General Observations On the Development of Performance Tests For Asphalt Concrete Mixes

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ABSTRACT

This paper presents a review and general observations of 12 years of research progress made during the Strategic Highway Research Program (SHRP) and National Cooperative Highway Research Program (NCHRP), to develop tests to characterize hot mix asphalt concrete properties related to pavement performance. Discussions in this paper include comparisons of test results obtained with crumb rubber modified asphalt mixtures.

SHRP developed a suite of tests to characterize mix properties to predict permanent deformation (rutting) and cracking distresses caused by either traffic loading or climatic conditions or the combination of the two. Tests developed included the repetitive simple shear test at constant height to predict rutting, four point flexural bending fatigue test to predict fatigue cracking, Indirect Tension Test (IDT) and Temperature Stress Restrained Specimen Test (TSRST) test to predict low temperature cracking. Most of this research was based on laboratory specimens prepared by the rolling wheel compactor.

The NCHRP Project 9-19 included tasks to develop simple performance test(s) to compliment the Superpave volumetric mixture design method, and to develop a fundamental materials characterization model and associated tests for future refinement of the Superpave performance models, mostly based on specimens produced by the Superpave Gyratory Compactor. Various forms of uniaxial / triaxial and shear tests were considered for use in both of these programs.

Associated with the development of these tests, research has also brought along correspondent models where fundamental material properties can be applied and respective shift factors to convert laboratory and model data into predictions of actual performance.

The purpose of this paper is to highlight some test developments and identify some correlation's made using the above tests. Inferences from the test results and models are drawn which may lead to potential improvements.

The Arizona Department of Transportation (ADOT) has been and continues to be involved in the support and evaluations of all these concepts.

INTRODUCTION

SHRP and NCHRP research programs have been charged with the task of development test methods and models to be used in evaluating and predicting pavement distress or performance (1, 2). Most of the tests developed by SHRP or NCHRP 9-19 provide fundamental stress-strain relationships that may indicate the expected field behavior of hot mix asphalt. Sample geometry is important to obtain true materials properties that assure consistent ranking among the mixes (3).

Since SHRP, and with the implementation of Superpave, the volumetric gyratory mix design procedures have now been widely used in the US. However, lagging very far behind has been the general adoption of testing and evaluation procedures based on performance tests and modeling capabilities that would actual permit mix design based on performance predictions.

Many issues have been affecting the adoption of such testing capabilities, sample preparation, cost of equipment, and training of personnel, amongst others. Also of importance is the standardization of quality control practices; that is, if a mix design is prepared using performance testing approach, shouldn't the quality control be done in such a way to be correlated to the expected performance testing?

The sample geometry used for triaxial and shear tests are generally acceptable for comparative analysis, but field quality control based on cores has lead to roadblocks in the implementation of these tests. Issues like confined testing when comparing dense and open graded mixes is very important and may not have been fully appreciated and indeed in some cases may have been ignored by many researchers (4,5).

NCHRP Project 9-19 had two primary objectives (2). The first was to recommend a simple performance test to be used with the Superpave volumetric mixture design procedure. The second was to develop advanced, fundamental characterization methods for asphalt concrete mixtures that can lead to subsequent modifications and enhancements to the Superpave distress prediction models. Various forms of triaxial / uniaxial and shear tests were considered for use in both of these tasks.

The effects of specimen size and geometry on laboratory measured material properties are important considerations for both the simple performance test and the advanced material characterization effort. The primary objective of one of the laboratory investigations was to determine, using specimens fabricated in the Superpave Gyratory Compactor, the minimum test specimen dimensions that will provide accurate mixture responses and material properties that are independent of the test specimen size and aggregate size. A number of tests were evaluated for use as the "simple performance test" and in the advanced materials characterization subtask of the study.

On the other hand, one performance test is not the answer for all distress. This paper presents some developments made during the past 12 years; it does not attempt to be thorough but rather tries to bring to light some key issues and progress made.

CONCEPT OF FUNDAMENTAL PERFORMANCE TESTS

Over the years, practitioners and researchers have been trying to predict the behavior of pavement structures in which hot mix asphalt concrete is a key component of the layered system. The list of the methods and methodologies attempted all over the world to predict pavement behavior is very extensive. It is not the purpose of this paper to summarize those methodologies, but rather to try to summarize the essence of some of the systems recently developed.

Basically, the most recent systems in pavement design analysis have five major cornerstones:

- Specimen fabrication
- Specimen conditioning prior to or during testing
- Conducting the “performance” test in the laboratory (or field)
- Incorporating of the test results in a model or formulation
- Correlating the model with actual field performance

SPECIMEN GEOMETRY, FABRICATION AND PREPARATION

The debates surrounding the methods and equipment used to prepare specimens for testing has been extensive, intensive and at times even associated with heated arguments. It is well known that specimens can be produced by: Marshall, Hveem, gyratory, rolling wheel, slab compactor and many other methods. Several types of gyratory equipment have been used as well as many types of rolling wheel compactors.

Comparisons of performance between several laboratory compaction methods and field cores revealed that the rolling wheel compactor produces predicted rut depths, which closely compare to that of field cores over a wide range of air-void contents as shown in Figure 1. (6)

During specimen preparation, one of the key aspects is achieving the desired target air void content, binder content and to the extent possible the same aggregate skeleton structure and uniform film thickness as obtained in the field (either after compaction or after several years of traffic). Figure 2 illustrates the influence that air void content and binder content can have on the predicted number of Equivalent 18 kip Single Axle Loads (ESAL’s) to reach 12.5 mm rut depth (1).

It has been well demonstrated that the method of specimen fabrication affects material properties measured in hot mix asphalt. Furthermore not all methods produce equally uniform specimens, and therefore coring or sawing may be required to obtain specimens, which are reasonably uniform and suitable for testing.

Many researchers have been particularly concerned with determining the appropriate geometry (height to diameter) of the specimens taking into consideration the maximum aggregate size used in the mixes (3,7,8,9). The size of the specimens (height, length or diameter) has also been related to the particular test used to determine specific mix properties.

Weissman was one of the first to use the concept of the representative volume element (RVE) in asphalt concrete (7). The RVE determines the minimum specimen dimensions required to obtain reliable and repeatable laboratory test data. The RVE is defined as the smallest material volume large enough so that global characteristics of the material remain constant, regardless of the location of the RVE. This definition implies that when specimens larger than the RVE are used, consistent results are more likely to be obtained. Unfortunately, it is not always possible to use specimens larger than the RVE and it is important to understand the impact thereof.

