design, construction, and maintenance are based on observations made over the past 25 years:

1. An open-graded ACFC will not drain properly unless there are proper transverse geometries. Reducing the distance the water must travel should be considered.
2. Although the film coatings on particles in an open-graded ACFC are thicker than in dense-graded designs, a planned maintenance program that requires a fog seal of rejuvenators and/or combined asphalt rejuvenators every two or three years is essential. Service-life performance is affected by the lack of such a program.
3. An open-graded ACFC has the ability to hide surface reflective cracking. It also provides space for subsequent fog seals of rejuvenating agents to retard cracking.
4. Since an open-graded ACFC is sensitive to bitumen quantity, temperature, and hauling distance, consideration should be given to control of the construction season.
5. Adequate sealing of the existing pavement surface before placement of an open-graded ACFC is essential.
6. Under high traffic volumes and speeds, an open-graded ACFC facilitates the handling of traffic during construction and reduces the effects of the splashing of surface water.

It is apparent that, as the need for safe surfaces for the vast highway network increases, more consideration will be given to the strategy of placing open-graded ACFCs. As traffic volumes increase, additional justification may be found for spending a greater initial amount of funds for wearing surfaces than is now considered feasible. At any rate, technology and experience have advanced to the point that the construction of premium surface courses cannot be justified, and there should be an increase in the applications of open-graded ACFCs in the years ahead.

As the era of asphalt-pavement recycling commences, its inherent advantages with regard to saving materials and energy continue to be discovered. The conception of saving energy by cold processing has carried over into the placement of ACFCs in that ACFCs can also be placed by cold-slurry processes. This ability to cold process an ACFC surface course makes it possible to consider an energy-saving strategy of cold processing for all pavement strategies on a rehabilitation project--the point being that, if one desires an ACFC and experience has been only with "hot" processing, it is possible to obtain a similar material by a cold-processing strategy.

ACKNOWLEDGMENT

The contents of this paper reflect our views, and we are responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the Arizona Department of Transportation.

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Performance Comparison Between a Conventional Overlay and a Heater-Scarification Overlay

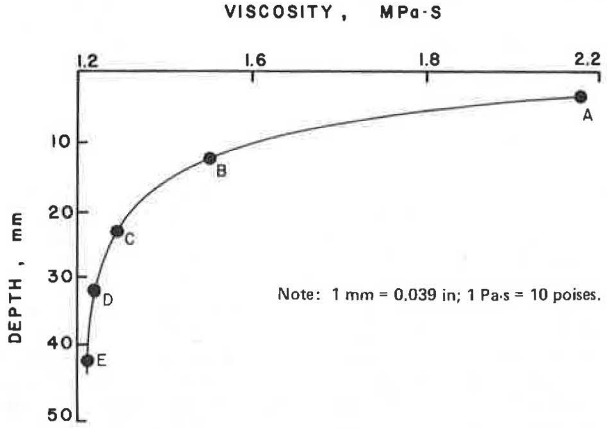
SAMUEL H. CARPENTER

The heater-scarification technique has become one of the most commonly accepted forms of pavement surface recycling in use today. This has been due primarily to the record of successful performance exhibited by these projects over a relatively long period of time. The performance characteristics of a typical heater-scarification overlay project are analytically examined and compared with those of a conventional overlay. The comparison examines fatigue cracking caused by wheel loadings and thermal-fatigue cracking caused by daily temperature cycles. The results are presented for one combination of aged asphalt and recycling agent and one overlay type. The results show that for this combination the commonly held statement that a 19- to 25-mm (0.75- to 1.0-in) depth of heater scarification with 38 mm (1.5 in) of overlay will perform as well as 89 mm (3.5 in) of conventional overlay has some validity. The calculations illustrate the need for laboratory testing to select the best recycling agent for the particular asphalt being recycled and the need to tailor the characteristics of the recycled binder to produce the desired product.

Heater scarification, one of the oldest forms of surface recycling, is used primarily to correct surface distress in bituminous pavements. Surface distress includes a number of types, such as rutting, raveling, weathering, and corrugations. Mixture problems such as asphalt content, gradation, or asphalt properties can also be altered during the

Figure 1. Typical heater-scarifier unit.

Figure 2. Variation of viscosity with depth for several pavement sections.



heater-scarification operation. It is this alteration of asphalt properties that provides a major performance improvement in the new pavement structure.

A typical heater-scarification unit is shown in Figure 1. There are a number of different units in operation today that accomplish basically the same result although the processes may differ slightly. The basic heater-scarification process follows a standard procedure:

1. The pavement surface is heated by indirect heat to a temperature in excess of 93°C (200°F) and to a depth of 25 mm (1.0 in) nominally.
2. Scarifier teeth pulled over the softened surface break up the pavement to a nominal depth of 25 mm.
3. A recycling agent may be added at this point to soften and rejuvenate the asphalt cement in the scarified mixture.
4. Mixture deficiencies may be corrected at this point by adding asphalt cement or aggregate and mixing it in with the scarified mixture.
5. The heater-scarified mixture may be compacted prior to application of the overlay, or a new asphalt concrete overlay is placed over the uncompacted heater-scarified layer and both are compacted simultaneously.

