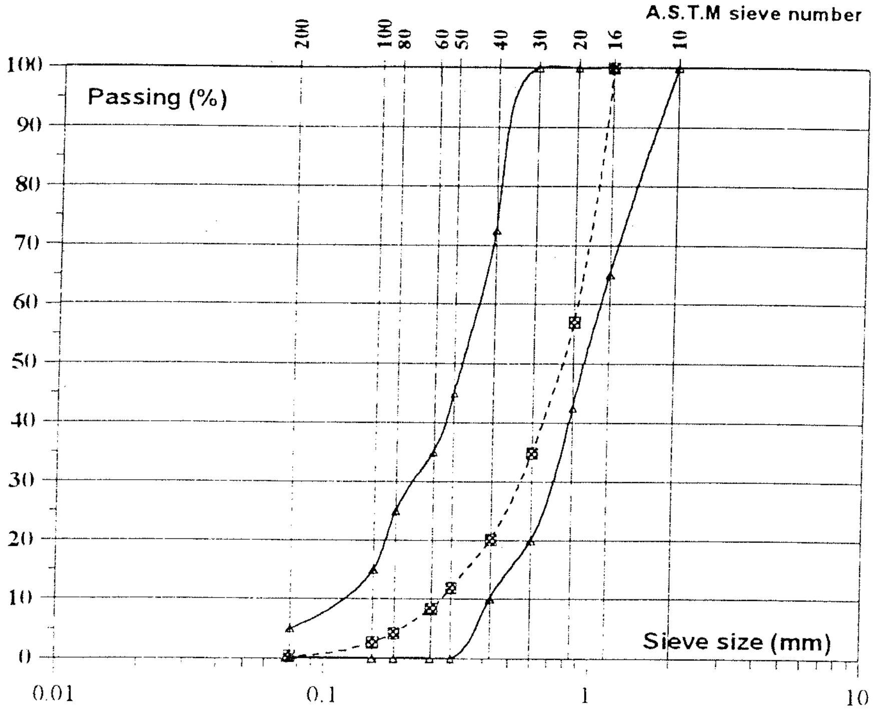

Figure 2. Rubber Grading Curve

2.1 Manufacture of Samples

The binder content for each grading was 9% for ARHM and 4.5% for DGAC. Compaction was made with a steel roller in a heating mould, in order to maintain compaction temperature. The molding of the plates was followed by the sawing of prismatic specimens with the appropriate dimension for each type of test.

The specimens were submitted to bulk density tests, with and without paraffin, as well as the theoretical maximum density test (after fatigue testing) in order to determine air void content.

In the first phase of the test program, half of ARHM and DGAC specimens were submitted to the Long Term Oven Aging (LTOA) procedure, consisting of maintaining the specimens in an oven, at 85°C for a 5 day period. Only specimens used for flexural fatigue tests and reflective cracking tests were subjected to this aging procedure.

3. Bending Tests to Determine Fatigue Life

Flexural fatigue tests are conducted according to the AASHTO TP 8-94 test procedure. They are intended to simulate pavement distress due to traffic loads during its expected design life. They also determine fatigue life, stiffness modulus, and the phase angle of the bituminous beams used. Fatigue life is defined as the number of cycles until a 50% decrease of the initial stiffness of the test beam is achieved.

3.1 Resistance to Fatigue

Figure 3 shows the flexural fatigue lines obtained by the *Laboratório Nacional de Engenharia Civil (LNEC)* for both materials studied after aging.

