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# Assessment of the Extended Fatigue Life for Rubber and Polymer Modified Asphalt Mixtures Using Flexural Bending Beam Fatigue Test

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## ABSTRACT

Load associated fatigue cracking is one of the major distress types occurring in flexible pavement systems. Flexural bending beam fatigue laboratory test has been used for several decades and is considered to be an integral part of the new superpave advanced characterization procedure. One of the most significant solutions to prolong the fatigue life for an asphaltic mixture is to utilize flexible materials as rubber or polymer fibers. A laboratory testing program was performed at Arizona State University (ASU) on a reference, Asphalt Rubber (AR) and polymer modified gap graded mixtures. Strain controlled fatigue tests were conducted according to American Association of State Highway and Transportation Officials (AASHTO) procedures. Using COANOVA statistical analysis approach, the results from the beam fatigue tests indicated that the AR and polymer modified gap graded mixtures would have much longer fatigue life compared with the reference (conventional) mixtures.

**KEYWORDS:** Pavement design, Hot mix asphalt, Fatigue, Asphalt rubber, Polymer fibers.

## INTRODUCTION

The flexural fatigue test is used to characterize the fatigue life of Hot Mix Asphalt (HMA) at intermediate pavement operating temperatures. This characterization is useful, since it provides estimates of HMA pavement layer fatigue life under repeated traffic loading. In a well designed pavement, strains in the pavement are low enough, so that fatigue is not a problem. However, when pavements are under-designed, strains are sufficiently high to cause fatigue failures under repeated loads. These failures ultimately result in fatigue cracking which will cause disintegration of the pavement if not maintained in time. A potential solution of this problem can be resolved by extending the fatigue life of HMA mixtures by introducing some additives that will make HMA more flexible. Several previous studies recommended using rubber and polymer fibers to improve the fatigue life of HMA.

The basic flexural fatigue test subjects an HMA beam to repeated flexural bending in a controlled atmosphere. In order to relate laboratory results to normally observed field performance, a shift factor of 10 to 20 is typically needed. Because of the testing equipment complexity and long testing times, the flexural fatigue test is primarily a research test and is not a standard test in superpave mix design or quality assurance testing.

The standard beam fatigue procedure is found in: AASHTO T 321: Determining the Fatigue Life of Compacted Hot-Mix Asphalt (HMA) Subjected to

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Repeated Flexural Bending (AASHTO, 2003). The flexural fatigue test has been used by various researchers to evaluate the fatigue performance of pavements (SHRP-A-404, 1994; Harvey and Monismith, 1993; Tayebali et al., 1995; Witczak et al., 2001).

## STUDY OBJECTIVE

The primary objective of this study was to evaluate the extension of the fatigue life by adding rubber or polymer fibers to the conventional Hot Mix Asphalt (HMA) mixtures. To accomplish this objective, a laboratory testing program was performed on a project that included three types of mixtures: reference, polymer modified and Asphalt Rubber (AR) modified gap graded mixes.

## BACKGROUND

In HMA pavements, fatigue cracking occurs when repeated traffic loads ultimately cause sufficient damage in a flexible pavement to result in fatigue cracking. A number of factors can influence a pavement's ability to withstand fatigue, including pavement structure. Thin pavements or those that do not have strong underlying layers are more likely to show fatigue cracking than thicker pavements or those with a strong support structure. The age of the pavement and the materials used in construction are also influential factors. The flexural fatigue test is used to investigate fatigue as it relates to HMA construction materials.

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). The basic structure for almost every fatigue model developed and presented in the literature for fatigue characterization is of the following form (AASHTO, 2003):

$$N_f = K_1\left(\frac{1}{\varepsilon_t}\right)^{k_2}\left(\frac{1}{E}\right)^{k_3} \qquad (1)$$

where:

$N_f$ = number of repetitions to fatigue cracking;

$\varepsilon_t$ = tensile strain at the critical location;

E = stiffness of the material;

$K_1$, $K_2$ and $K_3$=laboratory calibration parameters.

## TEST RESULTS AND ANALYSIS

### Mixtures' Characteristics

In 2008, a first cooperative effort between ASU and the Swedish Road Administration (SRA) took place in testing a reference and asphalt rubber gap graded mixtures placed on Malmo E6 External Ring Road in Sweden. In 2009, SRA and ASU undertook another joint effort to test three types of gap graded mixtures: reference, polymer-modified and rubber-modified mixtures, placed on E18 highway between the interchanges Järva-Krog and Bergshamra in the Stockholm area of Sweden.