Heater scarification works with the "top inch" of the pavement, although multiple passes may be used to get greater depths of scarification. This top inch is important. The asphalt cement in the top inch is normally oxidized and hardened in any pavement of appreciable age. This is shown in Figure 2, which depicts the variation of viscosity with depth and age (1). The rejuvenation of this top inch of asphalt cement may return the pavement to an overall condition that resembles that of a new pavement, depending on the distress present.

The heater-scarification process removes the cracking present on the surface and buries it under 25 mm of rejuvenated asphalt concrete. An overlay on top of this further buries the cracked surface. Statements based primarily on observations of heater-scarified overlaid pavements have indicated that 25 mm of heater scarification with 38 mm (1.5 in) of overlay will give the same performance as 63-76 mm (2.5-3.0 in) of new hot-mix overlay over the original pavement surface. These statements have been based primarily on the observed rate of appearance of reflection cracks on the new surface.

Cracks in the old surface may be propagated by traffic or temperature cycles. Traffic loadings will produce fatigue cracking whereas temperature cycles will produce thermal-fatigue cracking. These inputs alone may develop cracks in a new pavement structure and, with existing cracks in the underlying surface, will propagate reflection cracks. The basic indication of the performance of an overlay may be indicated by how rapidly cracks work through the overlay. This can be determined from a fracture mechanics approach and a viscoelastic analysis and has been done previously (2).

DETERIORATION IN THE OVERLAY

There are three methods by which deterioration in the form of cracking can be produced in an overlay over an old flexible pavement. These include

1. Development of normal fatigue cracking in the overlay,
2. Reflection cracking produced by vertical deformation at a crack as a result of wheel loadings, and
3. Thermal-fatigue cracking resulting from daily temperature cycles, which may produce a new crack in the overlay as well as propagate a reflection crack.

The crack-propagating mechanism that predominates for any one pavement will depend on the distress condition of the old pavement, the foundation support provided, the mixture variables, and the climate. The three mechanisms listed above are shown schematically in Figure 3.

If the surface is not badly cracked and mix deficiency is the only distress, reflection cracking will not be a problem in the overlay and fatigue cracking will be a possible distress while thermal-fatigue cracking may dominate. If the old pavement is very badly cracked, from whatever cause, it will provide a lower support value and fatigue cracking in the overlay will be prevalent. Thermal-fatigue cracking will also be active, but the thermal behavior of the old pavement will be minimized from the standpoint of reflection cracking. If the original pavement has transverse cracks spaced at regular intervals, reflection cracking and thermal-fatigue cracking will be important and the thermal characteristics of the old pavement will influence thermal-fatigue reflection cracking.

The mechanisms listed above are highly influenced by the support provided by the existing structural layers. Low support values will accelerate fatigue and reflection cracking that results from traffic, since these two forms of cracking are influenced by the same properties of the overlay, a resistance to

Figure 3. Three modes of crack propagation in a heater-scarified overlaid pavement.

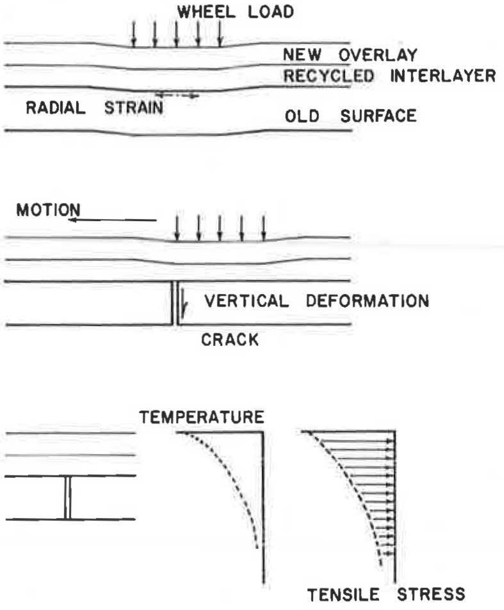
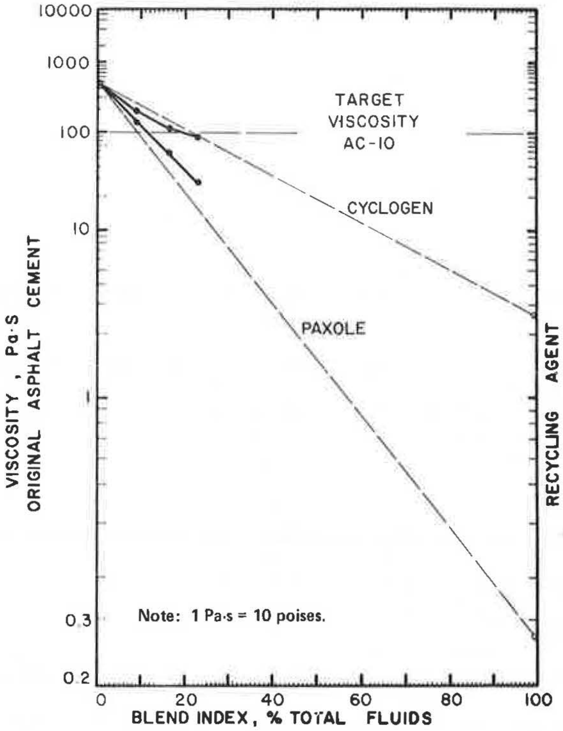


Figure 4. Blend index chart for selecting proper amount of recycling agent to produce a selected consistency.