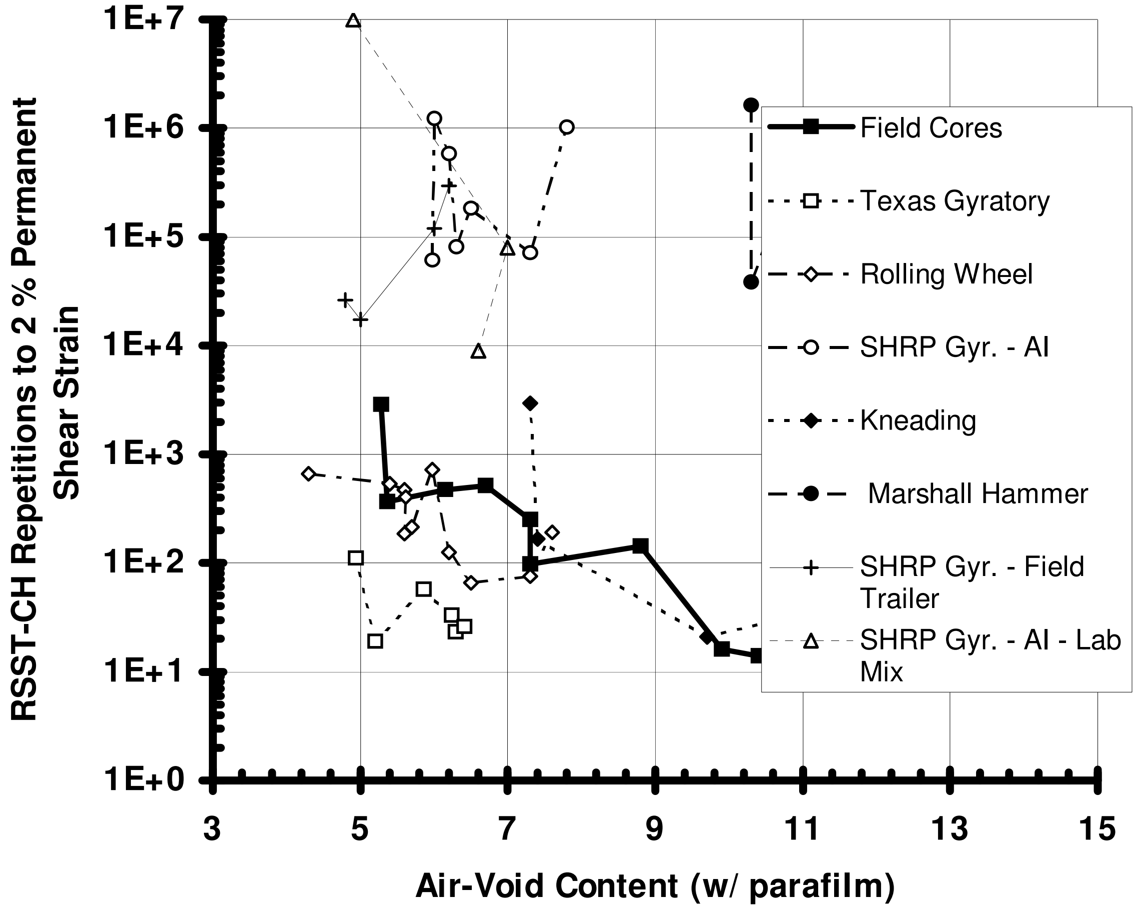

Figure 1 – Comparison of Shear Resistance of Specimens Produced by Different Compaction Methods at the Same Binder Content as a Function of Air Void Content.

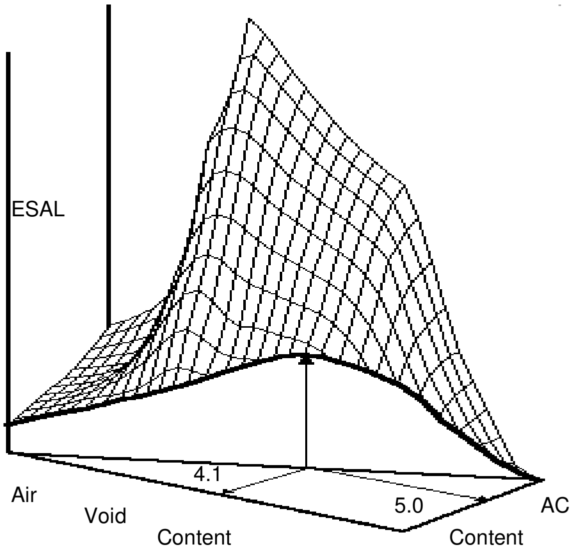

Figure 2 – Shear Resistance, in Terms of ESALs to 12.5 mm of Rut Depth, as a Function of Air Voids and Binder Content.

Using an innovative mesh generation technique, and nonlinear large strain finite element, Weissman modeled triaxial and shear tests. An example of a triaxial mesh is shown in Figure 3. The plots of results, presented in Figure 4, for E_{mastic} = 1 MPa clearly show large oscillations, even for gauge lengths larger than 100 mm (note: the nominal aggregate size was 19 mm). Similarly, Figure 5 presents the variability of shear strain in a specimen simulated during the Repetitive Simple Shear Test at Constant Height (RSST-CH) test.

To demonstrate the effect of the length-to-height ratio, a series of three-dimensional finite element simulations were conducted. It was concluded, as shown in Figure 6, that a 10 percent error, or less, in the predicted shear modulus (G) can be expected for specimens with a length-to-height ratio larger than three.

Weissman recommended that for the restricted triaxial test the specimen diameter should be larger than the RVE and the height should be at least twice the RVE plus the diameter (7). Specimens for a mix with a 19 mm nominal aggregate size should be about 125 mm in diameter and 350 mm tall. For the simple shear test at constant height, specimens should have a length to height ratio of at least 3. The height of the specimen should be at least the vertical RVE dimension, which for the analyses presented is about 100 mm. These dimensions need to be validated with laboratory tests. It also concluded it should be clear that no single test can span the complexities of asphalt concrete at elevated temperatures.

Another concern relates to the fact that even when RVE dimensions are encountered and selected to represent the laboratory binder-aggregate mix properties, the conditions in field do not correspond. As an example, consider the application of asphalt rubber open graded friction courses. Generally this mix is applied in 19 mm thick layers and the average particle size is 9 or 12 mm. Clearly the “end effects” and boundary conditions in which the mix is used in the field are quite different than the conditions under which fundamental properties of this mix would be obtained from RVE tests.

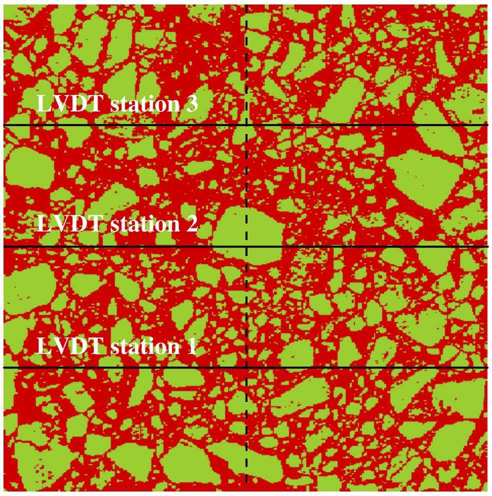

Figure 3 - Example of the Mesh for the Pleasanton Aggregate Mix, 640x640 Elements. Mesh Dimensions are 150x150 mm, Red = Mastic, Green = Aggregate, Locations of the Virtual LVDT Stations for Axial Tests in the Horizontal Direction, all LVDTs are Centered about the Dotted Line.

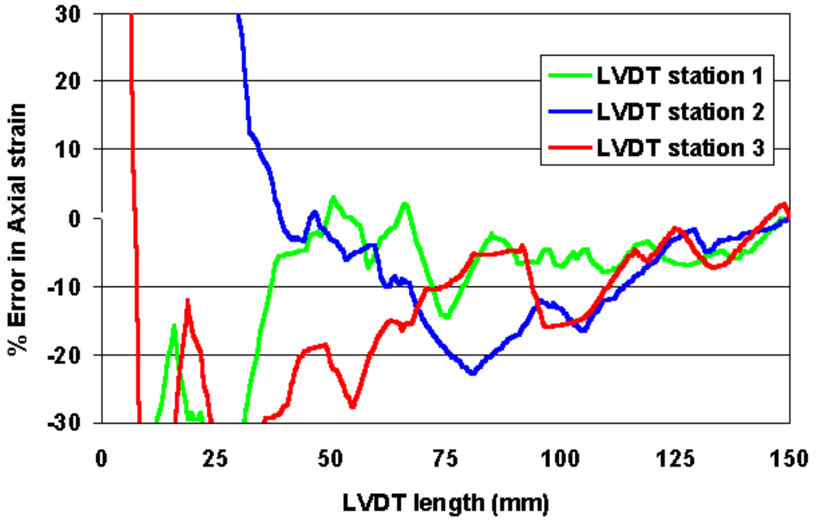

Figure 4 - Effect of Gauge Length on Measured Axial Strain (x Direction), Pleasanton Aggregate, $E_{aggregate}$ = 100 MPa and E_{mastic} = 1 MPa.

