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Application of Asphalt Rubber on New Highway Pavement Construction

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Asphalt rubber has been used for many years as a stress-absorbing membrane (SAM) or stress-absorbing membrane interlayer (SAMI) for both rigid and flexible pavement overlay systems in Arizona with satisfactory performance. In 1977, a new experimental application of asphalt rubber was used to build a low-volume highway pavement between Dewey and I-17 on AZ-169. Several experimental pavement sections were placed. After four years of service, only two sections are still in excellent condition with no cracks or ruts observed to date. One section consisted of a cement-treated base and the other a lime-fly ash-treated base. Each section received a SAMI and a 1-in wearing course. Other test sections failed, and constant patching is required to maintain a minimal level of service. Generally, cement-treated bases will always have shrinkage cracks that easily reflect through any asphalt concrete surface layer if without special treatment to retard crack propagation. A finite-element procedure was used as an aid in explaining why a SAMI can be used effectively to eliminate reflective cracks. It was found that SAMIs can significantly reduce crack tip stresses due to thermal and traffic loads and provide longer service life of the asphalt concrete surface layer.

In the early 1960s, asphalt rubber was originally used as a patching material for alligator-cracking-type failures in Arizona (1,2). Later it was developed as a stress-absorbing membrane (SAM) and stress-absorbing membrane interlayer (SAMI) for rehabilitation and overlay of cracked pavements (3-7). Asphalt rubber has also been used as a joint and crack seal material and as a waterproof membrane for the control of expansive clay subgrades.

Coetzee and Monismith (8) investigated the effectiveness of a SAMI as an overlay system over rigid pavements by inducing thermal and symmetrical traffic loading across a crack. Results of this study concluded that a SAMI can reduce stresses in overlays and can also prolong the service life of a typical overlay.

Many field studies of SAM and SAMI have been undertaken by the Arizona Department of Transportation. In 1977, a new area for application of asphalt rubber was introduced in the construction of a low-volume road with a cement-treated base (CTB). This paper discusses this new asphalt-rubber application.

CONSTRUCTION AND PERFORMANCE

The Dewey project, as it is often referred to, is on AZ-169 between mileposts 4.8 and 14.5 and is located approximately 80 miles north of Phoenix. It was constructed as a new connecting highway between Dewey, Arizona, and I-17. Currently, the average daily traffic (ADT) is approximately 1000 with 6

percent trucks. The embankments and grades were constructed in 1976 and surfacing was placed in August 1977. This project consisted of five test sections and one control section.

The original pavement design (before it was decided to build test pavements) called for stage construction of 6 in of full-depth asphalt concrete with an open-graded asphalt concrete friction course (ACFC) on the compacted subgrade. Initial surfacing was 2 in and the remaining 4 in was designated for future surfacing.

Subgrade material is primarily decomposed granite, clayey sand, and gravel with a plasticity index ranging as high as 69. The average project elevation is approximately 4400 ft, and winter months are often severe.

The characteristics of the control section and the five test sections are as follows:

1. Control section, station 262-520: The subgrade was compacted to 100 percent of maximum density (36-ft width). Two inches of asphalt concrete were placed on the compacted subgrade. Asphalt concrete was made with an AR2000 asphalt.

2. Test section 1, station 520-555, Lime-Fly Ash-Treated Base: Three percent quicklime and 12.5 percent fly ash (by weight of subgrade material) were added to in-place subgrade soil and thoroughly mixed to a depth of 6 in and then compacted to 100 percent of maximum density. An asphalt-rubber membrane was placed across the entire roadway, shoulders, and cut ditches. A 1-in ACFC was placed as a wearing course.

3. Test section 2, station 555-590, CTB: Four and one-half percent (by weight of subgrade material) portland cement was added to the in-place subgrade soil. This was thoroughly mixed to a depth of 6 in and then compacted to 100 percent of maximum density. An asphalt-rubber membrane was placed across the entire roadway, shoulders, and cut ditches. A 1-in ACFC was placed as a wearing course.

4. Test section 3, stations 590-640 and 670-765: The subgrade was compacted to 100 percent of maximum density. Asphalt rubber then was placed across the entire roadway, shoulders, and cut ditches. A 1-in ACFC was placed as a wearing course.

5. Test section 4, station 640-670: Same treatment as test section 3 except that an asphalt-rubber membrane was placed 2 ft down into the subgrade.

6. Test section 5, station 765-780, AR1000, Enzymatic SS: The subgrade was compacted to 100 percent of maximum density by using Enzymatic SS, a compaction aid. Two inches of asphalt concrete were placed on the subgrade as a wearing course. AR1000 asphalt was used in the production of the asphalt concrete.

Test sections 1 and 2 and the lime-fly ash and cement-stabilized sections have served perfectly with no visible problems or defects whatsoever, as

Figure 1. Test section 1: lime-fly ash subgrade, SAMI, and 1-in ACFC.