Note: 1 Pa·s = 10 poises.

strain-induced cracking. Because both types of deterioration are influenced by the same properties and produced by the same input, fatigue cracking is examined to show the relative influence of the heater-scarified interlayer on performance. Fatigue distress is easier to characterize and clearly demonstrates the influence of the heater-scarification process. If exact life predictions were needed, the two distress types would have to be investigated separately. Exact predictions of cracking times are beyond the scope of this paper.

Thermal-fatigue cracking does not depend on support values from the old pavement. This form of deterioration depends solely on the viscoelastic and thermal contraction properties of the asphalt concrete layers. These properties may be most influenced by the heater-scarification recycling process, which uses a recycling agent.

In an initial study of thermal reflection cracking of overlays by Chang, Lytton, and Carpenter (2), the following conclusion was developed. To most effectively retard this cracking, the original pavement should be overlaid with a thin layer of low-modulus material and then with a higher-modulus material. Both materials should be as temperature insensitive as possible--i.e., there should be a low increase in stiffness with temperature drop.

This layer arrangement is easily attainable in the heater-scarification process. The stiffness characteristics of the heater-scarified interlayer may be controlled by the recycling agent used. The use of a stress-relieving interlayer such as this has been recognized for quite some time (3,4). The remainder of this paper presents the procedures used to analyze heater-scarified recycled materials, the input properties for these procedures, and the resulting differences in service life between the two rehabilitation methods.

PAVEMENT PROPERTIES

The pavement being examined in this paper is from a class 1 surface mix in service as a shoulder on I-94 in Peoria, Illinois. Samples were brought to the laboratory and crushed, and the asphalt cement was extracted and recovered. The properties of the recovered asphalt cement are as follows: Penetration at 25°C (77°F) = 3.5 mm (0.13 in), viscosity at 60°C (141°F) = 480 Pa•s (4800 poises), and softening point (ring and ball) = 50.5°C (124°F). It should be recognized that these properties are the average over the entire thickness of 20.3 cm (8 in). For an actual heater-scarification operation, only the top 25 mm (1 in) should be evaluated. This would show an even higher viscosity, which would make it necessary to use a different amount of recycling agent to rejuvenate the aged binder.

The aged binder was rejuvenated to a viscosity of 100 Pa•s (1000 poises), the consistency of an AC-10 asphalt cement, by using Paxole 1009 recycling agent. The blending tests are shown in Figure 4. From this blend chart, a recycling-agent proportion of 12.5 percent by weight of aged binder (11.5 percent by weight of total fluids) was selected. The properties of this blend are given below for the blended material and the blended material following the thin-film oven test (TFOT) (ASTM D1754):

Condition	Penetration at 25°C (mm)	Viscosity at 60°C (Pa•s)	Softening Point (ring and ball) (°C)
Before TFOT	9.5	90	45
After TFOT	5.3	190	50

The TFOT values indicate properties that would exist in the recycled binder after mixing and compaction when the diffusion of the recycling agent into the aged binder is completed. The diffusion phenomenon was first reported by Carpenter and Wolosick (5) at the 1980 Annual Meeting of the Transportation Research Board.

A virgin AC-10 asphalt cement was selected from a construction project in central Illinois. This represents the virgin material that would be used in a new overlay. The test properties for this asphalt cement are given below:

Condition	Penetration at 25°C (mm)	Viscosity at 60°C (Pa•s)	Softening Point (ring and ball) (°C)
Before TFOT	8.0	111	46.0
After TFOT	5.6	285	51.5

Structural Characteristics

For comparative purposes in this paper, the original pavement was assumed to have 3.0 percent air voids, as was the overlay that used the AC-10. The air voids in the heater-scarified interlayer were reduced to slightly less than 3.0 percent by the addition of the recycling agent, which provided more total fluids to the mixture. The first structural property needed to characterize the performance of an asphalt concrete pavement is the stiffness modulus. Creep compliance and diametral resilient modulus are the two most common procedures used by researchers today to characterize the stiffness of asphalt concrete. The creep-compliance curve for the recycled mixture in cylindrical compression is shown in Figure 5.

These data can be obtained in any well-equipped research laboratory, and the tests should be performed whenever possible. When it is not possible, reasonably accurate comparisons can still be made by using any of the accepted nomographic procedures (6; 7; 8, p. 358). A computerized version of the Van der Poel nomograph was used to generate the stiffness relations used in this study (9). Basically, this involved calculating the entire relaxation-modulus curve for each material. Relaxation modulus is related to creep compliance by the following:

$$D(t) = [1/E(t)](\sin m\pi/m\pi) \qquad (1)$$

where

D(t) = creep compliance at time t,
E(t) = relaxation (stiffness) modulus at time t, and
m = slope of the straight-line portion of the viscoelastic master curve that is being used.

Figure 5. Creep-compliance curve for actual recycled material with resilient modulus data superimposed (138-kPa load range).