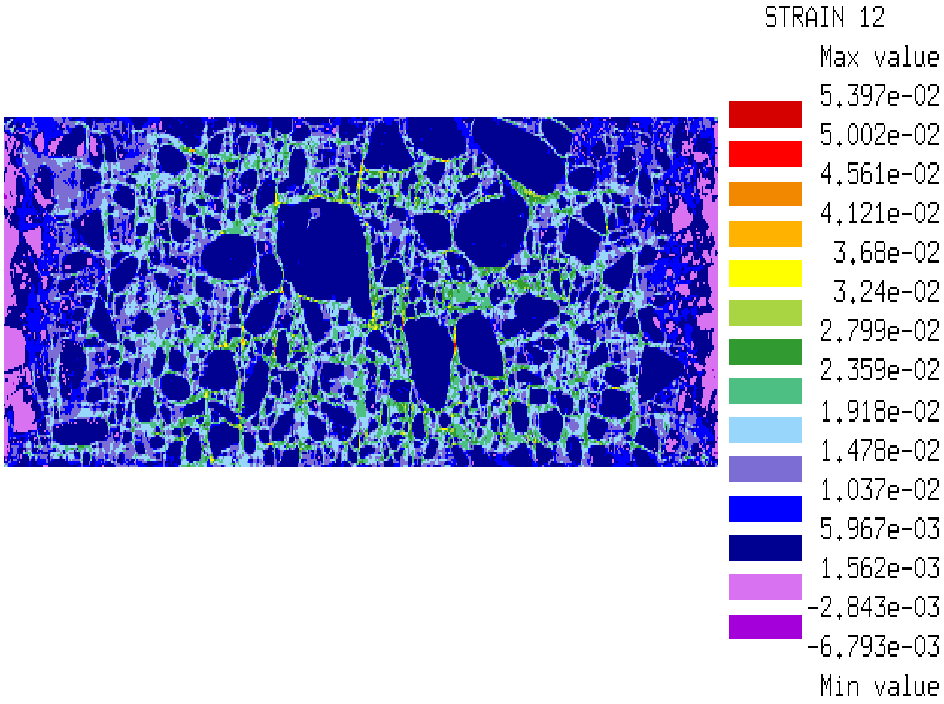

Figure 5 Shear Strain Distribution for a Plane Strain Simulation of a Simple Shear at Constant Height Test; Height = 75 mm and Length = 225 mm.

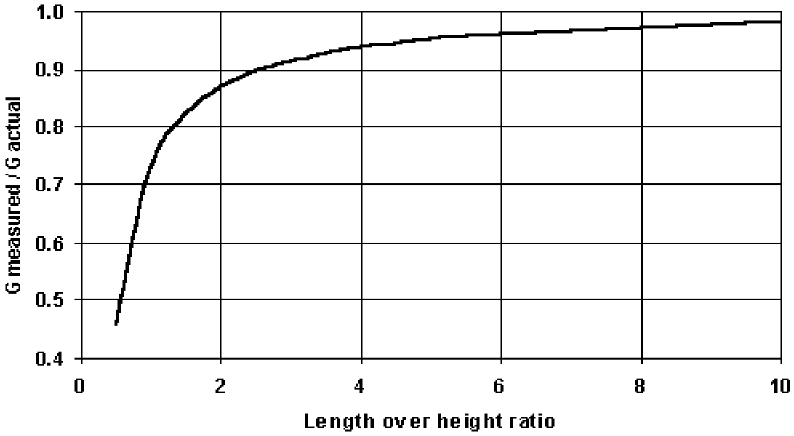

Figure 6 - Convergence of the Measured G with Increasing Length to Height Ratio.

One of the activities considered critical to successful completion of NCHRP Project 9-19 was to conduct a detailed laboratory study to define the minimum specimen size to be used with uniaxial and shear test specimens for a wide range of nominal aggregate size mixtures. Some of the NCHRP Project 9-19 data, presented in Figure 7, supports what was shown in Figure 4. The permanent shear strain measured varies as a function of the specimen diameter (represented by the LVDT gage length).

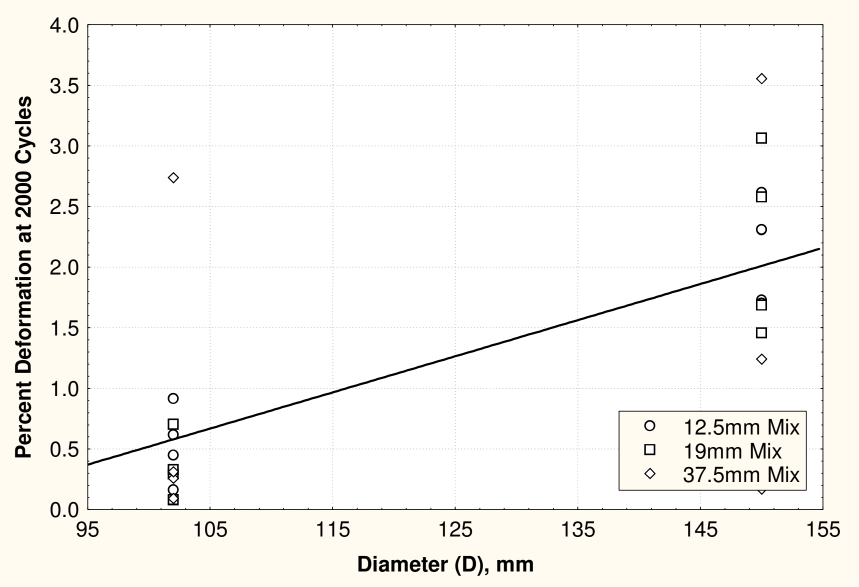

Figure 7 - Effect of Specimen Diameter of Permanent Strains of Shear Tests after 2000 Load Cycles.

Specimen and Mix Conditioning to Simulate Aging and Moisture Damage

Attempts have been made to condition specimens and mixes prior to testing to better simulate environment aspects that affect mix properties (temperature, oxidation, moisture, thermal cycles). During SHRP Short Term and Long-term oven aging has been developed and proposed. However the effectiveness of those aging methods has not been demonstrated for all climatic regions, plant types and duration of the compaction process. (10,11)

The combined effect of aging and moisture damage has been almost ignored in the research literature and therefore comparisons between the combined effects of all factors influencing actual performance are extremely limited, if not existent. A documented example on effect of fatigue aging has been reported by Raad (12). Comparisons were made from beams taken from 10 year old pavements of dense graded mix and an asphalt rubber mix with beams made with the original materials.

Figures 8 and 9 show the effect of the environmental effect on fatigue life of four point bending tests. It is interesting to notice that asphalt rubber materials appear to resist aging better then conventional mixes.

