

the AC content remaining constant. The increased AC content resulted in a reduced ATB void content (Table 3) from an average of 11.1 percent for the control to 6.7 percent for the increased AC section. This may be an important factor in the improved performance.

#### CONCLUSIONS

This research on transverse cracking and the temperature susceptibility of asphalt cement supports the following conclusions:

1. An improved sealant or sealing procedure is needed if transverse joints are to be used in asphalt pavements.
2. The PVN is an effective measure of the temperature susceptibility of asphalt cements.
3. The use of a high-temperature-susceptible asphalt cement produced severe transverse cracking.
4. The use of asphalt cements with low temperature susceptibility will reduce the frequency of transverse cracking.
5. An increased asphalt cement content in the ATB will reduce the frequency of transverse cracking.

#### RECOMMENDATIONS

Earlier Iowa DOT specifications for asphalt cement did not ensure the best possible pavement. A recommendation for an improved specification was made on the basis of this research. A change from AASHTO M226 Table 1 requirements to Table 2 requirements has been adopted for 1984 projects.

Before this project the AC content specified for ATB was 4.75 percent. Mix designs are now used to determine the AC content and limit the void content.

This should yield improved performance and extended life of full-depth asphalt pavements.

#### ACKNOWLEDGMENTS

Research project HR-217 was sponsored by the Iowa Highway Research Board with Primary Road Research Funding of \$43,000. The excellent cooperation of Larry Parrott and the Cessford Construction Company personnel in constructing the special sections was appreciated.

Iowa DOT personnel William Crawford, Erv Shaffer, Raymond Ellis, and others of the Manchester Construction Residency along with Dick Merritt, Dennis Lohrer, and the District 6 materials personnel provided good inspection, monitoring, and documentation of the research. Robert Shelquist, Lowell Zearley (Office of Materials) and Don Jordison (Office of Construction) supported the research with their expertise.

#### REFERENCES

1. N.W. McLeod. Asphalt Cement: Pen-Vis Number and Its Application to Moduli of Stiffness. ASTM Journal of Testing and Evaluation, Vol. 4, No. 4, July 1976.
2. R.M. Morchinek. Sawing Joints to Control Cracking in Flexible Pavement. Minnesota DOT Special Study 315, Progress Report. Minnesota Department of Transportation, St. Paul, 1974.

Publication of this paper sponsored by Committee on Flexible Pavement Construction.

## Laboratory Evaluation of an Asphalt-Rubber SAL

R. A. JIMENEZ and W. R. MEIER, JR.

#### ABSTRACT

The evaluation of a mixture of asphalt and rubber to serve as a strain attenuating layer (SAL) in asphaltic concrete overlays is discussed. The mixture consisted of a blend of asphalt and rubber and the SAL was made with and without stone chips. The tests used for the evaluation were developed to simulate certain pavement loadings and they were classified as repeated vertical shear, static horizontal shear, repeated horizontal shear, and flexure fatigue. Calculations were carried out to determine the effects of the SAL on stresses in the laboratory models and also in flexible layered pavement systems. The laboratory test results showed that the layers without the stone chips had the best performance. The calculations for the laboratory and pavement models indicated that the greatest effect brought about by the attenuating layer was in reduction of horizontal shear at the overlay-asphalt-rubber layer interface and that there must be a limiting thickness of that layer to prevent tensile overstress of the bottom surface of the asphaltic concrete overlay.

A reflection crack is one that develops in an overlay and is directly over a preexistent crack in its supporting layer. In asphaltic concrete overlays, the supporting layer may have cracked from (a) shrinkage stresses, (b) load stresses, or (c) the reflection crack phenomenon. The supporting layer may be composed of portland cement concrete, asphaltic concrete, cement-treated base, or a clay-bound soil course.

The design of overlays has included the concept of making the overlay thick enough to resist the stresses causing reflection cracking or placing a layer of low deformation modulus between the old pavement surface and the new overlay. The first method is generally expensive, especially if wire mesh is used, and is not always successful. In the second method a layer of unbound granular base, or a large-stone-open-asphalt-bound base, or a relatively thin asphalt-rubber chip seal has been found to minimize the incidence of reflection cracking. It is surmised that the success of those materials was due to their low deformation modulus.

Asphalt-rubber (A-R) is a mixture of asphalt and fine grindings from rubber tires. Its properties and uses have been reported by McDonald (1), Morris and McDonald (2), Green and Tolonen (3), and Jimenez (4). The Arizona Department of Transportation (ADOT) has used the asphalt-rubber chip seal since the early 1970s as an anti-reflection-cracking material (2).

Jimenez (4) suggests that reflection cracking is brought about by shear stresses rather than by tensile stresses. That statement was made on the basis of results from laboratory testing that attempted to simulate field loading conditions. In those tests, an asphaltic concrete beam was attached to aluminum plates with RC-250 or asphalt-rubber; however, the asphalt-rubber serving as the anti-reflection-cracking material did not have the stone chips. Also, (as will be done in this paper) the low deformation modulus material will be labeled a "strain attenuating layer" (SAL).

In Arizona, two types of asphalt-rubber are used for the construction of SALs. The rubber in one kind is synthetic and obtained from passenger vehicle tires; the other one is a combination of synthetic and natural rubber obtained from truck tires. The A-R made with the passenger vehicle tire grindings is mixed with a low viscosity asphalt and the other A-R is mixed with a high viscosity asphalt plus a small amount of an extender oil (an aromatic material). A limited investigation comparing the viscosity of these two asphalt-rubber mixtures was reported by Jimenez (5).

This paper is a discussion of a portion of a larger program (6) that was concerned with determining differences between the two types of A-R and also those resulting from the use of stone chips in the SAL; further, only one of the two A-R systems will be discussed. The work plan included testing beams simulating an overlay situation under loadings of (a) repeated vertical shear, (b) static horizontal shear, (c) repeated horizontal shear, and (d) flexural fatigue. In addition, calculations were performed for determining the effects of SALs on stresses for assumed flexible pavement layered systems and also for the laboratory models.

#### MATERIALS USED

In the planning of the work program, it was the intention that there would not be a variation in materials other than the A-Rs. However, because of increasing the scope of work and rerunning tests for checking purposes, the asphaltic concrete for making

the beams was not held to a constant mixture. Nevertheless, for a particular group comparison, the asphaltic concrete mixture was not a variable.

#### Asphalt

A low viscosity asphalt, AR-1000, was furnished by Sahuaro Petroleum for mixing with styrene-butadiene rubber (SBR) granules. The asphalt was assumed to meet ADOT's specifications (7).

#### Rubber

The rubber to be used with the Sahuaro asphalt was obtained from Atlos Rubber, Inc., of Los Angeles, California, and characterized as Overflex TP 044.