Rice specific gravities for the mixtures were determined. Beam specimens were prepared according to the Strategic Highway Research Program (SHRP) and the American Association of State Highway and Transportation Officials (AASHTO): SHRP M-009 and AASHTO T321-03 (AASHTO, 2003). 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.

The designated road section within the construction project had three asphalt mixtures: a reference gap graded mix (designation: ABS 16 70/100) used as a control, a polymer modified mixture (designation: ABS 16 Nypol 50/100-75) and a rubber modified mixture (designation: GAP 16) that contained approximately 20 percent ground tire rubber (crumb rubber). Figure 1 displays the road in Stockholm area where the three mixtures were placed.

The Swedish Road Administration (SRA) provided information stating that the field compaction/air voids for the three mixtures was around 3.0%. The original mix designs were done using the Marshall Mix design method. The *in-situ* mixture properties of the Stockholm pavement test sections are reported in Table 1, which includes % binder contents by mass of the mixes, Marshall Percent void contents by volume of the mixes and maximum theoretical specific gravity values of the mixes estimated at ASU laboratories. Table 2 shows the reported average aggregate gradations for the mixtures. The base bitumen used was Pen 70/100. The polymer bitumen was designated Nypol 50/100-75 and rubber was GAP 16.

**Figure 1: Test sections in fast lanes on E18 highway between the Järva-Krog and Bergshamra interchanges**

**Table 1: Mixture characteristics, Stockholm highway**

| Mix | Binder Content (%) | Air Voids (%) | Gmm |
|---|---|---|---|
| Reference ABS 16 70/100 | 5.9 | 2.6 | 2.4642 |
| Polymer ABS 16 Nypol 50/100-75 | 5.9 | 2.6 | 2.4558 |
| Rubber GAP 16 | 8.7 | 2.4 | 2.3588 |

### Determination of $K_1$ and $K_2$ Coefficients at Each Temperature

It has been accepted for many years that the fatigue behavior of asphalt-aggregate mixes can be characterized by a relationship of the form:

$$N_f = K_1 \left(1 / \in_o\right)^{K_2} \quad (2)$$

where:

$\varepsilon_o$ = initial tensile strain;

$K_1$ and $K_2$ = experimentally determined coefficients.

The above-stated relationship is applicable to a given asphalt mix. Moreover, the fatigue relationship (flexural strain *versus* the number of loading cycles) for each mixture is shown in Figure 2, which illustrates determining $K_1$ and $K_2$ values for all three mixes using "50% of the initial stiffness" method to determine $N_f$ . The relationships obtained have good measures of model accuracy as indicated by the coefficient of determination ($R^2$). Comparing fatigue curves for different mixes is not straightforward, because of the different mixes' moduli. A look at the fatigue model coefficients may provide some guidance. Therefore, the below comparisons are made in general terms.

A summary of the regression equations is shown in Table 3. The $R^2$ values are an indication of good to very good model accuracy. The relationships obtained are rational in that lower fatigue life (number of repetitions) is obtained as temperature decreases.

**Table 2: Average aggregate gradations, Stockholm highway**

| | **Sieve Size (mm)** | **Reference** | **Polymer** | **Rubber** |
|---|---|---|---|---|
| **Gradation (% passing by mass of each sieve)** | 22.4 | 100 | 100 | 100 |
| | 16 | 98 | 98 | 98 |
| | 11.2 | 65 | 65 | 68 |
| | 8 | 38 | 38 | 44 |
| | 4 | 23 | 23 | 24 |
| | 2 | 21 | 21 | 22 |
| | 0.063 | 10.5 | 10.5 | 7.5 |

**Table 3: Summary of regression coefficients for the fatigue relationships for 70 °F using different approaches to find $N_f$**

| **$N_f$ determination method** | **Reference mix** | | | **AR mix** | | | **Polymer mix** | | |
|---|---|---|---|---|---|---|---|---|---|
| | $K_1$ | $K_2$ | $R^2$ | $K_1$ | $K_2$ | $R^2$ | $K_1$ | $K_2$ | $R^2$ |
| 50% of the initial stiffness | 5E-10 | 4.17 | 0.946 | 1E-09 | 4.17 | 0.984 | 2E-09 | 4.16 | 0.961 |