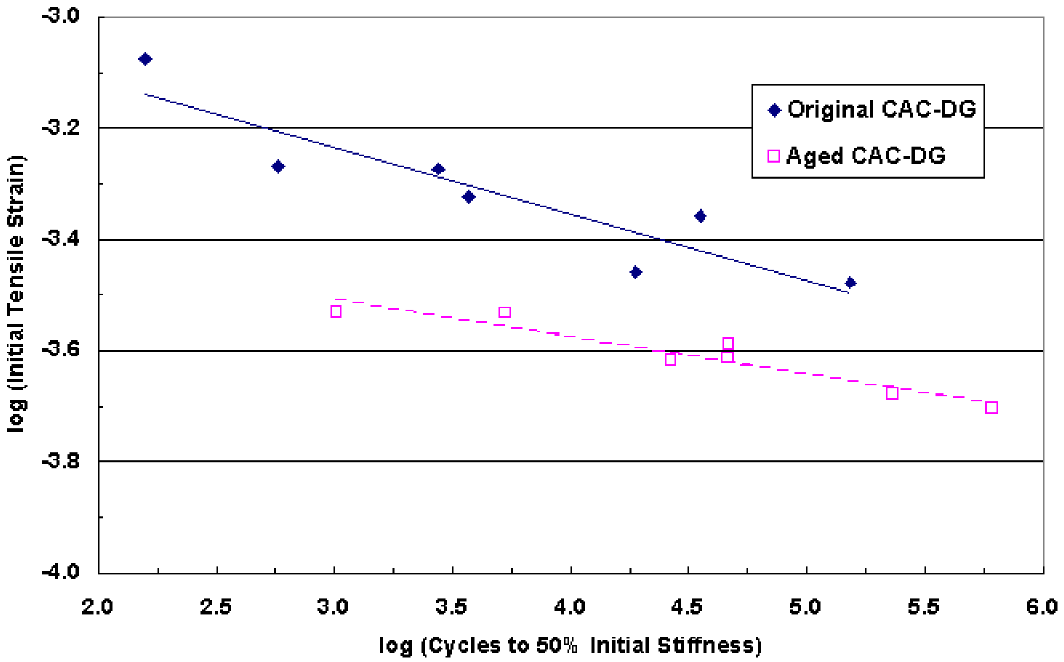

Figure 8 - Comparison of Flexural Fatigue Life on Aged and Unaged Dense Graded Mixes after 10 Years in the Field (Untrafficed)

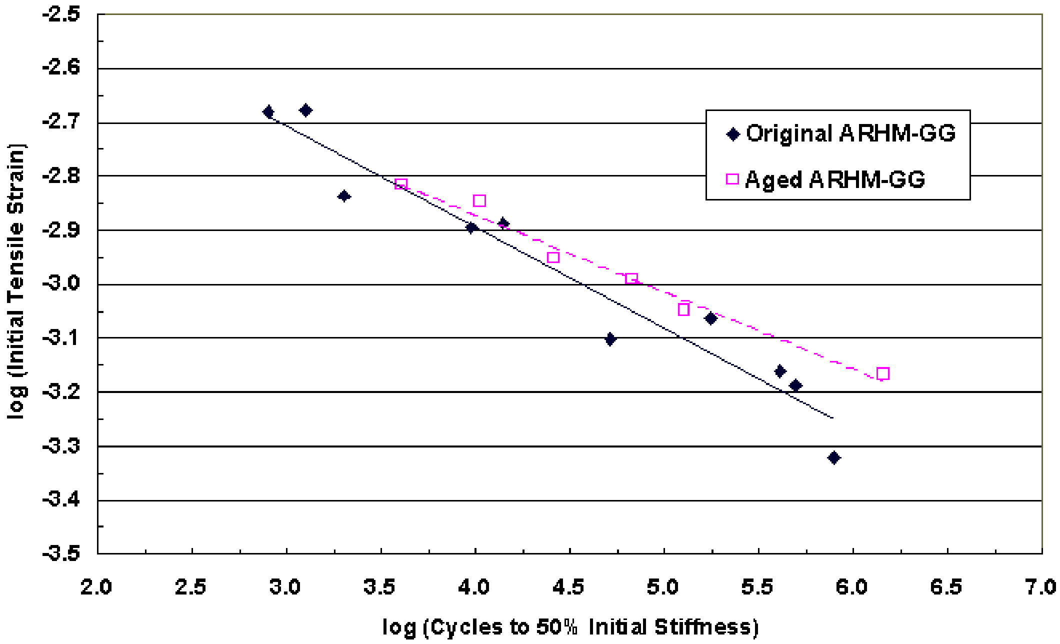

Figure 9 - Comparison of Flexural Fatigue Life on Aged and Unaged of Asphalt Rubber Materials after 10 years in the Field (Untrafficed)

PERFORMANCE TESTS

Both SHRP and NCHRP have identified as key performance indicators tests that would measure the stiffness, fatigue, permanent deformation and thermal cracking characteristic of the mixes (2, 13). It has also been recognized that reflective cracking is also a distress mode for which specific models and tests are required independent of the model properties obtained directly SHRP, SUPERPAVE or NCHRP distress or performance indicators.

One of the key aspects on the new series of tests proposed for mix characterization has been the impetus of being able to determine fundamental material properties that could be fed into numeric models.

Furthermore in the development of the performance tests the following factors have been generally considered:

- Reliability of the test parameter to distinguish between the performances of a wide range of mixtures.
- Repeatability of the test and the sensitivity of the test parameter to different mixture variables.
- Complexity of the test procedure.
- Cost of the equipment and testing preparation requirements.
- Testing time needed to complete the testing program.
- Technical level or experience required from the operator.

Based on experience, state of the art testing research and modeling, the following table was proposed summarizing the tests form each research program.

Table 1 – Comparison of Test Selection and Conditioning During SHRP (1993) and NCHRP (2003)

	SHRP	**NCHRP**	**Observations**
Specimen Laboratory Compaction	Rolling Wheel	Superpave Gyratory	NCHRP was mandated to use Gyratory Specimens. Equipment was redesigned to accommodate larger specimen sizes from where specimens are cored.
Tests to Determine Stiffness of the Mixes	Shear Frequency Sweeps at Constant Height at different temperatures	Uniaxial Compression Dynamic Modulus Test at different Frequencies and temperatures	
Tests to Determine Fatigue properties of Mixes	Four Point Flexural Bending	Four Point Flexural Bending	Tests conducted at representative field temperature and different strains levels
Tests to Determine Permanent Deformation	Repetitive Simple Shear test at Constant Height	Uniaxial Compression Creep Test	Tests conducted at representatively high pavement temperature
Tests to determine Low Temperature Cracking	TSRST	Indirect Tensile Creep and Strengths Tests / Dynamic Modulus	
Method of Aging Mix to simulate plant aging	STOA	STOA	
Method to Age Specimen to simulate Aging in the field	LTOA - 85 C for 5 days	Being Investigated	
Moisture Damage	ECS	Being Investigated	
Tests to determine Reflective Cracking resistance	Not addressed. No test proposed	Model in 2002 Design Guide. No test proposed	Not Addressed. No test proposed
Method to conduct Quality control tests of the performance based permanent deformation parameters	Cores from the field tested in the shear Test at representatively high pavement temperature	Criteria Under Development	
Method to conduct Quality control tests of the performance based fatigue parameters	Beams from the field tested in flexural fatigue test	Beams from the field tested in flexural fatigue test	
Method to conduct Quality control tests of the stiffness properties	Shear of Flexural tests on cores or beams from the field	Flexural Stiffness correlated to Uniaxial Stiffness	

CORRELATION'S BETWEEN MODELED AND OBSERVED PERFORMANCE

The quality of the selection of specimen preparation, test method and model used to predict distress can be evaluated by the correlation's obtained between predicted and measured performance. Below some examples have been taken from selected literature:

Data from SHRP

An investigation of the relationship between cycles in RSST-CH and ESALs was carried out for pavements less than 10 years old (14). A very clear trend was observed with very little variability as shown in Figure 10.