No measurements were made on the rubber; however, Jimenez (4,5) presents particle size distribution data for the Atlos rubber TP 044. The bulk (97 percent) of the rubber particles passed the No. 16 sieve and were retained on the No. 50 sieve.

#### Asphalt Rubber

The Sahuaro A-R was made with 78 percent AR-1000 and 22 percent TP 044 by total weight. The procedure for making and storing the A-R blends is given elsewhere (6).

#### Asphaltic Concrete

Asphaltic concrete mixtures came from the Tanner Company plant in Tucson. Large quantities of regular plant production were obtained and stored in 5-gal (19-L) metal cans. A proven satisfactory procedure for storing and sampling the asphaltic mixtures in the containers is discussed elsewhere (4).

#### Stone Chips and Sand

The stone chips came from a Tanner Company stockpile used for chip sealing. The chips used with the A-R for the SAL were one size, 3/8 in. (No. 4).

A concrete sand was used to correspond to a blotting operation in field construction and applied at the rate of 1.6 kg per square meter (3 lb per square yard). It had been anticipated that, if the stone chips were to be omitted in actual construction of an SAL, a blotting sand would be required to carry construction traffic over the straight A-R. At present, it is believed that the A-R-only SAL can be constructed with or without having construction traffic coming in direct contact with the A-R.

#### TEST AND PROCEDURES

Test procedures for characterizing A-R blends have not been standardized; however, an extensive amount of laboratory measurement and results has been reported by Rosner and Chehovits (8). Also, aging test results are discussed by Jimenez and Meier (6).

Original work and tests on laboratory models to investigate the effects of SALs on the resistance to reflection cracking are reported by Jimenez (4) as well as by Jimenez, Morris, and DaDeppo (9). The test procedures developed in the laboratory of the University of Arizona are described by Jimenez (6) and minimal discussion of details will be presented in this section. Standard tests or those developed elsewhere will be referenced to the related publication.

### Making Composite Beams

The laboratory pavement model was composed of two aluminum plates to serve as the cracked supporting layer to an overlay, a tack coat of asphalt cement or the SAL to tie the overlay to the supporting layer, and an asphaltic concrete to represent the overlay. Each aluminum plate was 152 x 508 x 12.7 mm (6 x 20 x 1/2 in.) and the asphaltic concrete beam was 127 mm (5 in.) wide and 610 mm (24 in.) long. The height of beam was 76.2 mm (3 in.). The procedures for placing the tack coat (or SALs) and for the compaction of the asphaltic-aluminum beam are given elsewhere (6).

### Repeated Vertical Shear Test

The repeated vertical shear test was developed to simulate wheel loads being transmitted from one side of a crack to the other by the overlay. The setup and testing procedures are described elsewhere (4,6); Figure 1 is a photograph. Note that the placement of the load is not exactly as occurs in a pavement, but it is believed that the test is appropriate for comparing the response of different SAL treatments to the test.

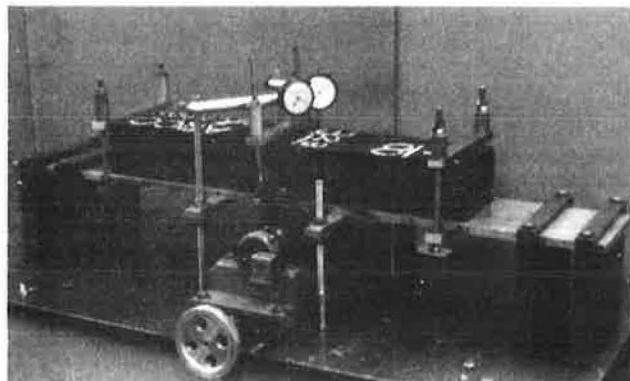


FIGURE 1 Setup for the repeated vertical shear test.

### Static Horizontal Shear Test

The effect of this test was thought to be comparable to that which occurs at the interface of an overlay or an SAL and at the crack of the old pavement surface as the system undergoes cooling. An examination of Figure 2 will show that the load applied axially to the aluminum plates was transmitted to the asphaltic beam through the SAL.

### Repeated Horizontal Shear Test

The repetitive nature of this test was considered to represent a repeated shear stress caused by the passage of traffic loads over the crack; it is recognized that the maximum shear stress caused by traffic is not necessarily of a horizontal direction. The testing procedure is described elsewhere (6); Figure 3 is a photograph of this setup.

### Flexural Fatigue

The flexural fatigue procedure was called the "deflectometer test." The making and testing of speci-

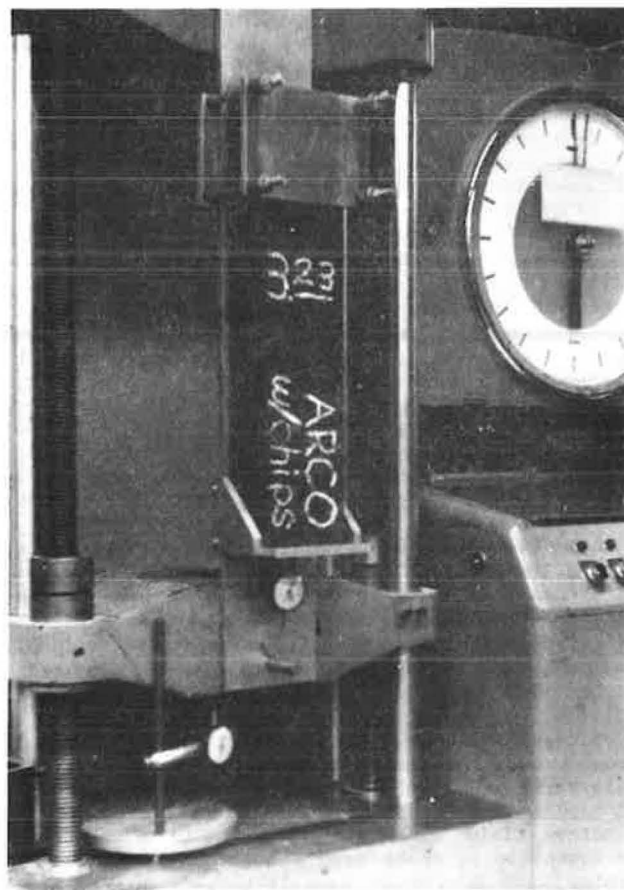


FIGURE 2 Setup for the static horizontal shear test.

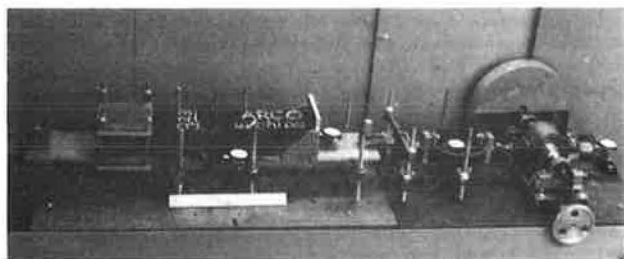


FIGURE 3 Setup for the repeated horizontal shear test.

mens 457 mm (18 in.) in diameter has been reported to ADOT (10) as well as to ASTM (11).