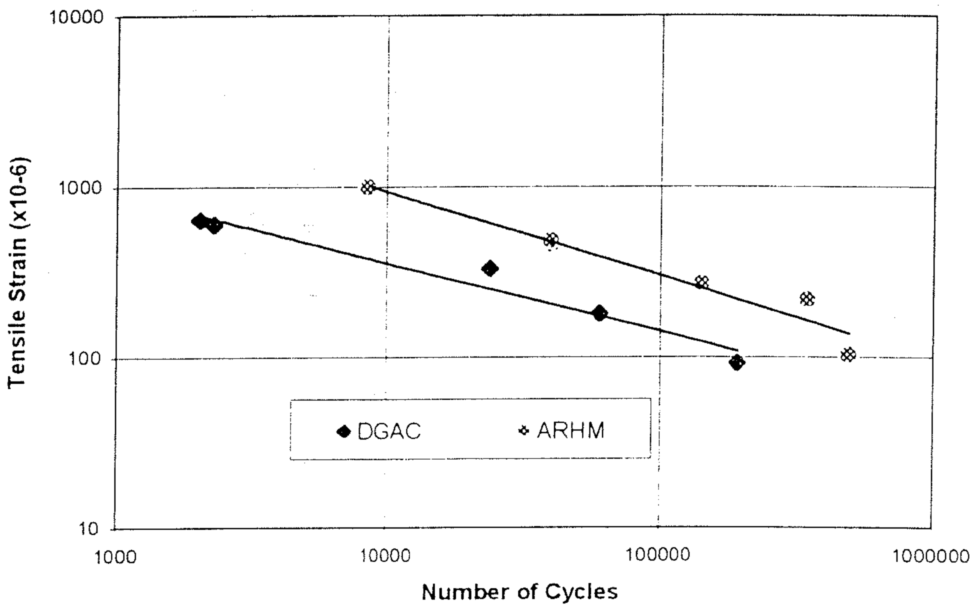

Figure 3. Fatigue Performance at 22°C for Aged Specimens

By comparing the two bending beam fatigue regression lines, one for the DGAC and other for the ARHM, it is clear that ARHM exhibits a significantly better fatigue behavior.

Figure 4 shows the first test results obtained in a series of companion flexural fatigue tests conducted at *CONSULPAV* for both mixes, aged and non-aged, where the specimen dimensions were 63 x 50 x 380 mm. In terms of number of cycles to failure, this figure clearly shows that the fatigue resistance of ARHM is up to 10 times better than that of DGAC. All tests were executed under displacement controlled conditions. Also, the ARHM mix appears to be less sensitive to aging. This effect is more clearly illustrated by looking at the change in stiffness for the two mixes, as described in the next section.

3.2 Stiffness Modulus

Figure 5 shows the evolution of stiffness modulus as a function of tensile strain in the tests made at *CONSULPAV*. This figure shows only a slight increase of the modulus of the LTOA ARHM specimens. On the other hand, DGAC mixes stiffen considerably due to the same LTOA (aging), where the stiffness increased from around 5000 to over 7000 MPa. It was, however, observed that the stiffness modulus of the aged beams tested at *LNEC* was around 5000 MPa. It is possible that due to the thickness of the size of the *LNEC* specimens, the aging conditions imposed were not as severe as in the thinner specimens tested at *CONSULPAV*. The modulus of the ARHM mixes was virtually identical in the beams tested at *CONSULPAV* and *LNEC* if the higher testing temperatures used at *LNEC* are taken into account.

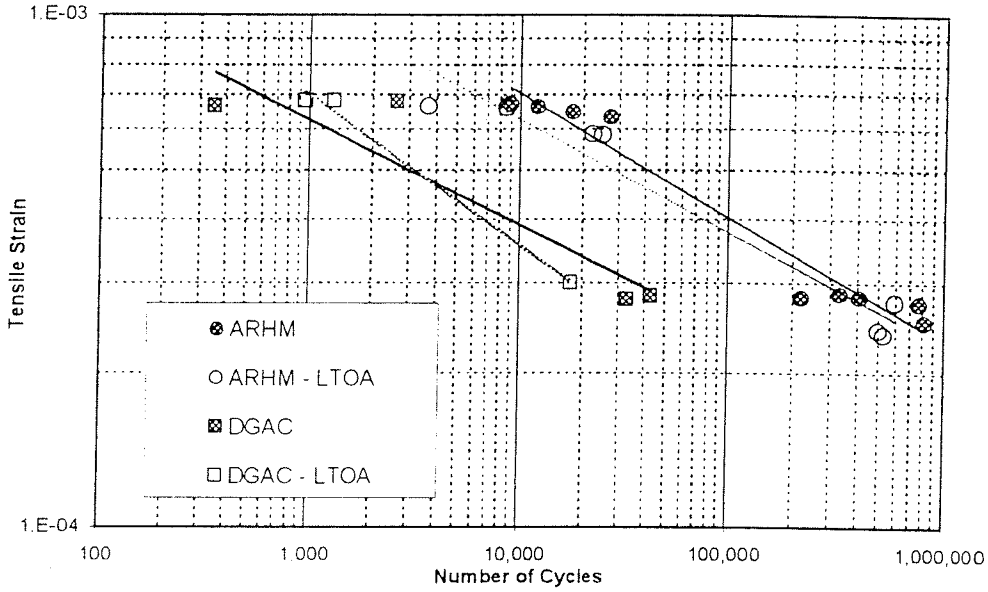

Figure 4. Fatigue Performance Comparison between Aged and Non-Aged ARHM and DGAC Specimens (50 x 62.5 x 380 mm), at 20°C