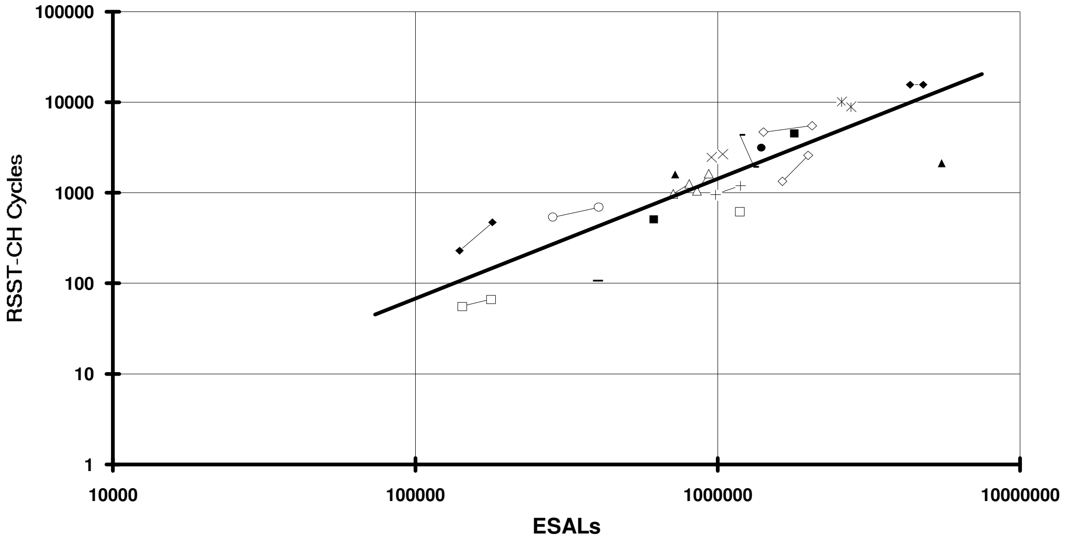

Figure 10 - Variation of the Number of Cycles in RSST-CH to the Field Permanent Shear Strain with ESAL's for the Sections that did not Exhibit Significant Aging.

Data from ADOT

The Arizona Department of Transportation in cooperation with the Federal Highway Administration and private industry designed and built numerous experimental paving projects from 1993 through 2001. Projects were built in a variety of different Arizona climatic zones representing hot desert climates and cold snowfall mountainous regions. Traffic truck loading levels also varied from state highways to major Interstate freeways.

The purpose of all of these projects is to use new laboratory tests developed as part of the SHRP and the Superpave Models to characterize cracking and rutting of various hot mix asphalt types. The fatigue cracking test is the four point bending beam test. The rutting test is the repetitive simple shear test at constant height and the triaxial creep test.

As a result of this early experimental work, the ADOT adopted the SHRP asphalt grading system in 1997 for all paving projects. SHRP consensus aggregate properties with regard to a greater degree of crushed coarse and fine particles and the fine aggregate angularity were also adopted in 1997. Asphalt rubber open graded friction courses and gap graded mixes continue to be used to compliment the structural HMA layers as the final wearing surface.

From 1993 to the present hundreds of laboratory tests have been conducted to predict the rutting and fatigue cracking potential of Arizona asphalt mixes. The RSST-CH rutting tests were performed on disk type specimens of 50 mm height, 150 mm in diameter. Tests were conducted at the anticipated high pavement temperature in the field typically 64 to 70°C. By using the analysis method derived by Sousa the resultant shear strain behavior could be approximated into a future rut depth as a function of the number of ESAL's. Virtually all of the mixes tested representing the 33 test sections indicated that no more than ten mm of rutting would occur over the ten year period with exception of one project where more than 10 mm rut depth was predicted.

Figure 11 compares the rut depths predicted and observed over the last eight years for all mixes and test sections, which amounts to 201 data points. The data points reflect three types of compaction, gyratory, rolling wheel and cores compacted with a steel wheel during construction. For the most part there is good agreement between the predicted and observed rutting for cores and rolling wheel specimens. With the exception of the one project it appears there is a good chance that all the other test sections will comply with the design rutting criteria.

The one failing short test section (one kilometer in length) was built to observe whether the predicted rutting failure would occur and it indeed did occur. This failing test section was removed and replaced at the sixth year of its life. Similar test sections and various mixes are being evaluated using the new triaxial simple performance test for rutting. Results of that research will also be compared with future field performance (15,16).

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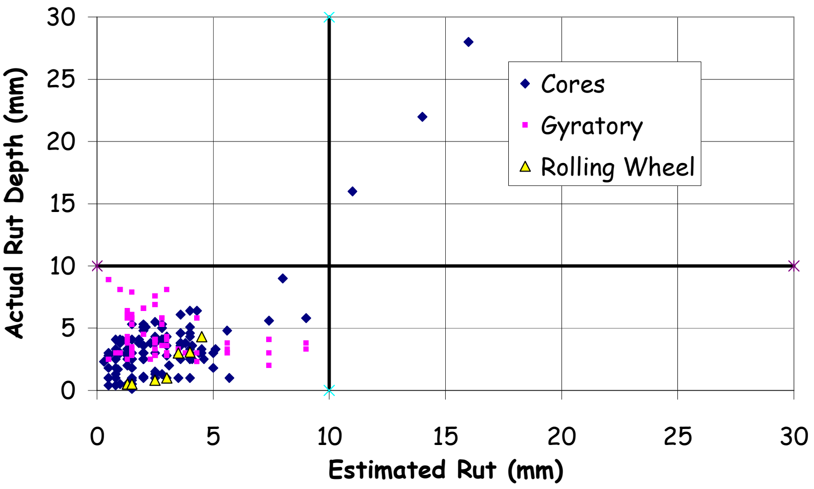

Figure 11 – Comparison Between Actual and Predicted Rut Depth from RSST-CH Data.

The test section data was further segregated into the mix types and the predicted and observed rutting for the sixth year of observed performance was plotted and shown on Figure 12. This figure further illustrates how the measured RSST-CH generally agreed well with the performance for the various mixes.

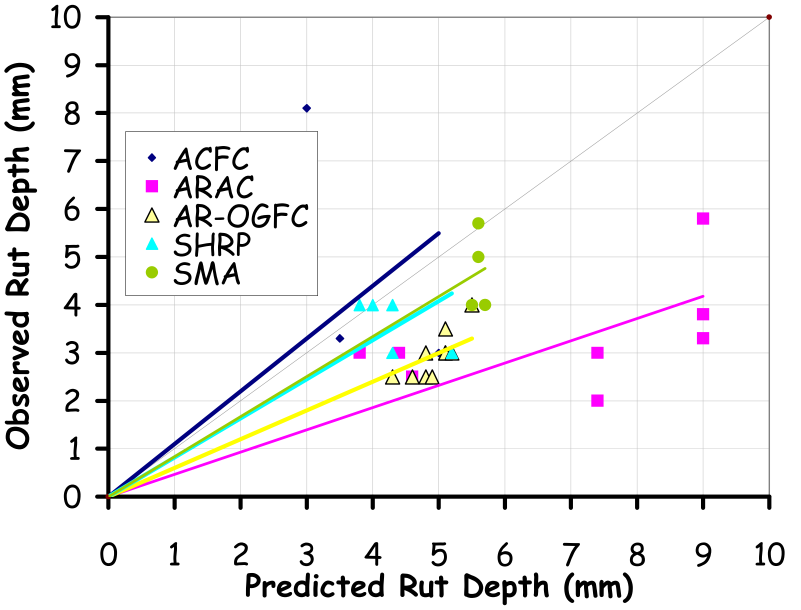

Figure 12 – Rut Depth Predicted vs Observed for the 6th year.