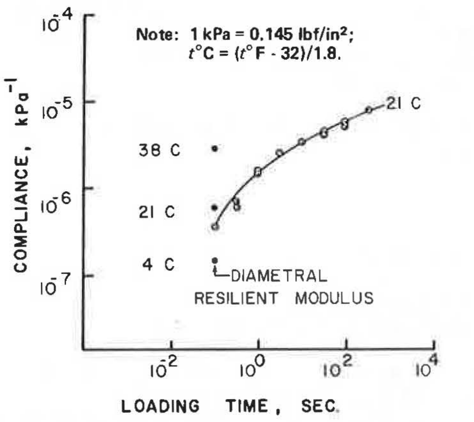
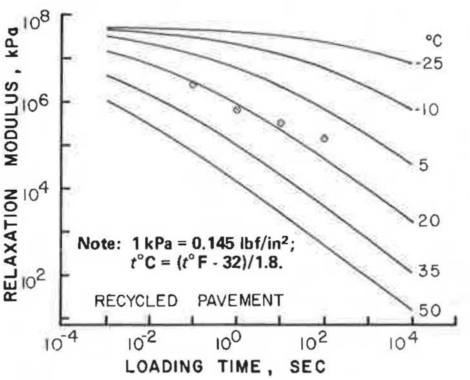


Figure 6. Computer-generated relaxation curves for recycled material examined with laboratory data superimposed.



The relaxation curves for the recycled material are shown in Figure 6. The laboratory data are superimposed, and the values of diametral resilient modulus are indicated. Figure 7 shows the computer-generated relaxation curves for the AC-10 overlay and for the original pavement, calculated in a similar manner. The calculations for the overlay and the recycled material were performed by using the asphalt cement properties after the TFOT aging because these values could be considered more typical of those that would exist in the finished pavement. It must also be realized that the surface layer, the AC-10 overlay, will age, whereas the heater-scarified interlayer will age little, if any. This difference in aging will stiffen the properties of the surface layer, making it more susceptible to cracking.

The master relaxation curves for each of the three materials are shown in Figure 8. The reference temperature is taken as 5°C (41°F). The

Figure 7. Computer-generated relaxation curves.

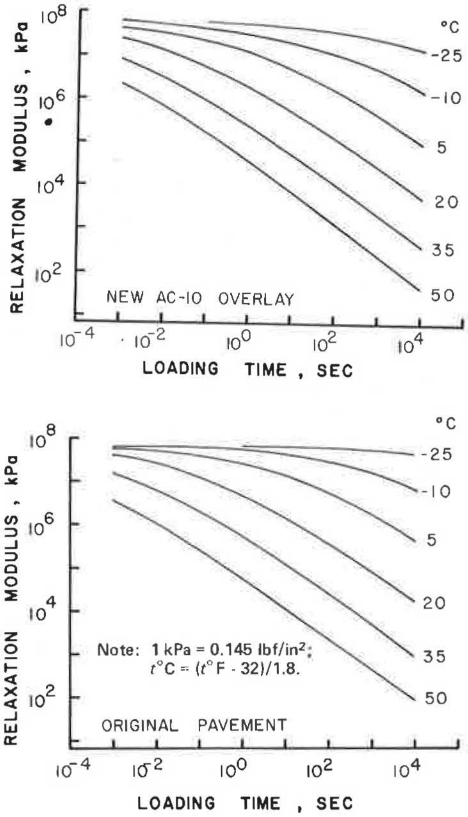


Figure 8. Master relaxation curves for materials examined.

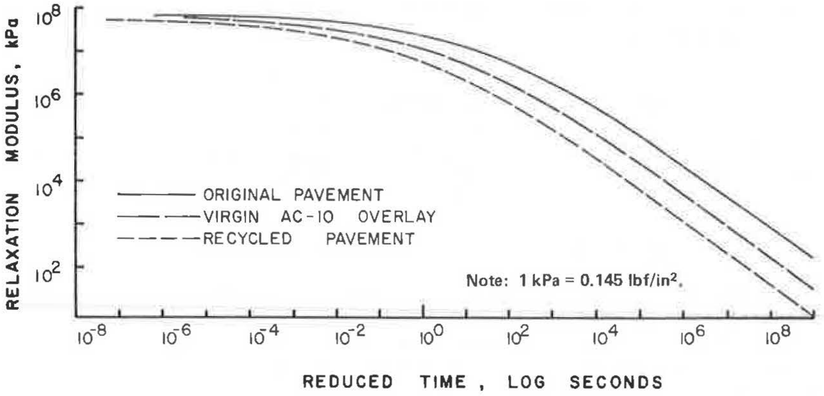
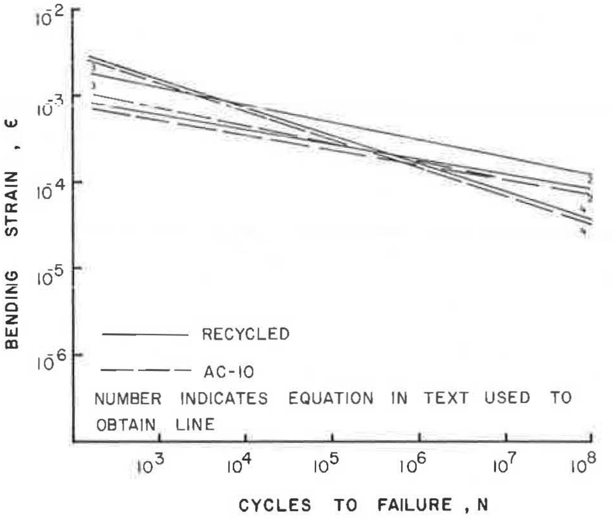