Figure 2. Test section 2: CTB, SAMI, and 1-in ACFC.



Figure 3. Pavement core at station 540.



shown in Figures 1 and 2. Several pavement cores were taken from these test sections. A typical core is shown in Figure 3. All other test sections, as well as the control section, have experienced some degree of distress; performance of even the best of which has been judged unacceptable. Examples of these sections are shown in Figures 4 and 5. The control section and the other three test sections experienced numerous construction difficulties. The intent was to encapsulate the pavement subgrade to prevent moisture change and, thereby, rely on the inherent strength of a cohesive soil molded at optimum density and moisture content. These sections might have performed better if different construction procedures were followed. The asphalt-rubber membrane was placed directly on the compacted subgrade. During construction, asphalt concrete haul trucks were allowed to travel on the recently completed membrane and very often picked up the membrane. These areas were never patched. As a result, a complete, intact membrane seal was never achieved. During the first winter (which was very wet), it became apparent that these sections were doomed to failure. An asphalt-rubber membrane can be properly placed if construction procedures are controlled to prevent pickup of the membrane from the subgrade.

A great deal was learned from this test project. Although we know stabilized bases will crack, especially CTBs, both of these test sections (sections 1

Figure 4. Test section 3.



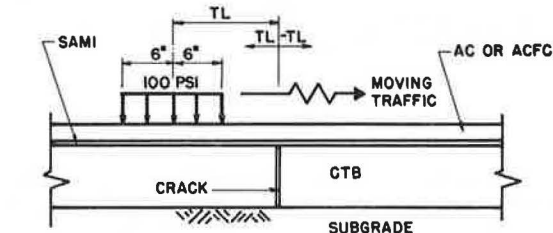
Figure 5. Test section 5.



Table 1. Range of pavement layer properties.

Item	Elastic Modulus, E (ksi)	Shear Modulus, G (ksi)	Poisson Ratio, μ	Thermal Coefficient, α (per °F)	Thickness, t (in)
Asphalt concrete or ACFC	100-500	40-200	0.3	0.000 012 5	1-4
SAMI	0.2-2.0	0.08-0.8	0.35	0.000 015	0.4
CTB	1000-4000	420-1680	0.2	0.000 003 9	6-10
Subgrade	10	4	0.48	0.000 01	40

Figure 6. General configuration of pavement structure with CTB and a crack.



LOADING CASE	A	B	C	D	E	F	G	H	I	H'	G'	F'	E'	D'	C'	B'	A'
TL (IN)	16	14	12	10	8	6	4	2	0	-2	-4	-6	-8	-10	-12	-14	-16

Figure 7. General input pavement temperature profile.

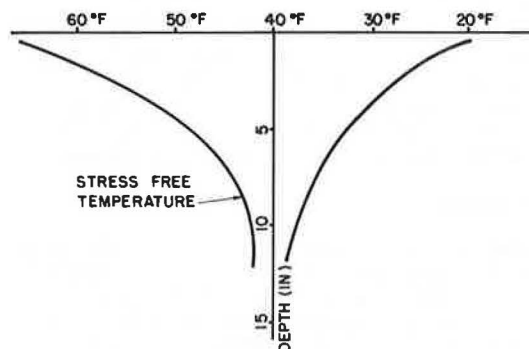
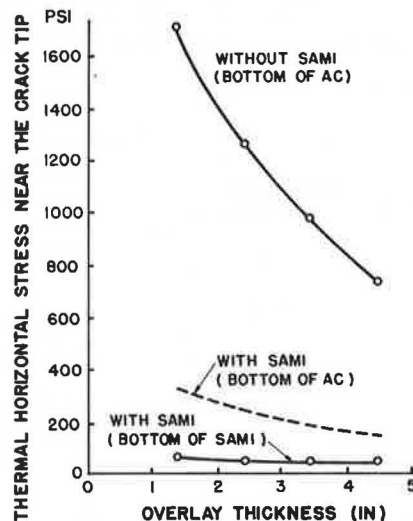


Figure 8. Effects of SAMI on thermal horizontal stress near crack tip.



and 2) remain crack-free after four years of service. The SAMI has effectively prevented transmission of the cracks in the stabilized base through to the 1-in-thick surface course.

Asphalt rubber has shown its effectiveness in preventing reflective cracking in overlays over existing pavements, and it was expected that a membrane would do the same on new construction with stabilized bases.

ANALYTICAL STUDIES

An analysis was conducted of the theoretical behavior of the structure to explore the basic reason why the asphalt rubber prevented reflective cracking as well as to provide a method to determine the structural adequacy of the systems.