Data from NCHRP

The constitutive relationship used in the 2002 Design Guide for permanent deformation is based upon the statistical analysis of laboratory repeated load permanent deformation tests.

While statistical relationships used for asphalt mixtures are reasonable, a field adjustment factor is necessary. Such factors can be determined from the calibration-validation of LTTP data. Work conducted under NCHRP 9-19 Project has yielded several AC mixture data undergoing repeated load permanent deformation testing. The mixtures, temperatures, and stress levels investigated covered a wide data range of the variables introduced in the statistical modeling.

The permanent deformation developed by Kaloush used the original Leahy data in combination with the NCHRP Project test results (17,18). This resulted in a total database of 3500 permanent strain data points being used in the regression analysis.

This model for permanent deformation is incorporated in the 2002 Design Guide to provide the plastic strain under specific pavement conditions for a total number of load repetitions. Seasonal variations are also considered in the analysis because conditions vary from one season to another (e.g., temperature, resilient strain, moisture). Permanent deformation is estimated for each layer and at each computational location, using pavement responses calculated through elastic layer analysis at the mid-depth of each sub layer.
Computations of permanent deformations are done at locations defined by the analysis module for regular traffic. Alternatively, for special wheel configurations, the user is allowed to select the location points of interest for evaluation. In the ensuing models described, equivalent number of load cycles for each sub-season is found by solving the

permanent deformation model for N with the accumulated deformation up to the sub-season and material properties and load conditions prevailing in the given sub-season.

Figure 13 shows an example of the correlations obtained between observed and predicted rut depth for the calibrated permanent deformation model based on LTPP data.

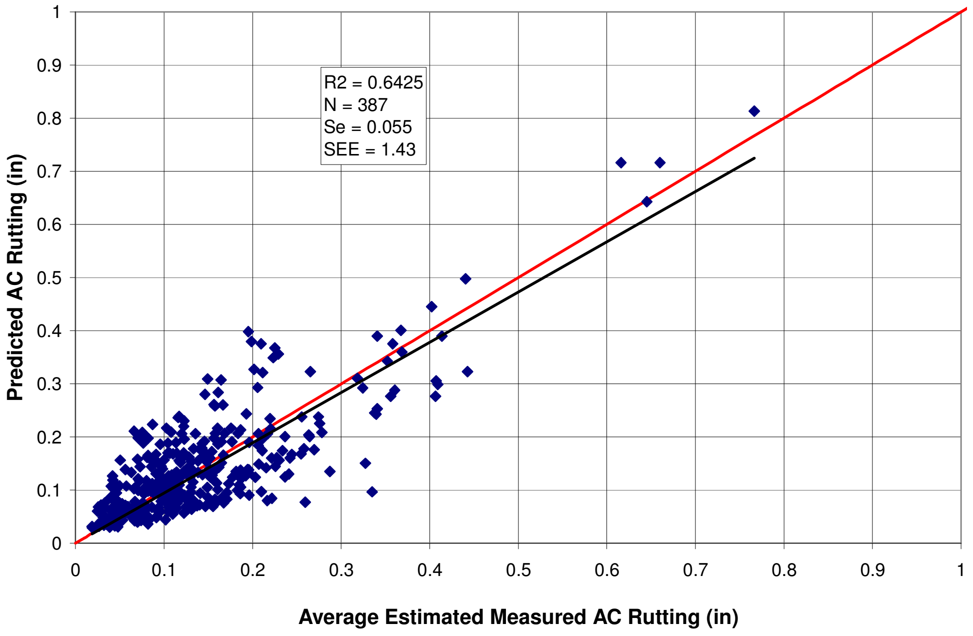

Figure 13 – Comparison Between Predicted and Measured Rutting.

To characterize the fatigue in asphalt layer, numerous model forms can be found in the existing literature. The most commonly used model form to predict the number of load repetitions to fatigue cracking is a function of the tensile strain and mix stiffness (modulus). The critical locations may either be at the surface and result in top-down cracking or at the bottom of the asphaltic layer and result in bottom-up cracking.

With the current state of knowledge, several fatigue relationships were developed in the past. Most of relationships available have a common basic structure and are function of the stiffness of the mix and the tensile strain. Based on that information, specific knowledge of many sites and the use of a finite element approach predictions where made and compared with actual observed data.

Figure 14 shows an example of the correlations obtained between observed and predicted fatigue cracking based on LTPP data.

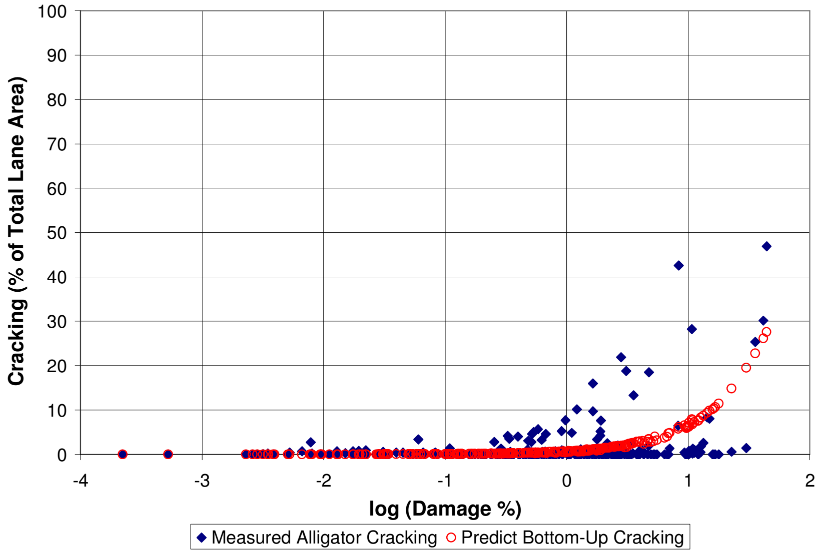

Figure 14 - Comparison Between Predicted and Measured Percent Fatigue Cracking.

Data from RPA

The Rubber Pavements Association (RPA) in 1999 promoted the development of an mechanistic overlay design method for reflective cracking (19). Reflective cracking is cracking that occurs in a hot mix asphalt (HMA) overlay after it has been applied to an existing cracked paved surface. RPA's interest in sponsoring this research effort was based upon the long-standing observation that asphalt rubber (AR) hot mixes appear to reduce the occurrence of reflective cracking. A need to develop a mechanistic approach to the design of AR-HMA and conventional HMA overlays was felt which could be of help to them in their future use of the mechanistically based 2002 AASHTO Pavement Design Guide.

The research project first involved the development of a model based on the Finite Element Method (FEM). The FEM approach was selected since it appeared to be the most sensible way to address the unusual stress and strain contours generated by a heavy wheel load moving over or near a crack. To calibrate the FEM-modeled crack movements, actual field measurements with a Crack Activity Meter (CAM) and a Falling Weight Deflectometer (FWD) were both conducted, in Portugal, Arizona and California. The majority of the field testing was conducted on cracked highway pavements in Arizona. Beams of were tested with the four-point bending beam fatigue test developed during SHRP. Results of these tests indicated that beam fatigue test measurements could be used to derive the necessary input parameters to the FEM model. With this knowledge, it was now possible to determine which parameters best fit the FEM reflective cracking statistical simulation as a function of heavy truck traffic. The model predicts how many heavy wheel loads and their attendant stresses and strains are needed to initiate and propagate a reflective crack.