Figure 9. Fatigue curves predicted from asphalt cement and mix properties.



difference in the stiffness relations for these three materials is very dramatic. The original pavement is the stiffest; this is expected since it is composed of an aged asphalt cement. The difference between the AC-10 overlay and the recycled interlayer is greater than may have been expected. This emphasizes a difference in the aging characteristics of a recycled asphalt versus those of a virgin asphalt cement that has been noted by a number of researchers: A recycled asphalt cement will generally age less than a virgin asphalt cement in the same condition. Although the TFOT may not indicate long-term field aging precisely, the relative comparison it provides is valid and it does indicate what is in the pavement after mixing. It must be noted that the virgin AC-10 and the rejuvenated asphalt cement had similar properties according to the common classification tests before aging in the TFOT.

These computer-generated curves for relaxation (stiffness) modulus, the appropriate shift functions, and the asphalt cement properties are used in the next section of this paper to calculate thermal stresses, fatigue relations, and layer stiffnesses for performance comparisons of a conventional overlay and the heater-scarified overlay method.

FATIGUE PROPERTIES

Nomographic procedures have been developed to estimate the fatigue curves for mixtures that use the binder and mix properties developed by the Shell research group in France (10). The equations they developed for constant stress and constant strain are, respectively,

$$\epsilon = (0.300 \times PI - 0.015 \times PI \times Vb + 0.08 \times Vb - 0.198) \times Sm^{-0.28} \times N^{-0.2} \quad (2)$$

and

$$\epsilon = (4.102 \times PI - 0.205 \times PI \times Vb + 1.094 \times Vb - 2.707) \times Sm^{-0.36} \times N^{-0.2} \quad (3)$$

where

ε = initial bending or radial strain,
PI = penetration index of the binder,
Vb = volumetric bitumen content of the mix,
Sm = stiffness modulus of the mix (Pa), and
N = number of cycles to failure.

Regression equations based on extensive analysis of fatigue-testing data reported in the literature were developed and reported in NCHRP Report 195 (11). The equation is as follows:

$$N = (1.213 \times 10^6)(PEN/10)^{0.22}(Va)^{-1.79}(Pb)^{-1.81}(Sm/10\,000)^{-0.71} \div (\epsilon \times 10^{-6}/100)^{-3.07} \quad (4)$$

where

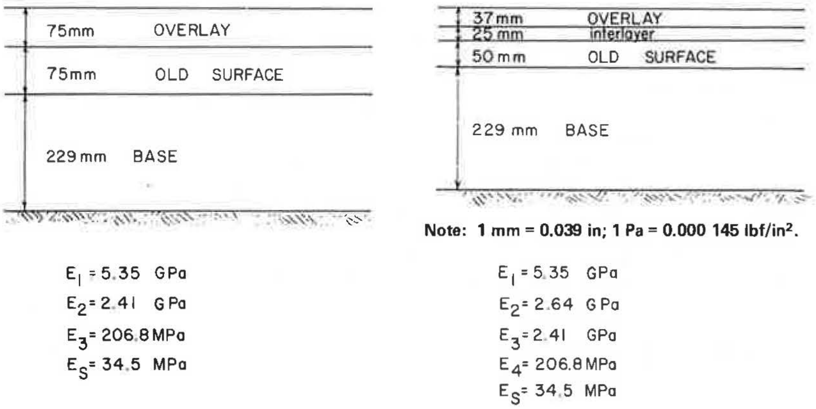
PEN = penetration at 25°C,
Va = air voids in the total mixture,
Pb = asphalt content, and
Sm = mix stiffness modulus (lbf/in²).

These equations have been plotted in Figure 9 for the new overlay and the recycled material. The mixture properties are the same as those used to calculate the relaxation curves. The data shown in Figure 9 illustrate that the recycled interlayer material will have better fatigue properties than an overlay with the virgin AC-10 asphalt cement. The actual fatigue life of the pavement will depend on the thickness of the layers and the resultant strains produced by wheel loadings.

In analyzing an actual project, samples should be tested for the stiffness and fatigue data needed for a fatigue-life comparison of the different pavement structures being considered. The stiffness is needed as an input material property for the structural program to calculate the radial strain at the bottom of the asphalt layer. This strain is then used in the fatigue curve to calculate the number of load applications to failure.

The stiffness values used for the fatigue analysis were obtained from the computer-generated relaxation curves at a temperature of 20°C (72°F) and a loading time of 0.1 s for each asphalt layer being

Figure 10. Properties of pavement sections analyzed.



Note: 1 mm = 0.039 in; 1 Pa = 0.000 145 lbf/in².

Table 1. Input parameters for calculations of viscoelastic thermal stresses.