**COANOVA Statistical Analysis of the Equality of the Fatigue Life for Different Mixtures**

In order to determine whether modifying the conventional mix by adding rubber or polymer made a significant improvement in the fatigue life performance or not, the COANOVA statistical approach introduced by Neter et al. (1974) and Motulsky et al. (2003) was utilized. The detailed procedure is explained as follows:

1. Hypothesis; Ho: two mixture types produced similar fatigue lives.

   Ha: two mixtures produce different fatigue lives.
2. Fit the full, or unrestricted model to get the error sum of squares SSE(F)=SSE1 + SSE2, where SSE1 is the error sum of squares for regression method 1 and SSE2 is the error sum of squares for regression method 2; and the total degrees of freedom df(F)=df1+df2.
3. Fit the reduced or restricted model (combine each data set into one big data set) under the Ho hypothesis that all mixture types produced similar fatigue life, and obtain the error sum of squares SSE(R) and degrees of freedom df(R) for the reduced model.
4. Calculate the F* statistic using the equation:

$$F^* = \frac{SSE(R) - SSE(F)}{df(R) - df(F)} \div \frac{SSE(F)}{df(F)} \qquad (3)$$

5. Obtain the p-value by using EXCEL internal function of F probability distribution for the two data sets (FDIST):

$$P - value = FDIST\,(F^*, df_a, df_b) \qquad (4)$$

where: dfa=df(R)-df(F) and dfb=df(F).

6. Reject Ho if p-value <= α to conclude that each mixture has a different fatigue life. Otherwise, Ho hypothesis that the mixtures have the same fatigue life is to be accepted.

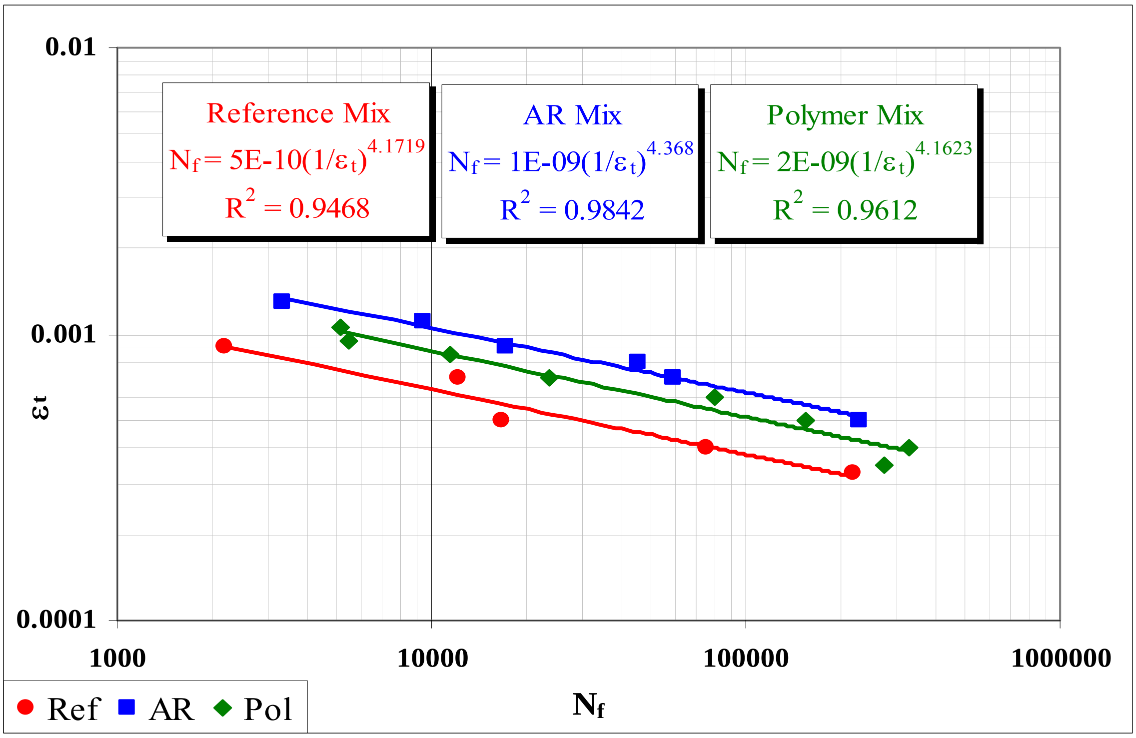

**Figure 2: Comparison between all Swedish mixes at 70°F using Nf at 50% of the initial stiffness**

The p-value is the level of significance, which is defined as the probability of obtaining a value of the test statistic that is as likely or more likely to reject Ho as the actual observed value of the test statistic. This probability is computed assuming that the null hypothesis is true. Thus, if the level of significance (p-value) is a small value, then the sample data fail to support Ho and our decision is to reject Ho (Baburamani and Porter, 1996). To determine the rejection region, the value of type I error, α, should be pre-set based on research requirements and sample size. A traditional α-value of 0.05 can be used when the sample size is not very large.