To convert this mathematical statistical model into a practical pavement design method for reflective cracking, it was necessary to review considerable actual field cracking data and material layer properties. From these data, the estimated traffic to cause reflective cracking was calculated from the layer thicknesses and layer moduli in a variety of pavements. These calculated numbers were compared to both the actual (observed) number of equivalent axle loads and the (observed) percent cracking. A very novel relationship was derived, which indicates that as long as the ratio between the estimated and actual traffic to cause reflective cracking stays below one, no cracking will occur. For ratios above one, different levels of percent cracking are calculated and observed. Aging and temperature adjustment factors were also a novel adjunct to this new approach.

The final product of this research is a spreadsheet where the pavement design engineer inputs the expected design level of cracking, the thicknesses of the layers, and their elastic moduli. The moduli may be back calculated or determined in any reasonable manner, as long as they represent the *in situ* conditions in the field. The resultant curves, one for the PG 70-10 HMA-DG and one for the AR-HMA-GG mix, estimate the thickness of an overlay for the specified level of reflective cracking, over a wide range of truck traffic loadings. To-date, the proposed method mainly applies to these two mix types, for climatic conditions similar to those encountered in the (mainly) desert southwest.

With additional research, other overlay design curves can be developed for other mixes, other climates, and other field-observed historical reflective cracking levels. This research describes the development of a mechanistic reflective cracking model based upon a FEM approach that can also be used for other materials and climates.

This research project successfully developed a mechanistic empirical method to design hot mix asphalt overlays to resist reflective cracking based on the results of four point bending tests and specific reflective cracking models developed during the research sponsored by RPA. The specific design method was calibrated and is applicable for dense grade asphalt hot mixes and gap grade asphalt rubber hot mixes used in Arizona. It probably can also be applied to Southern California and Western Texas.

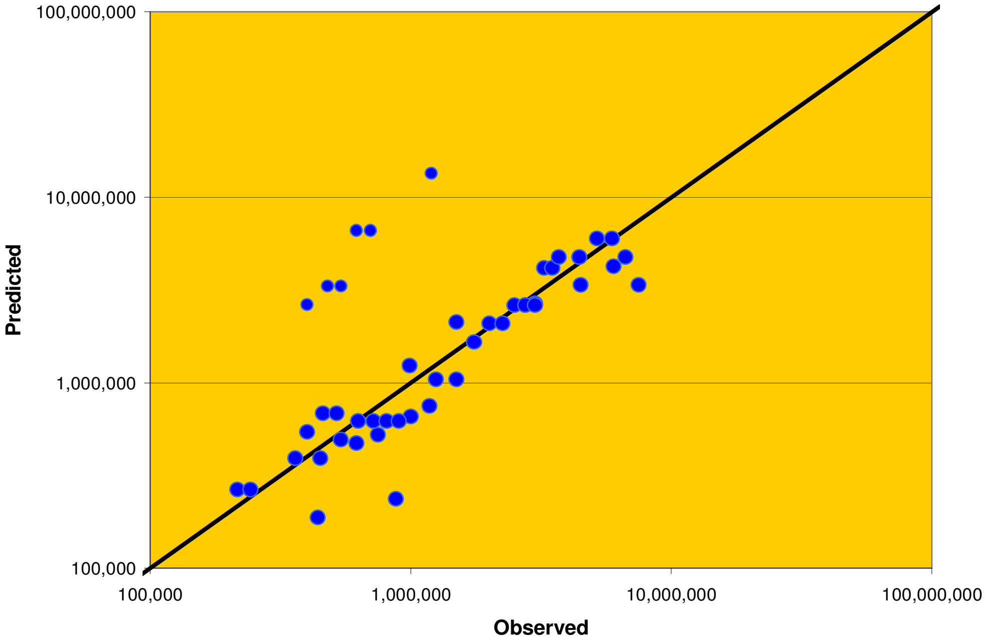

Figure 15 – Comparison Between Modeled and Predicted Number of ESALs to the Reported Crack Level for all Pavement Sections in the Database (Conventional and Asphalt Rubber).

OTHER VALIDATIONS OF EFFECTIVE OF PERFORMANCE TESTS

The validation of the applicability of the performance tests and relevant modeling may be also inferred by many other studies in which comparison between material properties of mixes with know observed performance corroborate the ranking in the laboratory results.

Data from ASU, Figure 16, shows a comparison of the different AR and Conventional mixtures (4, 20). The fatigue models developed for the mixtures have good to excellent measures of accuracy. The comparison in the figure is made at 50% reduction of initial stiffness for each mix. The relationships are rational in that higher binder content mixes yielded higher fatigue life despite the air void content variations between the mixtures. It is also noted that the asphalt rubber mixture would result in higher fatigue life than the conventional mix. The Arizona AR-ACFC and the Alberta AR mix have similar relationship and they would result in approximately 30 times longer fatigue life compared to the SRB PG76-16 mixture. The Arizona ARAC mix has lower performance than the other two asphalt rubber mixtures, but still would result in approximately 10 times longer fatigue life than the Arizona conventional mix.

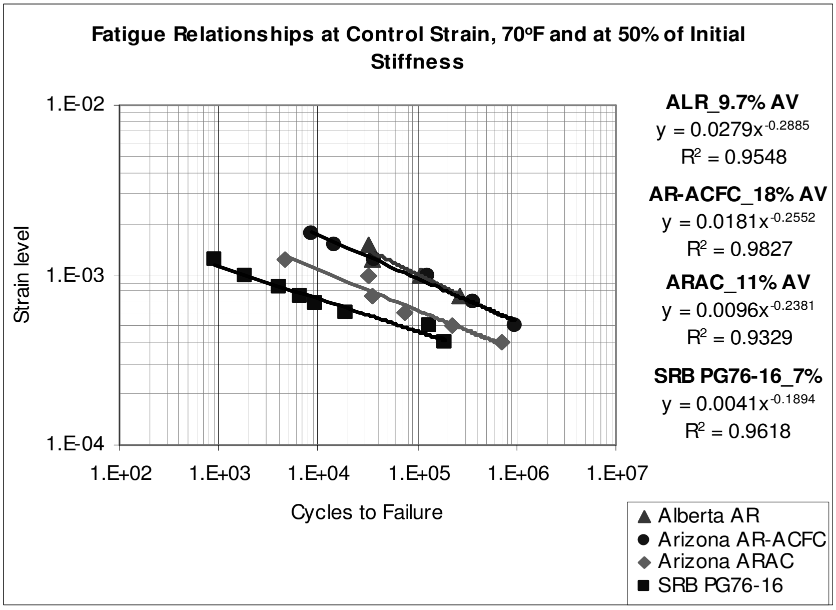

Figure 16. Controlled Strain Fatigue Relationships

The Asphalt Rubber E* responses followed a logical trend when air voids variation were compared. That is, a mix with 5% air voids content had a stiffer behavior than a mixture with 8% air voids. Similarly, AR mix with a PG 58-22 stock binder had a softer behavior than an AR mix using a PG 64-16 stock binder.

A great difference in Dynamic Modulus (E*) response was found when specimens were tested at unconfined and confined conditions, especially when the unconfined response was low (soft). Increments in E* values up to 400% were found at high temperature conditions and low frequency values. This is shown in Figure 17, where typical master curves for a Gap Graded mixture tested unconfined and at three levels of confinement: 69, 138, and 207 kPa (10, 20, and 30 psi) are shown.