It was the purpose of this testing to establish if there was any difference in fatigue resistance of the overlay should the SAL contain stone chips or not. As a consequence, the only difference to the standard procedure of making a specimen was to first place the SAL on an aluminum sheet 0.25 mm (0.010 in.) thick by 457 mm (18 in.) in diameter that had been diametrically slit at right angles--a length of 406 mm (16 in.). The asphaltic concrete mixture was placed and compacted over the aluminum-SAL system in the normal manner.

All specimens were stored for a period of 7 days before testing. The first day of storage was at 25°C (77°F) and the remaining 6 days at temperatures corresponding to the test temperatures in order for the system to come to some sort of equilibrium.

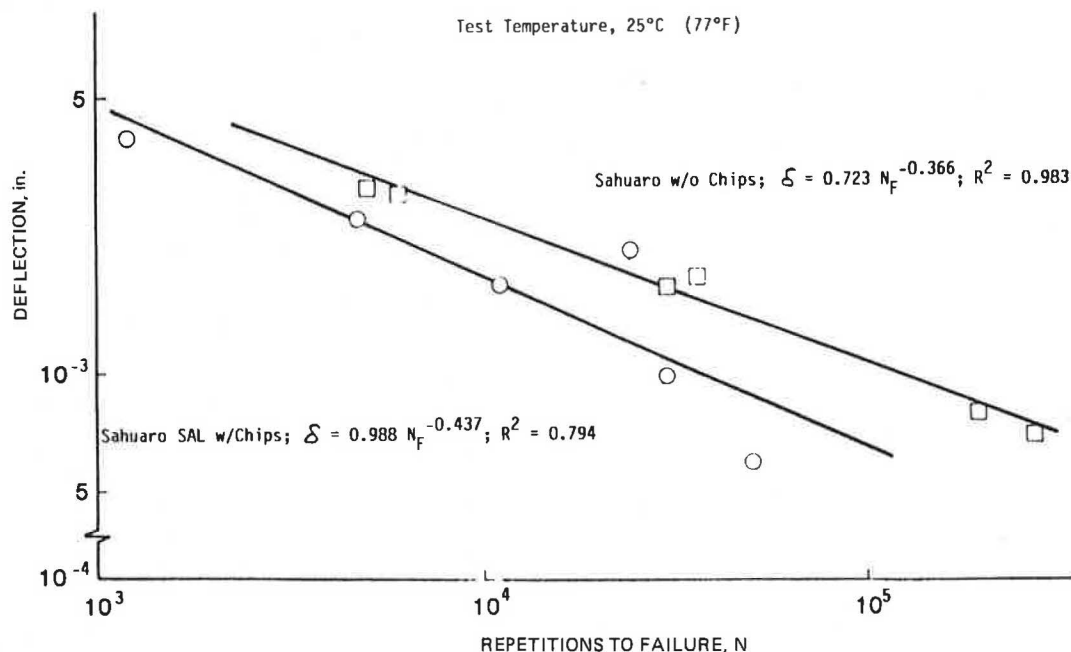


FIGURE 4 Fatigue relationship under repeated vertical shear for Sahuaro SAL.

## RESULTS AND DISCUSSION OF TESTS

The portion of the research presented here was to help establish differences in laboratory performance between the asphalt-rubber SALs with and without stone chips and to calculate the effects of an SAL on shear and tensile stresses in the overlay system. However, only the testing portion of the program will be discussed in this section.

Repeated Vertical Shear Test

The repeated vertical shear test was developed to simulate the passing of wheel loads from one side to the other side of a sublayer crack under an overlay. The relative performance of the SALs was established by comparing the effects of repeated vertical deflections on the number of their repetitions to cause failure. A plot of two typical curves showing this comparison is shown in Figure 4. The results of the tests performed using AR-4000 as a standard tack coat and the Sahuaro SALs are given in Table 1.

The data plotted in Figure 5 show quite clearly that the SAL without chips had a response superior to that of the AR-4000 tack coat or the SAL with the chips treatment. An examination of the average curves and their 95 percent confidence limits shows that for the SAL with no chips the variability in the test results was not as great as the variability in the test results for the SAL containing chips.

The much wider band of the 95 percent confidence limits for the SALs containing chips is attributed to the seemingly greater number and size of flaws or stress concentration points in the system. The same situation would be expected to occur in a field installation.

Static Horizontal Shear Test

The static horizontal shear test was thought to produce effects comparable to those produced when the underlying course of an overlay is subjected to temperature shrinkage that causes a crack to widen. The

TABLE 1 Resistance of Three SALs to Repeated Vertical Shear for Beams 3 x 5 x 24 in. Tested at 25°C, 1½ in. Mixture

Repeated Vertical Deflection $\delta$ (10 <sup>-3</sup> in.)	N <sub>F</sub> to Failure (x 10 <sup>3</sup> )
AR-4000 SAL Without Chips	
5	80
8	120 <sup>a</sup>
15	20
20	26
29	3.2
Sahuaro SAL With Chips	
6	50 <sup>a</sup>
10	30 <sup>a</sup>
17	11
21	24
25	4.7
40	1.2
Sahuaro SAL Without Chips	
7	275
8	195 <sup>a</sup>
17	30
18	36
29	6
30	5

<sup>a</sup> Failure by separation of SAL from AC beam. Other specimens failed by cracking of AC beam.

tests were performed at three extension rates and various measurements were recorded (Table 2).

The most consistent measurement from which to compare the response of the SALs was that of maximum load. Figure 6 shows the effect of extension rate on the maximum load carried or transferred by the different SALs. An interpretation of the data is that the SAL with the smallest maximum load would have the best performance because it would transfer the smallest load to the overlay. In this context the Sahuaro performed better than the AR-4000 tack. The distinction between chips and no chips is not clearly defined.