Asphalt Cement	D_1	m	T_a	β	C_1	C_2
Original Peoria	7.463	0.68	−204	43.23	38.20	496.11
Rejuvenated Peoria (TFOT)	6.553	0.71	−170	33.74	29.72	425.25
AC-10 (TFOT)	7.260	0.79	−200	38.88	34.45	489.34

Note: $\alpha = -1.35 \times 10^{-6}/°F$ for all materials, D_1 = compliance at intercept of straight-line portion of master curve and time log t = 0, m = slope of straight-line portion of master curve, T_a, β = constants in the analytic solution to the Williams-Landell-Ferry equation, and C_1, C_2 = constants in the Williams-Landell-Ferry equation.

investigated. These stiffness values are shown in Figure 10. The stiffness value for the original layer has been reduced significantly to illustrate the loss in modulus due to extensive fatigue cracking, presumably the cause for the needed rehabilitation. The modulus of the granular layer also was selected to represent a saturated material. A linear elastic layer program was used to calculate radial strains at the base of the new material under an 80-kN (18-kip) single axle. The strains and estimated fatigue lives for the overlay (A) and 25-mm heater-scarified interlayer plus overlay (B) are given below (1 mm = 0.039 in):

Layer	Thickness (mm)	Strain (mm/mm)	Cycles to Failure
A	50	-1.83×10^{-5}	9.5×10^{9}
	76	-6.73×10^{-5}	1.4×10^{7}
	102	8.26×10^{-5}	5.1×10^{6}
B	63.5	9.08×10^{-5}	5.5×10^{6}
	89	$+1.21\times10^{-4}$	1.3×10^{6}
	114	$+1.22\times10^{-4}$	1.2×10^{6}

The prediction of fatigue lives from computer-generated pavement responses is highly dependent on the modulus values chosen for the original asphalt concrete and granular base. If the modulus value of the aged layer is used without a reduction for cracking [12 414 MPa (1 800 000 lbf/in²)], the predicted fatigue lives would be unrealistically high. The values calculated here may even be on the high side. Care must be exercised in selecting pavement parameters for an analysis of this nature. The numbers presented here indicate acceptable fatigue lives for both the overlay alone and the surface recycled pavement.

THERMAL-STRESS REFLECTION CRACKING

Thermal Stresses

Daily temperature cycles build up thermal tensile stresses in the asphalt concrete layers. These stresses will propagate a thermal-fatigue crack from the top downward in a pavement in which there are no cracks beneath the surface layer. This was recognized by Shahin (12) in his model, which attempted to quantify the appearance of thermal-fatigue cracking. When cracks exist beneath the surface layer, the temperature cycles will propagate a crack from the top and bottom toward the middle of the surface layer. The presence of the crack in the underlying layer provides such a stress concentration that crack initiation will most likely initiate at the bottom of the surface layer.

The first problem in predicting the rate of crack growth is in predicting the magnitude of the thermal stresses that are propagating the crack, a factor that has a considerable influence on the rate of crack growth. Thermal stress is dependent on the rate of temperature drop, the low temperature reached, and the viscoelastic time-temperature properties of the material. Previous attempts to predict these stresses have assumed "fictitious" loading times or have compared stresses at the assumed loading time of 20 000 s (12-14) to indicate which material is more susceptible to cracking.

A procedure developed for the solid-fuel rocket-propellant industry (15) and first applied to asphalt concrete pavements by Chang, Lytton, and Carpenter (2) has been shown to provide an accurate prediction of thermal stresses. This technique uses the viscoelastic curve, either relaxation or compliance, and actual climatic input for the temperature change. Previous examples have used laboratory-determined compliance data (2). Because these curves may not be readily obtained, the next best alternative is to use the nomographic procedures to develop the viscoelastic data. This procedure has been examined, and acceptable comparisons with laboratory data have been obtained.

The calculation procedures for the viscoelastic thermal stresses have been detailed elsewhere, and only the results are presented here. The input data extracted from the relaxation curves developed in the previous section are given in Table 1.

The temperature input data were developed from the heat-transfer program developed at the University of Illinois. The actual temperatures are for an average day in January at Abilene, Texas. These variations are not excessive and may be typical for a wide area of the Southwest. The surface temperature varied from 24° to 4°C (75°-41°F) from day to night. The temperature drop and time interval vary with depth into the pavement structure. This variation is shown in Figure 11 for the actual climatic data. These temperature and time values were used in the viscoelastic program.

The resulting thermal-stress distributions for the three materials are shown in Figure 12, where it is assumed the materials were placed as a surface. The relative magnitude of the stress for each material is as expected from a cursory analysis of the viscoelastic curves. The recycled interlayer produces the largest reduction in thermal stresses. The benefit of the heater-scarification interlayer becomes more apparent when the thermal stresses in each material are arranged to correspond to their structural relations. This has been done in Figure 13. The stress level in the interlayer is a definite improvement compared with a normal 77-mm (3-in) overlay.