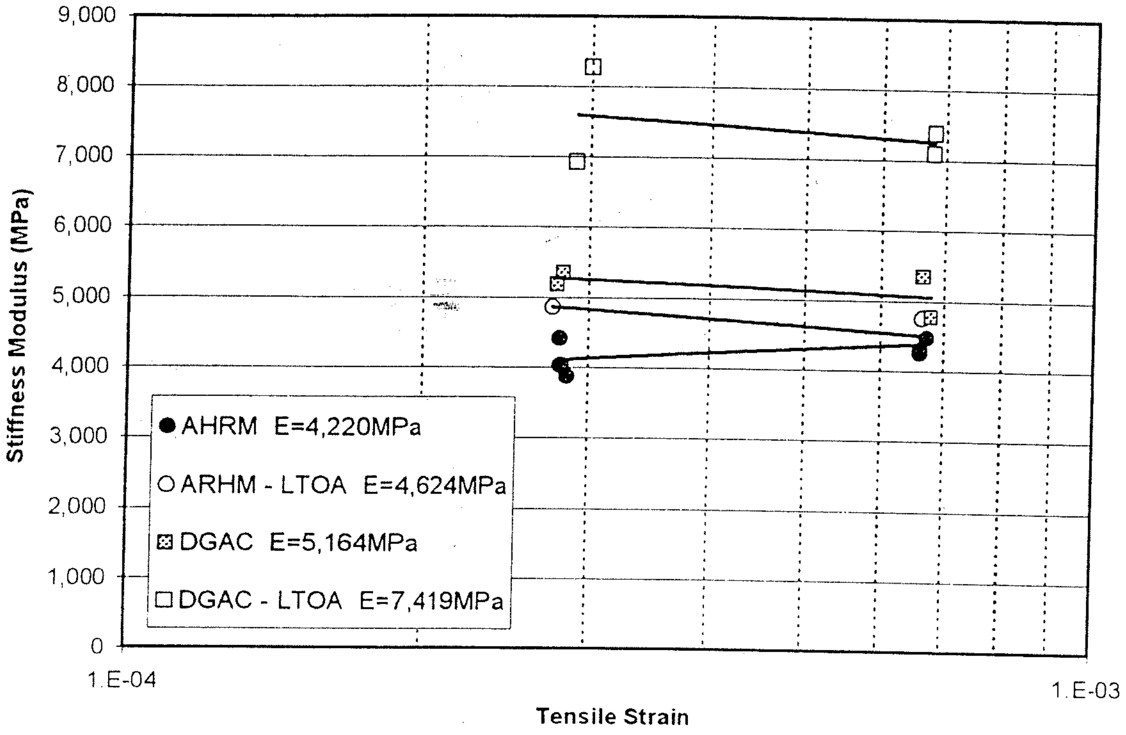

Figure 5. Stiffness Modulus as a Function of Tensile Strain at 20°C and 10 Hz.

3.3 Phase Angle

Figure 6 presents the phase angle as a function of tensile strain imposed during the test procedure. The phase angle in aged mixes appears to decrease with the aging process. Aging of DGAC and ARHM specimens do not appear to have a strong effect on phase angle.