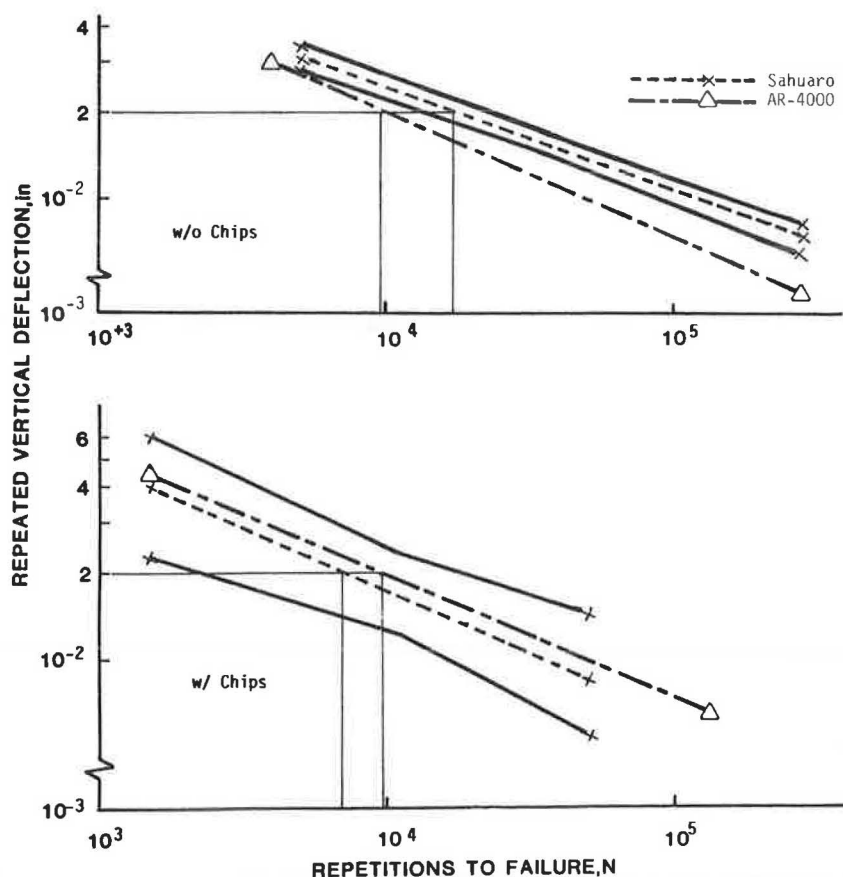


FIGURE 5 Ninety-five percent confidence limits for fatigue under repeated vertical shear for two SALs.

At this point it is thought necessary to remind the reader that the Sahuaro A-R was made with an AR-1000 asphalt. It is assumed that, due to the absorption of the cyclic portion, the resulting viscosity would still be less than that for the AR-4000 and thus be more yielding under load.

#### Repeated Horizontal Shear Test

The repeated horizontal shear test was designed to represent some shear stress in the SAL-beam system caused by the passages of wheel loads. Initial exam-

ination of the recorded data showed that interpretation was going to be difficult. For example, at the start of the test, the applied displacement caused a tensile load on the system; however, as the SAL elongated and the repeated cam displacement value was held constant, this effect caused a compressive load on the system. In addition, at times it was impossible to determine whether failure had occurred in the SAL or in the asphaltic beam.

Table 3 gives the data considered to best represent the responses to the test for the AR-4000 tack coat and the Sahuaro SAL, respectively. An examination of the table shows that for the AR-4000 tack

TABLE 2 Resistance of Three SALs to Static Horizontal Shear (Beams 3 x 5 x 24 in. Tested at 25°C, No. 1 1/2-in. Mixture)

	Sahuaro SAL								
	AR-4000 SAL Without Chips			SAL With Chips			SAL Without Chips		
	0.05 in./min	0.10 in./min	0.20 in./min	0.05 in./min	0.10 in./min	0.20 in./min	0.05 in./min	0.10 in./min	0.20 in./min
Maximum load (lb)	148	256	328	42	232	286	116	188	256
	158	300	364	194	132	274	130	230	292
Average	154	278	346	118	182	280	123	209	274
Slip at maximum load (10 <sup>-4</sup> in.)	51	10	35	450	160	930	240	500	920
	20	20	60	660	380	420	430	610	880
Average	36	15	43	555	270	675	335	555	900
Slip at rupture (10 <sup>-4</sup> in.)	51		45	900	910	1,270	280	620	1,200
	45	50	60	1,000	750	700	430		1,320
Average	48	50	47	950	830	985	355	620	1,260
Load at slip rupture (lb)	148		305	38	200	278	114	176	244
	132	256	350	190	120	268	130		270
Average	140	256	328	114	160	274	122	176	258

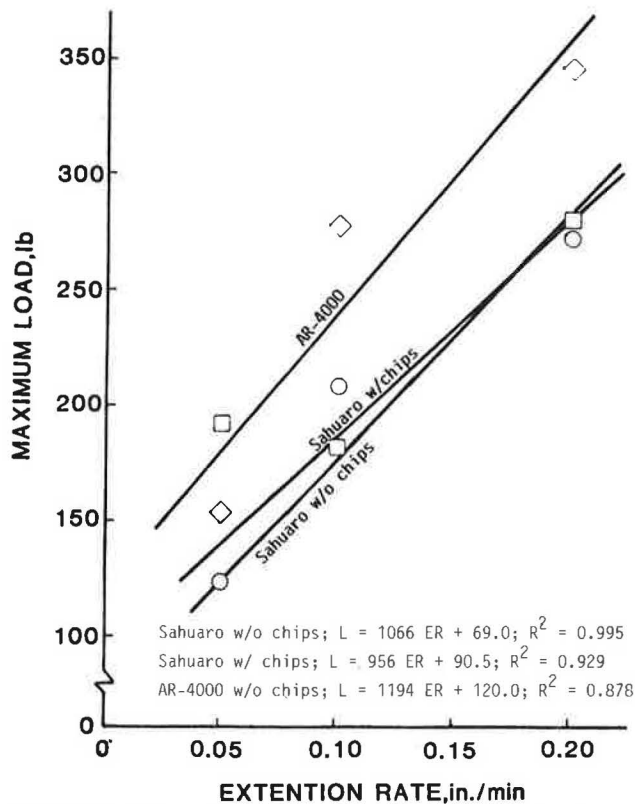


FIGURE 6 Effects of extension rates on maximum load under static horizontal shear for AR-4000 and Sahuaro SALs.

coat system, all of the failures occurred within the beam, and for the Sahuaro system, the SAL without chips was the layer that failed.

In Figure 7, curves are presented that show the effects of load on the number of repetitions to cause failure. The figure indicates, as did the curves for the repeated vertical shear test of Figure 5, that the SAL without chips performed better than the one with chips and that the variability of

TABLE 3 Resistance of Three SALs to Repeated Horizontal Shear (Beams 3 x 3 x 24 in. Tested at 25°C, No. 1 ½-in. Mixture)

Total Load (lb at 1,000 reps.)	$N_f$ to Failure (x 10 <sup>3</sup> )	Location of Failure
AR-4000 SAL Without Chips		
355	32	Beam
425	7	Beam
485	13	Beam
570	2	Beam
595	1.5	Beam
Sahuaro SAL With Chips		
315	35	SAL
340	6	SAL
400	15	Beam
410	4	SAL
410	30	SAL
455	5	SAL
495	2.5	Beam
525	3	SAL
540	4	Beam
Sahuaro SAL Without Chips		
370	90	SAL
470	30	SAL
485	40	SAL
555	4	SAL
570	10	SAL

response as indicated by  $R^2$  was greater for the system with chips.