Several finite-element method (FEM) computer programs were used for the analysis of stresses and strains. The primary computer program used for this study was a slightly modified static-analysis program for solid structures—namely, Solid SAP by Wilson (9). The slight modification of this program was in the calculation of the effective stress, which is defined by using the normal and shear stresses in an orthogonal Cartesian coordinate system, as follows:

$$S_{eff} = (1/\sqrt{2}) [(S_{11} - S_{22})^2 + (S_{22} - S_{33})^2 + (S_{33} - S_{11})^2 + 6(S_{12}^2 + S_{23}^2 + S_{31}^2)]^{1/2} \quad (1)$$

It is considered to be a realistic determinant for fracture (cracking) under the triaxial stress state that exists in the overlay pavement.

In order to reduce the cost of computer time, a linear elastic plane-strain analysis was assumed with up to 685 nodes and 620 elements. The general configuration of the pavement structure is shown in Figure 6. The range of different layer properties is given in Table 1. This does not exactly model the pavement condition in Dewey. However, the objective of this paper is to provide an analytical explanation for the apparent success of this new asphalt-rubber application.

Computer runs were not arranged as a factorial matrix due to the high cost of each run. Instead, several interesting variables were studied separately.

Thermal Effects

The general temperature profile shown in Figure 7 was used. Results of this study indicate the horizontal tensile stress near the crack tip reduced significantly as a result of the SAMI, as shown in Figure 8. The SAMI will not reduce the overall horizontal stress in asphalt concrete or an ACFC due to thermal expansion or contraction, but it will significantly reduce the stress concentration above the crack tip, thereby minimizing reflective cracking.

Overlay Thickness

Overlay thicknesses from 1 to 4 in were studied. For

Figure 9. Effects of SAMI on effective stress near crack tip.

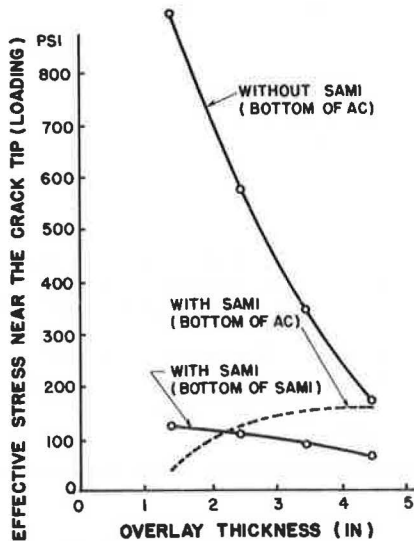


Figure 10. Influence of crack width on stresses.

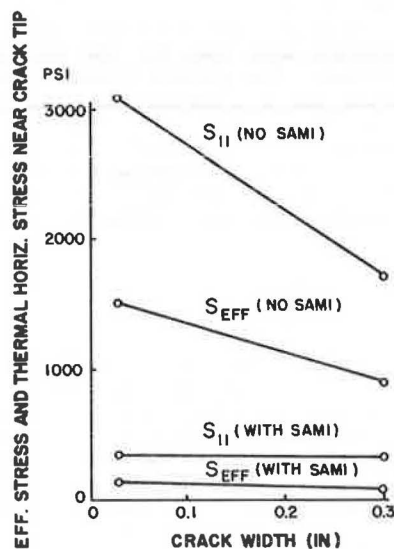


Figure 11. Influence line of effective stress near crack tip due to moving load.

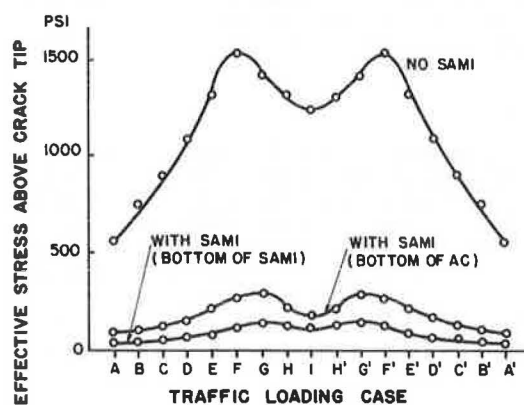
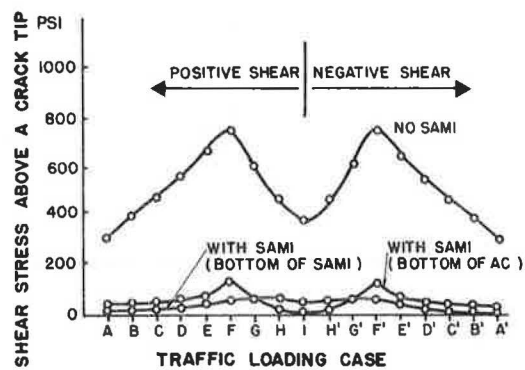


Figure 12. Influence line of shear stress near crack tip due to moving load.



an overlay without a SAMI, stresses were reduced significantly due to increasing thickness (Figures 8 and 9). However, for an overlay with SAMI, stresses were only slightly reduced due to the increasing overlay thickness. This indicates that, from an economical point of view, a thick overlay may not be justified for a reflective overlay design when SAMI is used.