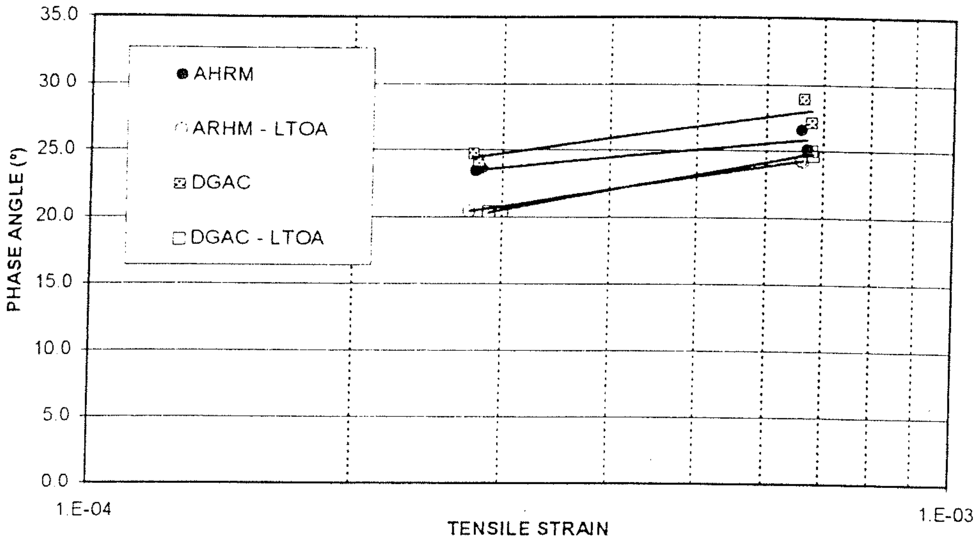

Figure 6. Phase Angle as a Function of Tensile Strain for ARHM and DGAC at 20°C

4. Permanent Deformation Characterization Tests

4.1 Wheel Tracking Tests

These tests were made at the *LNEC* according to the Spanish Standard "NLT-173/84 – *Resistencia a la deformación plástica de las mezclas bituminosas mediante la pista de ensayo de laboratorio*". In this test, the 300 x 300 x 50 mm specimen is compacted in a mould by vibratory compression for 4.75 seconds. It is then placed inside the testing machine in a temperature control chamber.

The test starts after submitting the specimen to a 60°C temperature for 4 hours. The load is applied, at a constant rate, and the specimen's deformation is recorded at 1, 3, 5, 10, 15, 20, 25, 30, 35, 40, 45, 60, 75, 90, 105 and 120 minutes after the test begins. The results shown in this study correspond to the following deformation parameters (velocity/minute): v105/120m. Two sets of three specimens were molded; one of the sets corresponds to DGAC (the CLTPi series) and the other corresponds to ARHM (the RLTPi series).

The density values obtained for the DGAC (CLTP1, CLTP2 and CLTP3) ranged between 2.289 and 2.292 g/cm^3. The theoretical maximum density of the mix (2.429 g/cm^3) means that the void content of the mix is about 5.7%. For the ARHM mix (RLTP1, RLTP2 and RLTP3), the density values ranged between 2.151 and 2,160 g/cm^3, corresponding to an average void content of 5.6%.

According to the NLT-143/74 test procedure, the relative compaction must be at least 97% of Marshall test density. Because the Marshall density was not known. comparisons were made using the theoretical maximum density values of both mixes (values above 92% are considered acceptable). DGAC showed a relative compaction of 94.3% and ARHM a 94.0% value. *Table 1* shows the results obtained on the wheel track device for the six specimens tested.

Table 1. Results of Wheel Track Tests

Specimen Identification		**Results**	
DGAC	CLTP1	V105/120=4x10^{-3} mm/min	Average value: 5.3 x 10^{-3} mm/min
	CLTP2	V105/120=4x10^{-3} mm/min	
	CLTP3	V105/120=8x10^{-3} mm/min	
ARHM	RLTP1	V105/120=7x10^{-3} mm/min	Average value: 8.6 x 10^{-3} mm/min
	RLTP2	V105/120=10x10^{-3} mm/min	
	RLTP3	V105/120=9x10^{-3} mm/min	

The wheel track test results show a deformation rate obtained for DGAC (CLTP1. CLTP2 and CLTP3) between 4 and 8 x 10^{-3} mm/min. the deformation rate obtained for the three ARHM specimens are quite similar. ranging between 7 and 10 x 10^{-3} mm/min. The limiting values proposed by the D.G. Carreteras (Spain) for the analysis of these test results depend on traffic intensity and climatic region. For the worst conditions. T0 and T1 traffic classes and a warm climate. the limiting value for v105/120m is 15 x 10^{-3} mm/min. Therefore. the results for both mixtures meet this value.

4.2 Repetitive Simple Shear Test at Constant Height

The Civil Engineering Laboratory *Universidade do Minho* used the Repetitive Simple Shear Test at Constant Height to characterize the relative rutting propensity of the two types of mixes in question. A total of 8 cylindrical specimens (4 for each mix). with a 150 mm diameter and a 50 mm thickness were tested.

Permanent deformation in asphalt mixes is due to densification (volume decrease due to air void content reduction and rearrangement of solid particles) and to plastic shear flow. Plastic shear flow occurs in constant volume conditions. Therefore. the resistance to permanent deformation of bituminous mixtures can be evaluated through the resistance to plastic shear deformation at constant volume.

This test is made on cylindrical specimens with a 150 mm diameter and a 50 mm thickness. through the repeated application of a 70 kPa shearing strain. for 0.6 seconds followed by a 0.1 second rest period. The test is conducted at an average temperature of the 7 highest daily temperatures measured in the pavement at a depth of 50 mm. The test allows the calculation of the constitutive law of the material as far as shearing resistance is concerned – see *Equation 1*.

$$PSS = a * N^b \tag{1}$$

Where: PSS = Plastic Shear Strain;

N = Number of loading cycles;

a, b = Coefficients.