#### Deflectometer Fatigue Testing

The fatigue testing of the SAL system was added to the evaluation program after initial test results indicated that the SAL without chips performed better than the one with chips. There had been some concern that fatigue life would be reduced if the SAL were built without chips.

A limited amount of fatigue testing was performed following the procedure described earlier. The test results are given in Table 4. The data show that al-

Test Temperature 25°C (77°F)

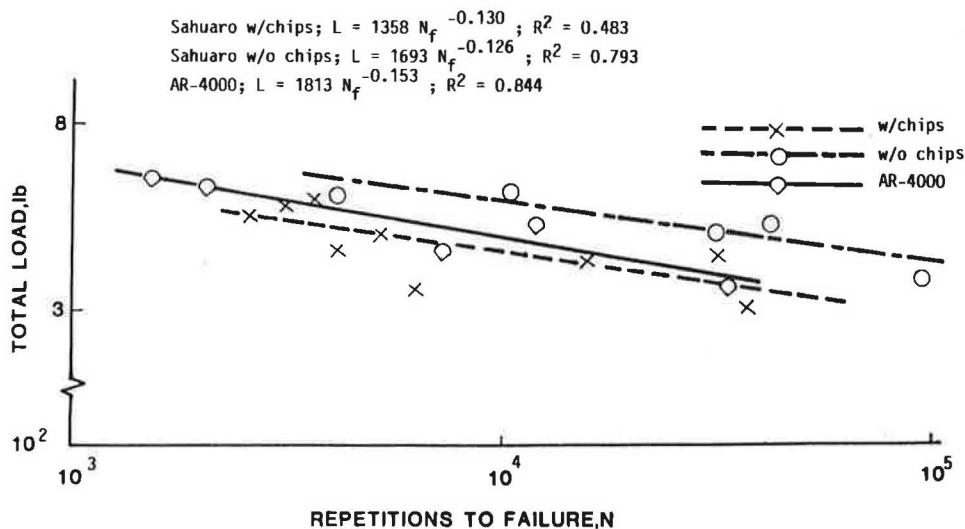


FIGURE 7 Fatigue relationship under repeated horizontal shear for various SALs.



**TABLE 4 Resistance to Flexural Fatigue of Sahuaro A-R SAL (Deflectometer Test at 25°C, No. 2 1/2-in. Mixture)**

Total Slab Thickness (in.)	AC Slab Thickness (in.)	AC Slab Stress (psi)	N <sub>f</sub> to Failure (x 10 <sup>3</sup> )
<b>SAL With Chips</b>			
2.30	2.03	94	450
2.30	2.04	93	400
2.30	2.03	94	500
<b>SAL Without Chips</b>			
2.12	1.98	99	650
2.07	1.93	104	450
2.11	1.97	100	500

Note: 1 in. = 25.4 mm and 1 psi = 6.89 kPa.

though the tensile stress at the bottom of the system was higher for specimens containing SAL without chips, the repetitions to cause failure were slightly greater than for the SAL system with chips. The data are limited in quantity, and the difference in repetitions to cause failure was small; therefore, it was assumed that there was no difference in fatigue life for the two sets of specimens. It is suspected, on the basis of the repeated shear tests, that the fatigue life of the two systems would be different and favor the SAL without the chips.

#### RESULTS AND DISCUSSION OF CALCULATIONS

Field experience and laboratory testing have shown the benefits of incorporating an SAL before an over-

lay is added to minimize reflection cracking. In planning the evaluation program, it was thought desirable to examine the influence of an SAL through the use of theoretical analysis of stresses.

The following sections are concerned with the stresses calculated for various five-layered pavement systems and also for the laboratory beam tests of vertical and horizontal shear.

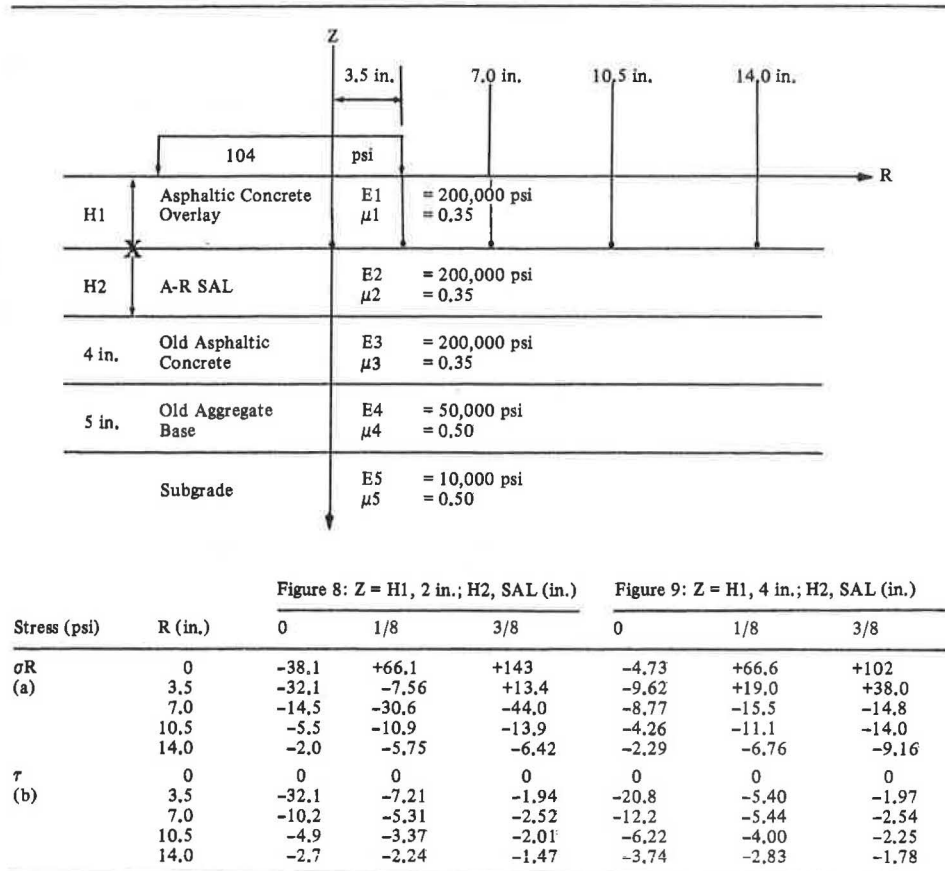
#### Calculated Stresses in Pavements with SALs

The CHEV5L computer program was used to calculate stresses in a five-layered pavement system. The new pavement was assumed to consist of an old three-layered system plus variable thicknesses of SAL and of overlays. The load and pavement properties are given in Table 5. This table also gives the radial and shear stresses calculated for points on the bottom of the overlays.