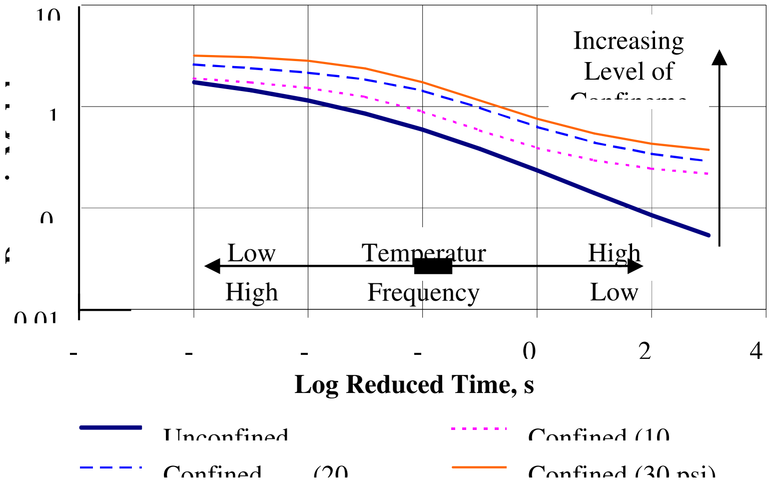

Figure 17. Comparison of E* Master Curves for the ARAC Gap Graded Mixture

An interesting observation was that for several of the replicates, the AR mixes showed similar response at high temperature conditions. That is, the E* values at 70, 100, and 130°F were quite similar. It was surmised that the insignificant changes in the AR E* values were due to the dominating effect of the crumb rubber at these higher temperatures in comparison to the role of the binder in the mix.

When compared to conventional mixtures, the Asphalt Rubber mixes were generally softer at unconfined conditions. However, when confined E* tests results were compared, it was found that the AR mixes had better response. Tables 2a and 2b rank various mixtures tested under similar conditions using a Modular Ratio. In these tables, mixes from NCHRP 9-19 test sections are also included (MnRoad, ALF, and WesTrack).

Table 2a shows that the unconfined E* test, at high temperature conditions, is not ranking the mixtures rationally according to their observed field performance. In the field, the Arizona AR mixes have shown strong resistance against rutting (permanent deformation). The unconfined tests are yielding, in general, lower E* responses when compared with conventional mixtures. When confined tests were used for the comparison (Table 2b), the AR mixes showed stiffer behavior than any other mix, and ranked higher than the stiffest conventional mixes.

Table 2. Summary of the Modular Ratio @ 100°F / 10 Hz for AR and Control Mixes

(a) Unconfined Condition

Mix ID	**Binder Type**	**AC %**	**Va %**	**Nom. Aggreg.**	**E***	**R**	**Rank**
I-17 PG 64-16	64-16 (R)	8.9	5.5	19.0-mm GG	490	4.02	1
WesTrack Section R4	64-22	5.3	6.6	19.0-mm FDGM	409	3.35	2
WesTrack Section R23	64-22	5.8	4.9	19.0-mm CDGM	327	2.68	3
I-17 PG 58-22	58-22 (R)	7.5	8.0	19.0-00 GG	296	2.43	4
ALF Lane 8	Novophalt	4.7	11.9	19.0-mm DGM	267	2.19	5
ALF Lane 12	AC-20	4.1	7.4	37.5-mm DGM	215	1.76	6
ADOT Conventional[1]	64-22	4.1	10.5	19.0-mm DGM	122	1.00	7
MnRoad Section 20	PEN 120/150	6.1	6.3	12.5-mm DGM	115	0.94	8
Alberta Rubber	Pen 150-200 (R)	8.9	9.7	19.0-mm GG	111	0.91	9
ARAC	58-22 (R)	6.8	10.9	19.0-mm GG	107	0.88	10
AR-ACFC	58-22 (R)	8.8	17.6	9.0-mm OG	101	0.83	11

(b) Confined Condition

Mix ID	**Binder Type**	**AC %**	**Va %**	**Nom. Aggreg.**	**E***	**R**	**Rank**
I-17 PG 64-16	64-16 (R)	8.9	5.5	19.0-mm GG	934	1.08	1
AR-ACFC	58-22 (R)	8.8	17.6	9.0-mm OG	875	1.02	2
ARAC[1]	58-22 (R)	6.8	10.9	19.0-mm GG	862	1.00	3
WesTrack Section R4	64-22	5.2	6.6	19.0-mm FDGM	812	0.94	4
I-17 PG 58-22	58-22 (R)	7.5	8.0	19.0-mm GG	746	0.87	5
ALF Lane 12	AC-20	4.1	7.4	37.5-mm DGM	664	0.77	6
Alberta Rubber	Pen 150-200 (R)	8.9	9.7	19.0-mm GG	579	0.67	7
WesTrack Section R23	64-22	5.8	4.9	19.0-mm CDGM	518	0.60	8
ALF Lane 8	Novophalt	4.8	7.7	19.0-mm DGM	314	0.36	9

Where: OG = Open Graded Mixture
DGM = Dense Graded Mixture
FDGM = Fine DGM

GG = Gap Graded Mixture
CGDM = Coarse DGM

[1] Reference Mix

Results from flexural fatigues tests executed in dense and mixes with conventional binders (DGAC, PG70-10) and mixes with asphalt rubber (ARC as Arizona Method and AR4000 with California asphalt rubber) have shown that flexural fatigue life can be as much as 50 times greater (21).

Such remarkable differences have been able to justify the use of extremely thin overlays of asphalt rubber (25mm thick) over slabs of Portland cement concrete in Arizona highways.

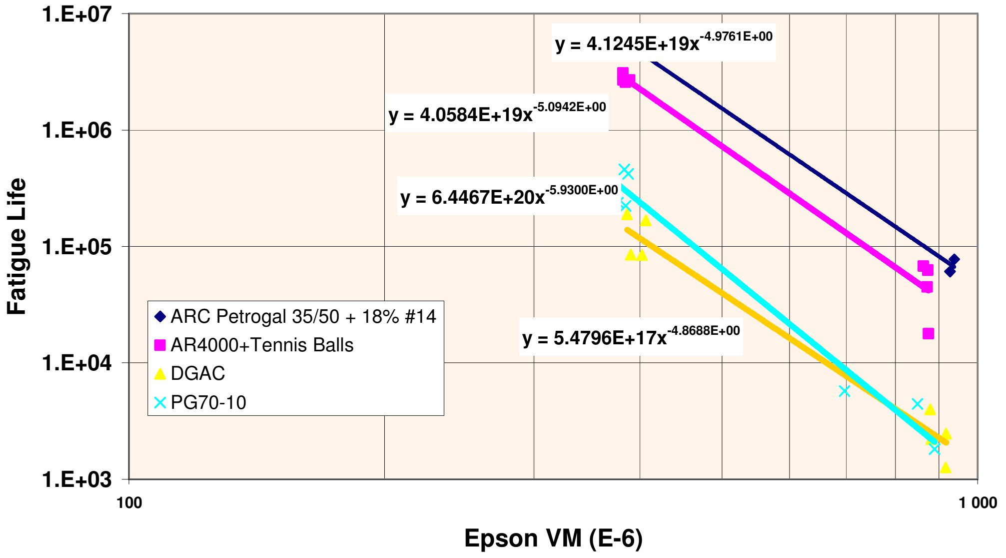

Figure 18 - Flexural Fatigue Life Function of EVM (Deviatoric Component of Strain Tensor).

CONCLUSIONS

This paper presented a brief summary of some concepts used to develop performance related tests during the last 12 years within SHRP and NCHRP research efforts. Some positives steps have been done towards the characterization of tests, methods and methodologies to evaluate and predict some of pavement distress. The concept of using different test methods to determine key parameters in different models appeared to be effective in predicting pavement performance. Nevertheless, some aspects of specimen conditioning such as long term aging and moisture damage appear to need further development. Furthermore, it appears unlikely that all key aspects of mix behavior and pavement performance can be inferred or measured from one single “simple” performance test.

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