The resistance of the bituminous mixture to permanent deformations is obtained through Equations 2 and 3 which relate the rut depth to the plastic shear strain and the number of 80 kN axis supported by the mixture to the number of cycles needed to obtain the elastic shearing extension.

$$\text{Rut Depth (mm)} = 294 * \text{Plastic Shear Strain} \tag{2}$$

$$\log(N) = -4.36 + 1.24 \log(80\text{ kN Axles}) \tag{3}$$

The mixes' resistance to permanent deformation is obtained through the average values obtained through all tests conducted. In this case, the tests were made on 4 specimens of each mixture at a 53°C constant temperature level.

Figure 7 shows the laboratory test results in terms of the number of 80 kN axles needed to achieve a rut depth of 12.5 mm.

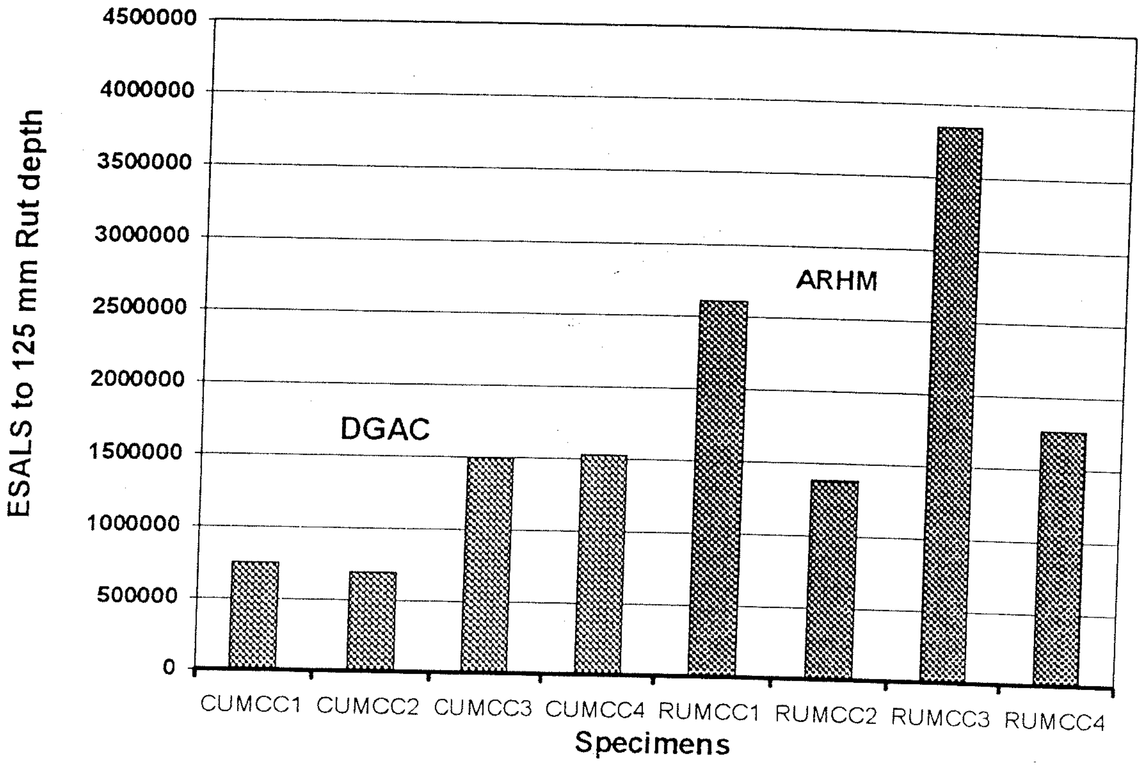

Figure 7. Comparison of Shear Resistance between DGAC and ARHM Mixes

The average values on a logarithmic scale show that DGAC results in approx. 12.5 mm of permanent deformation at 1.1 x 10^6 80kN axles, while ARHM results in the same 12.5 mm permanent deformation at 2.4 x 10^6 80kN axles.

5. Modeling Based on Flexural Fatigue Concepts

The results presented above indicate that the only two significant differences between ARHM detected by the tests performed were in their fatigue lives and their resistance to aging. Permanent deformation results did not show clear trends; in one test, AHRM performed slightly better while in another the reverse of this was observed.

From the fatigue tests, two clearly different flexural fatigue laws were obtained for AHRM and DGAC. It is therefore possible to evaluate analytically what would be the reduction in pavement thickness if those two materials were used in a full depth pavement structure.