Figures 8 and 9 show plots indicating the influence of various thicknesses of SAL on the radial and shear stresses at the bottom of the overlays. Both figures show quite clearly that the thickness of the SAL has a great effect on the radial and shear stresses for overlays 51 or 102 mm (2 or 4 in.) thick.

The thicker the SAL, the greater is the reduction of the shear stress. However, as the thickness of the SAL increases from a value of zero to 9.5 mm (0 to 3/8 in.), the radial stress beneath the center of the load goes from compression to a tensile value of more than 690 kPa (100 psi). This behavior points out a detrimental effect, and it is suggested that a limiting value of tensile stress for fatigue considerations should be less than 690 kPa (100 psi). As a

**TABLE 5 Radial and Shear Stresses at Bottom of Overlay for Conditions Shown (E<sub>5</sub> = 10,000 psi)**



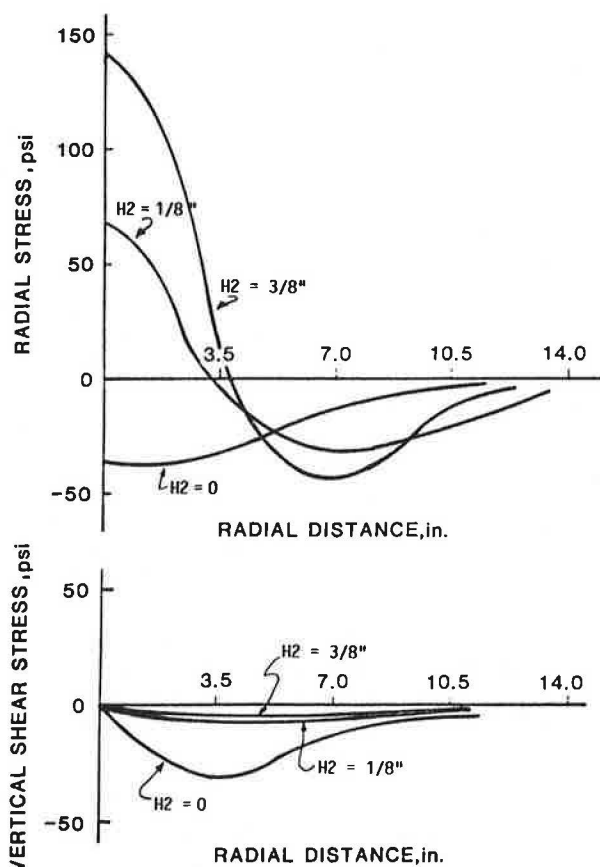


FIGURE 8 Calculated radial and shear stresses at bottom of overlay in a five-layer pavement with SAL and  $H_1 = 2$  in. (details in Table 5).

consequence, the spread rate of an SAL should not exceed about 3.2 L per square meter (0.7 gal per square yard) or a thickness of about 3.2 mm ( $1/8$  in.).

The data in Table 5 and others (6) show that neither increasing the thickness of the overlay to 102 mm (4 in.) nor decreasing  $E_5$  to 34 450 kPa (5,000 psi) had much effect on the maximum tensile stresses.

#### Calculated Stresses in the Laboratory Beam Tests

A sketch of the beam setup for the vertical and horizontal shear loads is shown in Figure 10. Stresses in the SAL and asphaltic concrete beam were calcu-

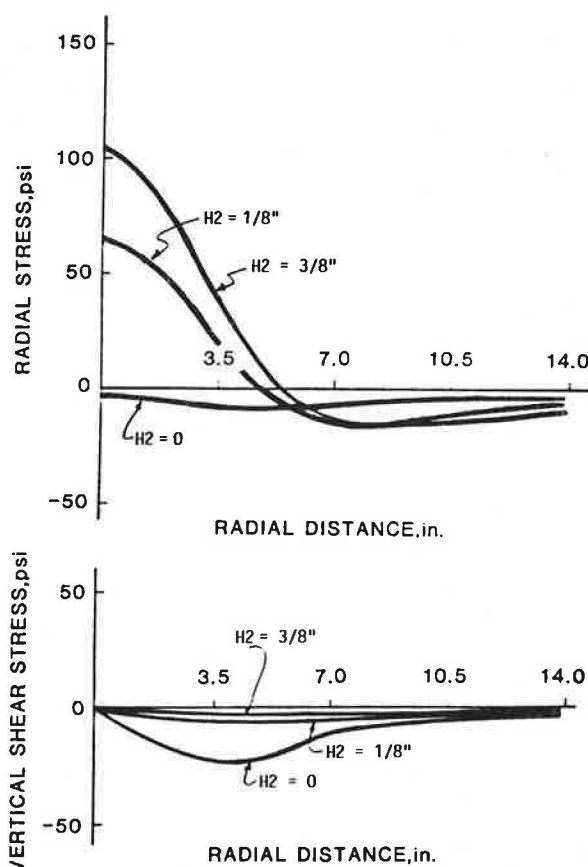


FIGURE 9 Calculated radial and shear stresses at bottom of overlay in a five-layer pavement with SAL and  $H_1 = 4$  in. (details in Table 5).

lated using regular beam theory and also a finite element method (12); however, only the beam theory data will be discussed.

The stresses under this theory were calculated for various thicknesses of beam and of SAL. The fundamental assumptions and boundary conditions for the vertical load have been contributed by DaDeppo (4). For the horizontal loading, only the boundary conditions were changed, as would be expected. Calculations were carried out for material properties:

Asphaltic concrete,  $E = 200,000$  psi and  $\mu = 0.35$

Asphalt-rubber,  $E = 2,000$  psi and  $\mu = 0.45$

Aluminum,  $E = 11,000,000$  psi and  $\mu = 0.33$

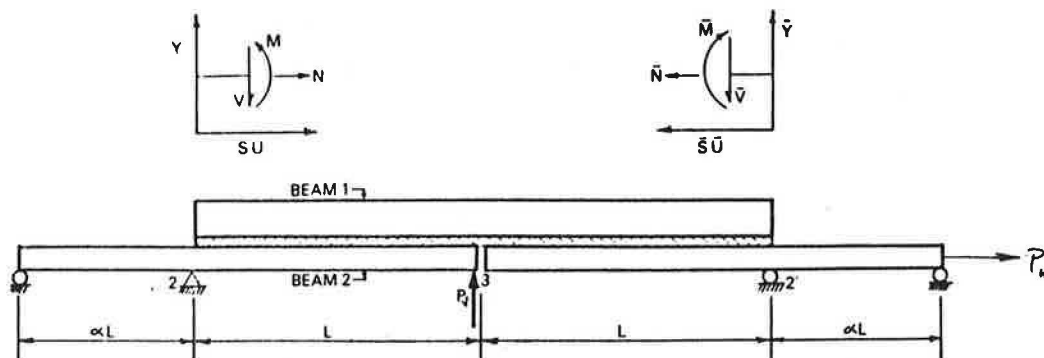


FIGURE 10 Beam setup for testing under repeated vertical load or repeated horizontal load.