Rate of Reflection Cracking

The rate of crack propagation can be effectively modeled by Paris' equation (16, p. 528). This relation has been verified by a number of researchers (17-19) as being applicable to asphaltic concrete:

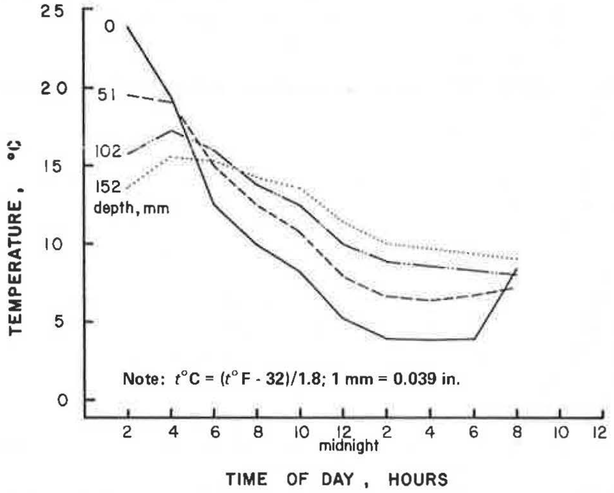
$$Nf = \int_{Co}^{Cf} [1/A(\Delta K)^n]\, dc \qquad (5)$$

where

Nf = number of cycles to failure,
Co = initial crack length,
Cf = final crack length following tensile-stress application,
A, n = viscoelastic and fracture properties of the mix,
ΔK = stress-intensity factor produced by thermal stress, and
dc = incremental crack growth.

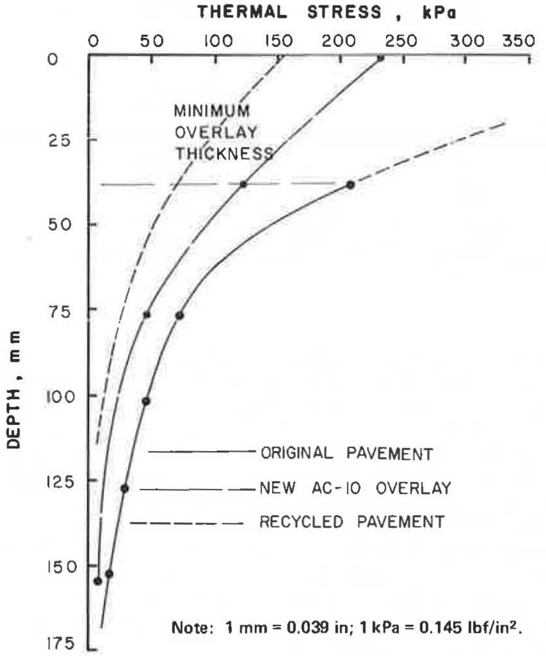
From theory (17), the factor n can be calculated as 2 [1 + (1/m)] from the relaxation curve, where m is the slope of the linear portion of the curve.

Figure 11. Temperature variation used to calculate thermal stresses.



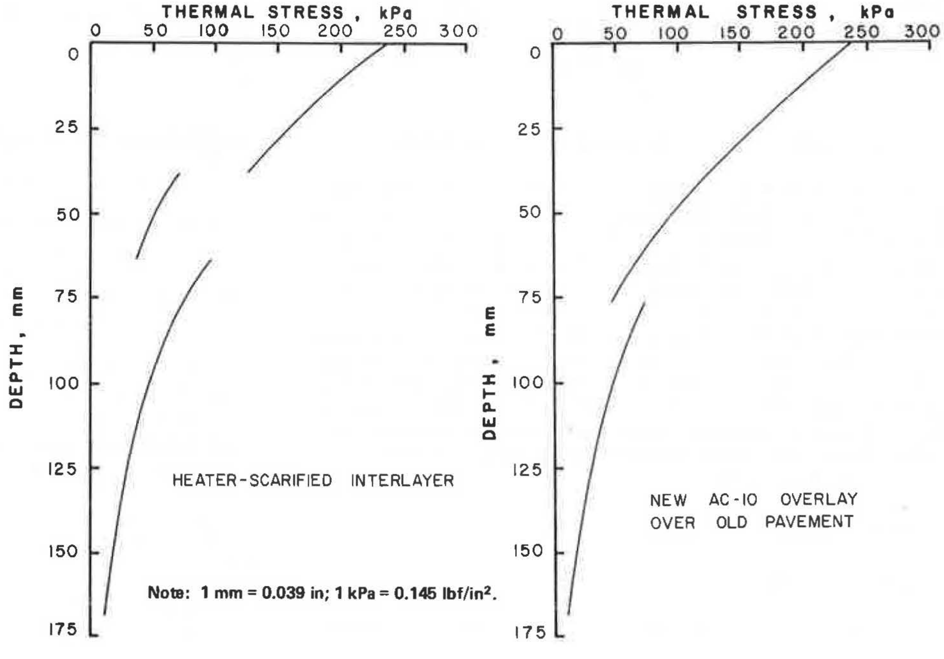
Note: t°C = (t°F - 32)/1.8; 1 mm = 0.039 in.

Figure 12. Variation in thermal stresses with depth for materials examined.



Note: 1 mm = 0.039 in; 1 kPa = 0.145 lbf/in².

Figure 13. Variation in thermal stresses with depth for pavement sections analyzed.



Note: 1 mm = 0.039 in; 1 kPa = 0.145 lbf/in².

The fracture parameter A can only be estimated from the literature. Typical values will range from 10^{-14} to 10^{-12}. There are not sufficient data available to relate the variation in A to asphalt properties. A value of 10^{-12} has been selected for calculations presented in this paper for all materials. The value of n will vary from 4.53 for the asphalt concrete overlay to 4.83 for the heater-scarified interlayer. These are representative of asphaltic materials.