The ELSYM program was used to compute the tensile stresses on the bottom of the asphalt concrete layer for each structure. The bituminous mixture modulus was varied between 4000, 4500 and 5000 MPa; the bituminous layer thickness was varied between 100 and 250 mm. The aggregate base layer was assumed to be 200 mm with a 250 MPa modulus. The subgrade modulus was varied between 50 and 150 MPa.

It was assumed that the reference temperature for the site was 20°C. As such, the modulus and fatigue lives obtained in laboratory were used directly in the analyses. It was assumed that the shift factor between laboratory fatigue life and actual fatigue life was one.

Under these assumptions, the relationship between pavement thickness and fatigue life is presented in *Figure 8* for the 150 MPa subgrade modulus case. The other subgrade modulus levels studied showed similar results.

For two levels of fatigue life, N = 100,000 and N = 300,000, comparisons were made between the relative thickness of the bituminous layer with the two types of mixes DGAC and AHRM for each of the subgrade modulus levels. The ratio between the two thicknesses was computed. This ratio is presented as a function of subgrade modulus in *Figure 9*.

It can be concluded that the ratio improves (i.e. decreases) as the traffic decreases and the foundation modulus increases. Based on this flexural data, layer thickness reductions varied between a factor of 0.55 and 0.7. This is, however, still not as convincing as the 0.5 reduction recommended by CalTrans and ADOT based on over 20 years of field observations.

It is, however, interesting to note that if those values are extrapolated to the level where the 0.5 reduction is achieved, a value for a subgrade modulus between 600 and 2000 MPa is obtained. This range of values corresponds to the level of "surface" or composite modulus obtained in FWD backcalculation analyses on cracked bituminous pavements.

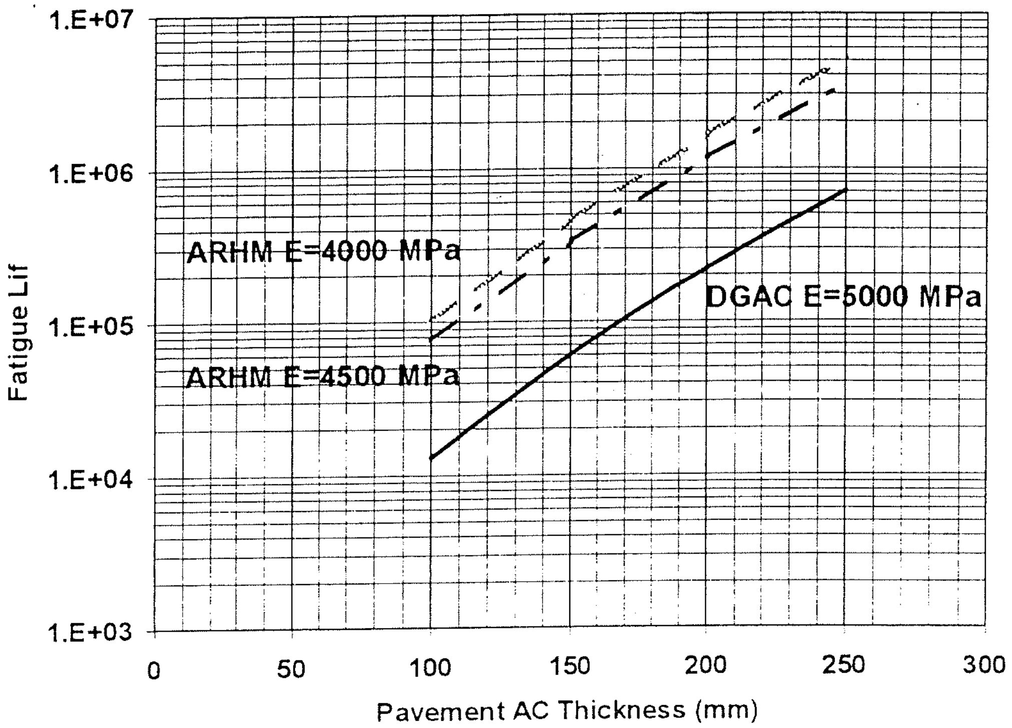

Figure 8. Relationship between Pavement Fatigue Life. Mix Type and Pavement Thickness for 150 MPa Subgrade Modulus