Table 6 gives the maximum values of stresses in the system for the vertical and horizontal loads, respectively. The data in Table 6 show that the SAL thickness of 2.80 mm (0.110 in.) was most effective in reducing the shearing stress in the beam when subjected to the vertical shear load. However, it is noted that there was not a significant reduction in tensile stress in the asphaltic beam. The shear stress was reduced from 1.60 to 0.61 kPa (0.232 to 0.089 psi) whereas the tensile stress was reduced from 5.59 to 5.04 kPa (0.811 to 0.731 psi) by varying the SAL thickness from 0.10 to 2.80 mm (0.004 to 0.110 in.).

TABLE 6 Calculated Maximum Value of Stresses at Interface for Two Shear Tests on Beams with Variable SAL Thicknesses Under a Unit Load

	Vertical Shear <sup>a</sup>		Horizontal Shear <sup>b</sup>	
SAL thickness (in.)	0.004	0.110	0.004	0.110
Shearing stress on SAL (psi)	0.571	0.064	-0.169	-0.030
Vertical stress on SAL (psi)	(-0.887)	(-0.261)		
	0.210	0.036	0.924	0.034
Shearing stress on beam (psi)	0.571	0.089	-0.169	0.030
Tensile stress on beam (psi)	0.811	0.731	0.224	0.181 <sup>c</sup>

<sup>a</sup> $\sigma$  for beam is horizontal (flexural + axial);  $\sigma$  for SAL is vertical and (-) is compression,  $\tau$  for beam is horizontal and (+) is tensile;  $\sigma$  for SAL is vertical and (+) is compressive.  
<sup>b</sup> Located vertically of the joint.

The calculated maximum stress for the horizontal unit shear load as given in Table 6 presents the same SAL thickness effects on the shearing and tensile stresses in the asphaltic beam. However, in this case the shearing stress was reduced by a factor of 5.6, whereas, for the vertical load, it was 2.6. The tensile stress was reduced by a factor of

1.2 for the horizontal load and by a factor of 1.11 for the vertical load.

Figures 11 and 12 show the variations in tensile and shearing stresses along the bottom of the asphaltic concrete beam. The data in the tables and the figures indicate that the principal beneficial effect of the SAL was the great reduction of the shearing stress at the bottom of the asphaltic beam.

## CONCLUSIONS

The laboratory testing and computational program has been aimed at determining differences in the performance of two asphalt-rubber systems designed to perform as a strain attenuating layer. The function of such a layer is to minimize reflection cracking of asphaltic concrete overlays. The composition and application rates of the A-R system were those in standard use by ADOT. The conclusions presented are warranted for the materials tested and are based on results obtained with various nonstandard tests, which were believed to serve adequately for acquiring qualitative values for comparing performance of the SAL systems.

1. Responses to the repeated vertical shear test at 25°C (77°F) indicated that the SAL system without chips had the best performance and that there was a much larger variability in the results obtained for the SAL with chips.

2. In the static horizontal shear test at 25°C (77°F), both Sahuaro SALs performed better than the AR-4000 tack in that they would seemingly transmit less load to the overlay for openings of a sublayer crack (assuming the effects of extension rate are comparable to those of temperature change).

3. Responses to the repeated horizontal shear

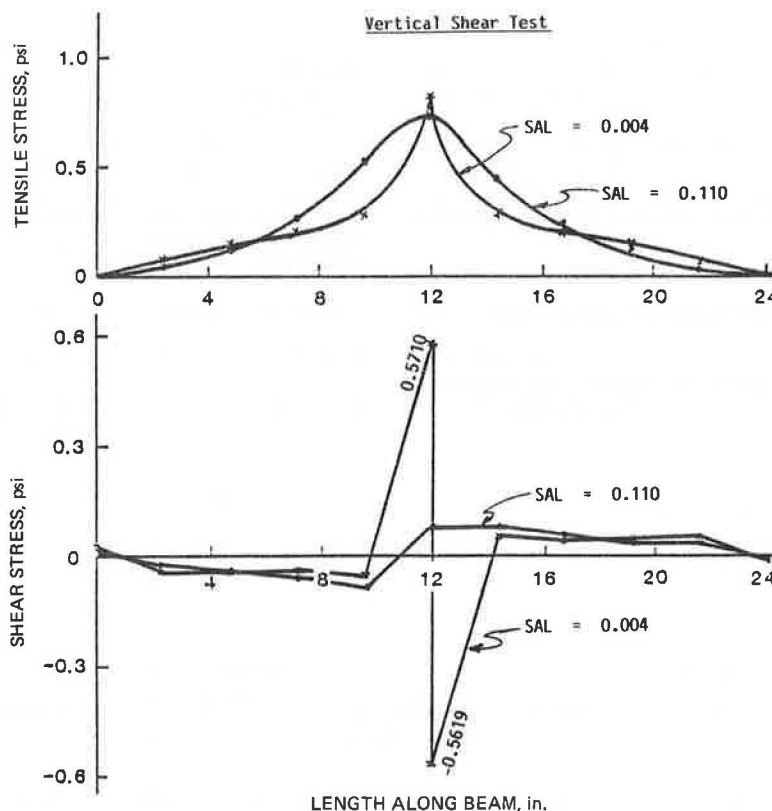


FIGURE 11 Calculated tensile and shear stresses in asphaltic beam 3 in. x 5 in. x 24 in. with SAL for the vertical shear load.