Crack Width

Only two different crack widths were investigated--0.03 and 0.3 in. Results show that when there is not a SAMI in the overlay system, the stress concentration problem is more serious for smaller cracks than larger cracks (Figure 10). For overlays with a SAMI, stresses stay approximately the same no matter what the crack width. It is assumed there is no load-transfer capacity across a crack, which is valid in most cases, depending on the magnitude of the crack width and vertical differential movements.

Effects of Moving Traffic

Traffic loading was represented by a 12-in long, 100-psi load moving from one side of the crack to the other, as shown in Figure 6. Shear and effective stresses are at a maximum when the edge of this simulated traffic load just reaches the location of a crack, as shown in Figures 11 and 12. This study also revealed that a SAMI can reduce effective stress and, more importantly, shear stress in the surface layer, which many researchers believe is one of the major factors that causes reflective cracking.

SUMMARY

1. SAMI can be used for the overlay of flexible and rigid pavements, for new construction, or anywhere else that stress concentration around a crack needs to be reduced.
2. SAMI can reduce stresses due to thermal changes as well as vertical shear stresses due to moving traffic loads.
3. SAMIs can retard (or eliminate) reflective cracks by reducing crack tip stresses. In many cases, crack tip stresses drop to 10 percent or less of the original stresses.
4. A three-dimensional finite-element analysis with more realistic time- and temperature-dependent material properties will provide better results. However, the computer time required may increase 10 to 20 times. The primary purpose of this paper is to report a new area for the application of asphalt rubber as a SAMI in the construction of new pavement and try to provide analytical explanations for the

apparent success of this new approach in pavement design.

5. During the analytical study, it was assumed that there is no load-transfer capability across a crack. This is especially true when the ratio of crack width to vertical differential movement of a crack is high. Results of this study imply that a SAMI will perform even better if there is some load-transfer capacity through a crack.

6. A better understanding of SAMI properties is needed through laboratory testing.

7. When a SAMI is used, the thickness of overlay becomes less critical. This may result in very economical approaches to overlay design.

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Characterizing Fatigue Life for Asphalt Concrete Pavements

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The evaluation of fatigue life for asphalt concrete pavements is very difficult because of limited knowledge as to fatigue damage relations for real pavements, reliable testing data for only a limited number of mixtures, and limited information as to how the fatigue life potential of an asphalt concrete pavement varies with temperature and mixture characteristics. This paper seeks to overcome some of these difficulties by (a) proposing a typical fatigue relation for a typical asphalt concrete mixture in place, (b) presenting procedures for modifying fatigue relations with changes in temperature and mixture stiffness, (c) proposing a procedure for taking specific mixture characteristics into account, and (d) offering a simplistic method of transforming fatigue life predictions into predictions of area cracked.

The characterization of fatigue life for asphalt concrete pavements is extremely complex and has been the subject of study by a number of researchers for more than two decades. Various laboratory tests have been employed, but the most common one involves small beams subjected to repetitive loading with either constant load or constant strain. The beams have been simply supported, supported on springs, or supported on a rubber medium to simulate a base and subgrade. One characteristic shared by all beam tests and other types of common laboratory tests is that none come close to simulating actual field conditions and a realistic crack-propagation process.

Shell Laboratories attempted a more accurate simulation with wheel-tracking tests, which produced more realistic crack propagation in small asphalt concrete slabs, but may have overpredicted fatigue life because of the lack of environmental effects. More recently, a number of attempts have been made to use laboratory test curves in conjunction with elastic-layer theory to predict the occurrence of

fatigue cracking distress in real pavements. Because the laboratory relations almost always grossly underpredict fatigue cracking, shift factors have been used to translate the predictions to approximate fatigue life actually measured in the field. Such fatigue curves appear to be the best available for use in predicting fatigue cracking.

The form of the fatigue relations in common use is derived from a logarithmic relation between either stress or strain and the number of load cycles to failure. The relations between the logarithm of stress or strain and the logarithm of load cycles are considered to be linear, which results in the following general equation:

$$N_i = K_1 \epsilon_i^{-K_2}$$

where

N_i = number of load cycles to failure for a loading that results in a tensile strain,
 ϵ_i = calculated strain under load,
 K_2 = inverse of absolute value of slope of logarithmic function, and

$K_1 = N_i \epsilon_i^{K_2}$ for any pair N_i and ϵ_i that satisfies the logarithmic function.

Both K_1 and K_2 depend primarily on material characteristics and temperature.

A very important problem with this form of fatigue life characterization is that this equation is