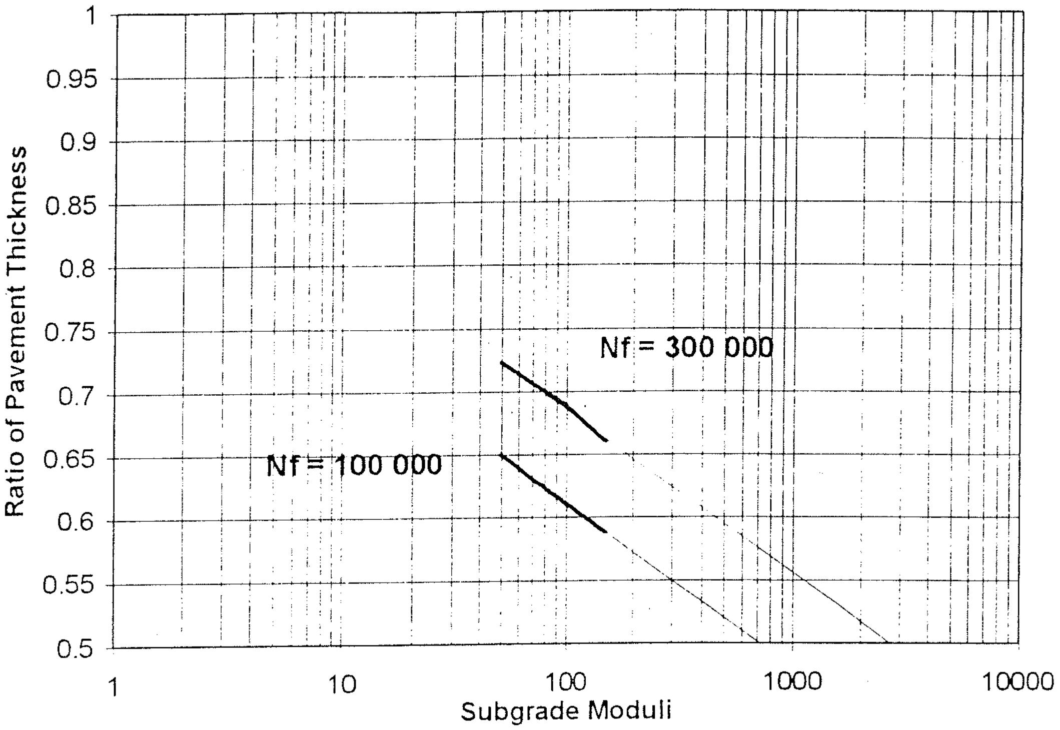

Figure 9. Effect of Subgrade Modulus and Traffic Level on Layer Equivalency Ratios for AHRM and DGAC

Based on the theoretical analyses of tensile strain on the bottom of the asphalt layer only, it would not be possible to justify the observed 50% reduction in overlay thickness using AHRM. It is therefore necessary to consider the possibility that the modeling tools, test methods, and aging conditions do not adequately reflect reality. Other mechanisms not modeled here are evidently responsible for the improved performance of these mixes in the field. Observations have shown that they perform well over cracked pavements. As such, efforts are now concentrated on evaluating the applicability of using a test procedure that directly captures the mechanisms of reflective cracking.

6. Reflective Cracking Tests

A very limited set of tests were performed using the Reflective Cracking Device (RCD) developed by Sousa et.al.(1996). Tests were executed under controlled displacement at 20°C . Combined shear and axial displacements were applied to the specimen at a 10 Hz frequency rate of loading. The crack width used was 10 mm, corresponding to approximately three times the average crack width measured in in-service pavements, as recommended by Pais (1999) due to disintegration of the walls of a crack in an actual pavement section.