In this case, two strain level-Nf lines that arrive from two different fatigue analysis methods were used. For example in Table 4, the comparison between conventional and polymer mixtures, regressed through power law, produced SSE (F) =SSE1 + SSE2 = 0.1943. For the combined regression curve from both mixtures, SSE(R) = 1.3147. The calculated F* = 63.444 with dfa = 1 and dfb= 11. Therefore, p-value = 0.000. Because p-value is much less than α=0.05, we conclude that the two mixture types are statistically different.

Figure 2 shows a comparison in the fatigue life between the three Swedish mixes at the same temperature (70°F). The AR mix had the highest fatigue life, while the reference mix had the lowest fatigue life.

## SUMMARY AND CONCLUSIONS

Constant strain flexural tests were performed according to the AASHTO T321-2003 and SHRP M-009 procedures to evaluate the fatigue performance of the reference, polymer and AR Swedish mixtures.

**Table 4: Comparison between all the Swedish mixes**

| Comparison | SEE(F) | SEE(R ) | df(F) | df(R ) | F* | df(a) | df(b) | P-value | Fcrit @ $\alpha$=0.05 | Decision |
|---|---|---|---|---|---|---|---|---|---|---|
| Ref. vs pol. | 0.1943 | 1.3147 | 11 | 12 | 63.444 | 1 | 11 | 0.0000 | 4.84 | Different |
| Ref. vs AR | 0.4723 | 3.1729 | 9 | 10 | 51.465 | 1 | 9 | 0.0001 | 5.12 | Different |
| Pol. vs AR | 0.5946 | 1.3613 | 12 | 13 | 15.472 | 1 | 12 | 0.0020 | 4.75 | Different |

The fatigue models developed for the mixtures in this study had excellent measures of accuracy and were rational in that lower fatigue life was obtained as the test temperature decreased.

Using COANOVA statistical analysis approach, the AR mix showed higher fatigue life than polymer and the reference mixtures. The comparison was done at 70°F. The AR mix resulted in approximately a 27 times greater fatigue life than the polymer mix. In addition, the AR mix resulted in about 91 times greater fatigue life than the reference mix. The fatigue properties of the asphalt mixtures presented in this work demonstrate that adding rubber or polymer fibers to HMA may have significant bearing on the ultimate performance of the mixture in the field under repetitive traffic. Although typically not a widely observed distress for military airfields, fatigue damage nevertheless occurs and should be minimized, especially for airfields critical to mobilization.

## REFERENCES

AASHTO Designation: T321-03. 2003 Determining the Fatigue Life of Compacted Hot- Mix Asphalt (HMA) Subjected to Repeated Flexural Bending.

Baburamani, P. S. and Porter, D. W. 1996. Dissipated Energy Approach to Fatigue Characterization of Asphalt Mixes. Proceedings combined 18th ARRB TR Conference Transit New Zealand Symposium, 327-347.

Harvey, J. and Monismith, C.L. 1993. Effect of Laboratory Asphalt Concrete Specimen Preparation Variables on Fatigue and Permanent Deformation Test Results Using Strategic Highway Research Program A-003A Proposed Testing Equipment, Record 1417, Transportation Research Board, Washington, D.C.

Motulsky, H. and Christopoulos, A. 2003. Fitting Models to Biological Data Using Linear and Nonlinear Regression, A Practical Guide to Curve Fitting. GraphPad Software Inc., San Diego, CA.

Neter, John and Wasserman, William. 1974. Applied Linear Statistical Models, Regression, Analysis of Variance and Experimental Design. Homewood, Illinois.

SHRP-A-404. 1994. Fatigue Response of Asphalt-Aggregate Mixes. Asphalt Research Program. Institute of Transportation Studies, University of California, Berkeley. Strategic Highway Research Program, National Research Council, Washington, D.C.

Tayebali, A.A., Deacon, J.A. and 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.

Witczak, M.W., Mamlouk, M. and 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.