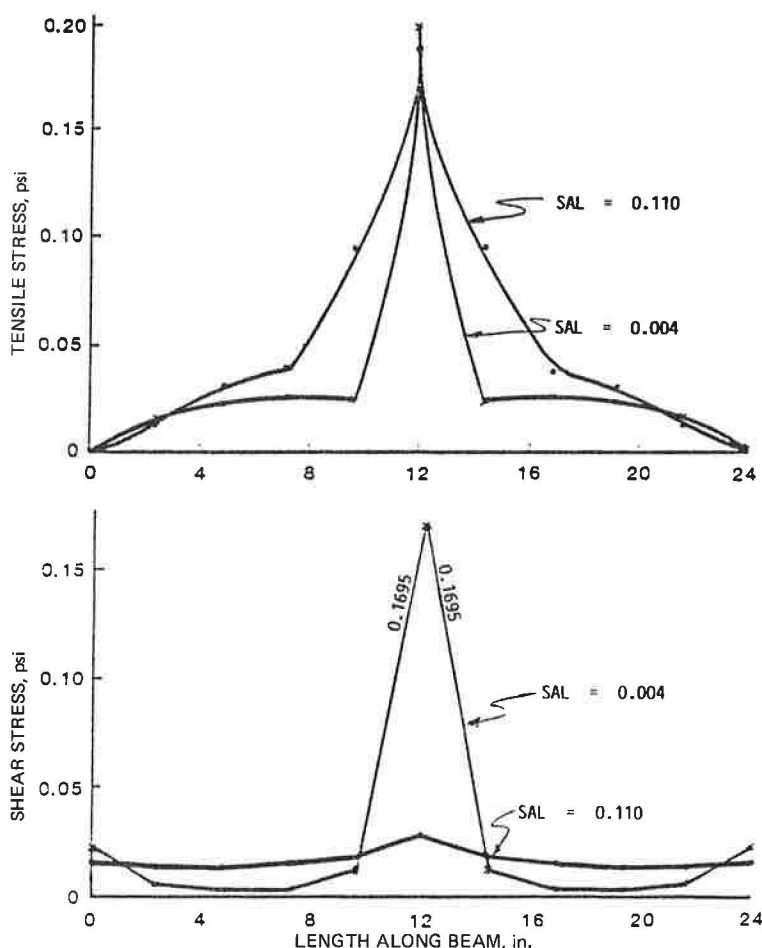


FIGURE 12 Calculated tensile and shear stresses in asphaltic beam 3 in. x 5 in. x 24 in. with SAL for the horizontal shear load.

test at 25°C (77°F) showed as before that the system of SAL without stone chips performed better than did the one with chips.

4. There was no significant difference in resistance to flexural fatigue between the SALs with and without chips.

5. Calculations for shear and tensile stresses at the bottom of the overlay in four different layered pavement systems showed that the shear stresses were greatly reduced through the use of an SAL. However, the tensile stresses were increased, and it is suggested that the thickness of the A-R SAL be limited to a thickness of 3.2 mm (1/8 in.), which corresponds to a maximum application rate of about 3.2 L per square meter (0.7 gal per square yard).

6. Calculations for shear and tensile stresses at the SAL-beam interface of the laboratory shear tests, using beam theory, showed that the SAL reduced the shear stress significantly but caused minimal change in the tensile stress when the system was loaded under vertical or horizontal shear.

7. These findings warrant and emphasize the need for a field installation of an SAL without the chips. Such a trial would serve to verify the findings and, if successful, would reduce the cost of an SAL.

#### ACKNOWLEDGMENTS

The cooperation received from the Arizona Department of Transportation and the Sahuaro Petroleum and As-

phalt Company is greatly appreciated. Particular individuals to be recognized are Gene Morris, former Director of the Arizona Transportation Research Center of ADOT; Frank McCullagh of ADOT; and two University of Arizona civil engineering students, John Patterson and Steve Wilson.

The authors sincerely value the consideration given by ADOT and FHWA to the sponsorship of this investigation and believe that the best use of asphalt-rubber in a strain attenuating layer has not been as yet made.

#### REFERENCES

1. C.H. McDonald. A New Patching Material for Pavement Failures. *In* Highway Research Record 146, HRB, National Research Council, Washington, D.C., 1966, pp. 1-16.
2. G.R. Morris and C.H. McDonald. Asphalt-Rubber Stress-Absorbing Membranes: Field Performance and State of the Art. *In* Transportation Research Record 595, TRB, National Research Council, Washington, D.C., 1976, pp. 52-58.
3. E.L. Green and W.J. Tolonen. The Chemical and Physical Properties of Asphalt-Rubber Mixtures--Basic Material Behavior. Report ADOT-RS-14(162). Arizona Department of Transportation, Tucson, 1977.
4. R.A. Jimenez. Testing Methods for Asphalt-Rubber. Report ADOT-RS-15(164). Arizona Department of Transportation, Tucson, 1978.

5. R.A. Jimenez. Testing Asphalt-Rubber with the Schewyer Rheometer. Report to NSF Grant Eng-78-10395. National Science Foundation, Washington, D.C., 1980.
6. R.A. Jimenez and W.R. Meier. Laboratory Evaluation of Anti-Reflection Cracking Materials. Report FHWA/AZ-83/186. Arizona Department of Transportation, Tucson, 1983.
7. Supplemental to Standard Specifications for Road and Bridge Construction. Arizona Department of Transportation, Tucson, 1975.
8. J.C. Rosner and J.G. Chehovits. Chemical and Physical Properties of Asphalt-Rubber Mixtures--Phase II. Report FHWA/AZ-82/159. Arizona Department of Transportation, Tucson, Vols. 1-5 and Summary, 1982.
9. R.A. Jimenez, G.R. Morris, and D.A. DaDeppo. Tests for a Strain-Attenuating Asphaltic Material. Proc., Association of Asphalt Paving Technologists, Vol. 48, 1979.
10. R.A. Jimenez. Structural Design of Asphalt Pavements for Arizona. Research Report Project HPR-1-12(142). Arizona Department of Transportation, Tucson, 1975.
11. R.A. Jimenez. Fatigue Testing of Asphalt Concrete Slabs. STP 508. ASTM, Washington, D.C., 1971.
12. R.T. Fort. Finite Element Analyses of Composite Beams. M.S. thesis. University of Arizona, Tucson, 1983.

---

Conversion factors used in this paper are

$^{\circ}\text{F} = 32 + 1.8^{\circ}\text{C}$   
 1 inch = 25.4 mm  
 1 lbm = 0.45 kg  
 1 lbf = 4.44 N  
 1 pcf = 16.03 kg/m<sup>3</sup>  
 1 psi = 6.89 kPa  
 1 gal/yd<sup>2</sup> = 4.53 L/m<sup>2</sup>  
 1 lbm/yd<sup>2</sup> = 4.88 kg/m<sup>2</sup>

Publication of this paper sponsored by Committee on Characteristics of Nonbituminous Components of Bituminous Paving Mixtures.

## Field Performance of Rubber-Modified Asphalt Paving Materials

T. S. SHULER, R. D. PAVLOVICH, and J. A. EPPS

### ABSTRACT

Six types of paving systems containing ground tire rubber are evaluated. Asphalt-rubber seal coats and interlayers are the construction applications in which most ground rubber has been used, and, therefore, most of the results of this study relate to these two paving processes. Asphalt-rubber interlayers studied in this research do not appear to always improve performance of overlays compared with control sections. However, the negative performance of some installations does not appear to be related to fundamental material properties but to inappropriate use of some interlayers. It is believed that improved performance of such systems can be demonstrated if use is limited to specified modes of pavement distress. Asphalt-rubber seal coat performance also indicates some unfavorable performance compared with control sections. However, this adverse performance can be related directly to a high incidence of flushing distress. A recommendation is given for design of asphalt-rubber seal coats similar to conventional seal coats. A lack of rational design procedure for determining material quantities is cited as the primary cause of some detrimental asphalt-rubber seal coat performance in the past. Four other rubber-modified paving processes were investigated; however, because of the relatively few projects involved, specific conclusions regarding these types of applications are difficult to assess. Further study is recommended as more projects of this type are constructed.