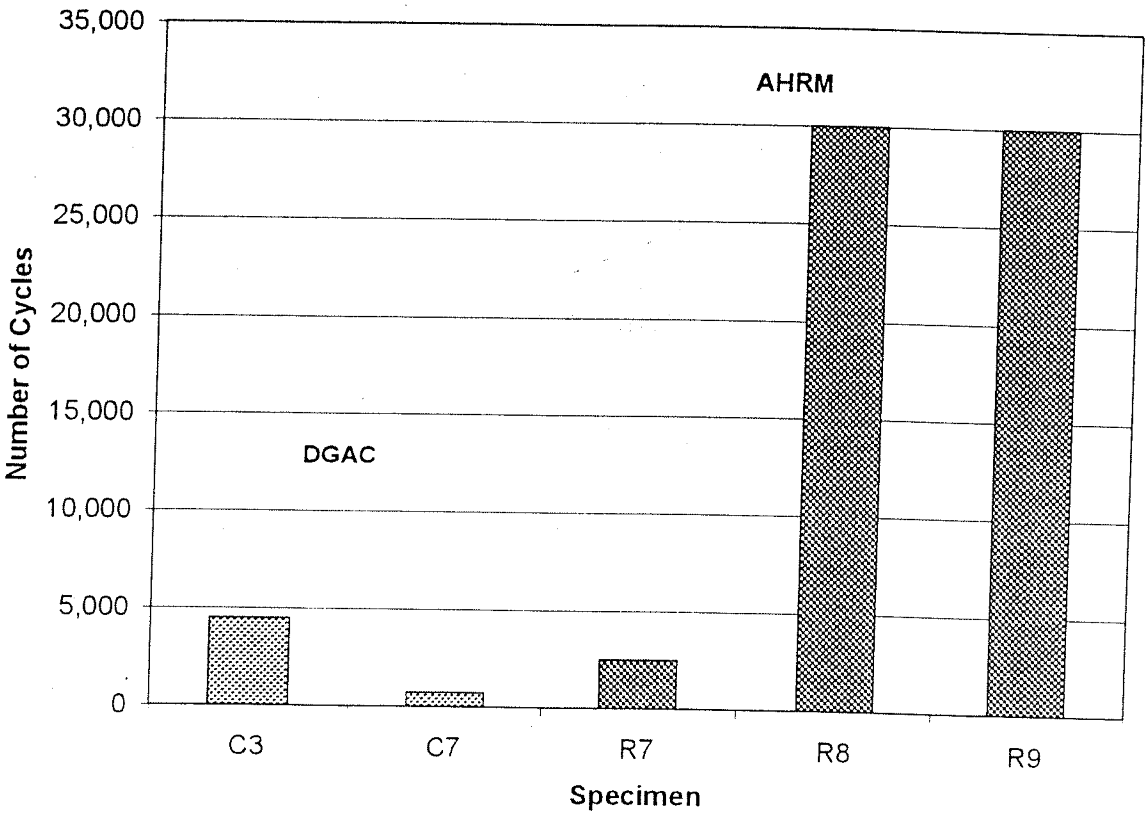

Figure 10. Comparison of the Number of Cycles to Reduce the Equivalent Shear Modulus above a Crack to 50% for AHRM and DGAC at 20°C and 10 Hz for a Shear Displacement Level of 0.4 mm.

Figure 10 shows a comparison between the behavior of the two types of types of mixes. The equivalent stiffness modulus in the crack zone was computed and plotted over the number of cycles as an indication of the damage potential above an existing crack.

It can be observed in *Figure 10* that ARHM possesses the capability to withstand reflective cracking better than the DGAC, on average about 8 times better. The scatter in the data is significant, thus some improvements are required in the RCD test protocol. However the results from the theoretical analyses carried out by Sousa et. al. (2000) indicate that the reflective cracking phenomenon is mostly a controlled stress mechanism. Nevertheless, models are not available yet to ascertain if this difference in laboratory performance can be equated to a reduction in overlay thickness of 50%.

7. Summary and Conclusions

The data present in this paper is part of an ongoing investigation to develop a mechanistic overlay design that directly takes into account the phenomenon of reflective cracking. Although the problem is a difficult one, it is a great advantage that California and Arizona as well as South Africa accept a 50% reduction in overlay thickness when AHRM is used instead DGAC. Therefore, the problem will be mostly solved when a set of tests, models, and transfer functions can reasonably predict that behavior.

In this paper, a series of results are presented as a fist attempt to evaluate the material properties of two mixes, taking into account the long term aging that takes place in the field. The results indicate that from a flexural fatigue analysis it is not possible to justify the 50% reduction in overlay thicknesses observed in practice. Although the fatigue life of AHRM was about 10 times that of DGAC, results indicate that only a 60% to 70% reduction would be gained. Furthermore, the results indicate, at least for the two mixes tested, the relative resistance to permanent deformation was identical. On wheel track tests, DGAC performed slightly better while the opposite was found in Repetitive Simple Shear Tests.

The effect of aging cannot be ignored in this comparisons, as AHRM is much less sensitive to aging then is DGAC. As such, tests conducted under controlled stress conditions are likely to perform much more in favor of the fatigue properties of ARHM the longer the test specimens are aged.

The effect of specimen size on LTOA also needs to be considered. Large specimens may take considerable more time to age in the laboratory than small specimens. Reflective cracking tests executed on aged specimens under displacement control indicate an 8-fold increase in the performance of ARHM over DGAC. However, due to the large scatter in the data, a further investigation is underway.

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