The stress-intensity factor is needed to numerically integrate Equation 5 and obtain an estimate of the number of cycles to failure. In its simplest form, the stress will experience a singularity of the crack tip of magnitude $1/\sqrt{r}$, where r is the radius of the crack tip. The stress-intensity factor K is the magnitude of this increase. For similar geometric arrangements, r will be similar for all materials and the stress-intensity factors will be proportional to the tensile stress. If one uses this simplified approach with the tensile stresses indicating the stress-intensity factors, the number of cycles to failure will be proportional to the actual value obtained when the actual stress-intensity factors are used. The values obtained by integrating Equation 5 with tensile stresses are as follows: (a) For a new 76 mm (3-in) overlay, Nf = 400; (b) for a 25-mm (1-in) interlayer with a 38-mm (1.5-in) new overlay, Nf = 1200.

The results indicate that the heater-scarifier process could last nearly three times as long as a 76-mm overlay under the effects of thermal stresses. Assuming these stresses occur during a fourth of the year, the life of the overlay would be approximately 4 years whereas the heater-scarified pavement would last nearly 12 years. This life is considerably shorter than the period covered by the fatigue analysis. This indicates that the environmental influence in this example will be more severe than fatigue and that surface recycling will definitely show a benefit.

This performance level is highly dependent on the thermal stresses that develop. These stress levels will depend on the rejuvenating effect of the recycling agent on the aged binder. The factor of three may be an upper limit that results from a very good combination of the two asphalts examined in this study. A more in-depth study would examine the influence of several recycling agents to select the best combination to minimize thermal stresses but at the same time not adversely affect the fatigue characteristics of the pavement. Preliminary studies with another recycling agent, several reclaimed asphalts from pavements in Illinois, and virgin asphalt cements from new construction in Illinois are providing results similar to those presented here.

CONCLUSIONS

The study discussed in this paper has shown that the materials produced in the heater-scarification recycling process have the potential to perform at least as well as a new overlay 76 to 102 mm (3-4 in) thick. Proper selection of recycling agent and virgin asphalt for the overlay can provide a far longer life for the heater-scarified overlaid pavement from a consideration of environmental damage. This fact combines well with the fact that surface recycling can be a very economical alternative.

The main point that should be obtained from this paper is that a technology does exist that allows relative performance to be accurately investigated. The performance comparisons can then be used to help justify surface recycling from considerations other than just cost. The performance comparisons commonly attributed to heater scarification have been based primarily on observations of in-service pavements. The results presented here are among the first analytic data to indicate why the observations show the heater-scarification process to be so successful. The soft interlayer lessens the accumulation of damage due to climatic influence without adversely affecting the fatigue life.

This paper presents numerical results for one actual material that was put through the recycling process and tested. The encouraging results indicate that further studies on the characteristics of a 100 percent recycled material with recycling agents added are needed if the full benefits of heater-scarification recycling are to be realized. This paper uses calculated or predicted values for fatigue and stiffness values. Further laboratory study is needed to characterize these 100 percent recycled materials to verify the validity of the predictive schemes for these materials and to quantify any problems that may develop through indiscriminate use of recycling agents with certain asphalts.

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The contents of this paper reflect my views, and I am responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the Illinois Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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Analysis and Repair of Water-Damaged Bituminous Pavement

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An investigation of several bituminous concrete pavements on the Interstate system that experienced failures suspected to have been caused by stripping is reported. On two of the pavements, the degree of deterioration and potential serviceability was determined from the indirect tensile strength of cores and Dynaflect test results. Recommendations based on the investigation have resulted in repairs that are believed to be best suited to each situation. An emulsion mix design was developed for stripped bituminous concrete removed from a project with the expectation that it could be used as a surface mix on a highway with a low volume of traffic; however, because of risks involving performance, it was recommended for use as a base course. Resurfacing on a project that had experienced stripping failure is being monitored, and its performance is being evaluated.

Stripping, which is the separation of the asphalt coating from the surface of the aggregate in flexible pavements, has resulted in considerable damage to several Virginia pavements in recent years. The deterioration that has resulted from the stripping has varied in severity from minor cracking to almost complete disintegration of the pavement. In 1978, stripping was suspected to be causing deterioration on several Interstate pavements, and an investigation was undertaken to determine the condition of several sections of distressed pavement and to recommend rehabilitative measures.

Although stripping problems in bituminous pavements have been encountered for many years, little attention has been given to selecting the most appropriate rehabilitative measures for particular situations. Usually, a resurfacing is applied as a temporary solution to the problem and no attempt is made to optimize the service life of the pavement. The initial step in deciding on the best type of repair for a given situation should be to determine the cause of failure, the degree of damage, and the strength of the overall pavement structure. The type of repair and rehabilitation selected should prevent further deterioration, where necessary, and strengthen the pavement structure so that it will provide satisfactory service. Other important factors that must be considered are limitations on the funds that are available and such construction-related restraints as the need to maintain the flow of traffic and the occurrence of minimum bridge clearances that limit the thickness of resurfacings. In Virginia, limitations on maintenance funds are becoming severe because of the reduction in tax revenue occasioned by reduced consumption of gasoline and inflation.

TESTS USED

In the investigation reported here, a testing program was designed to determine the strength of the overall pavement structure and that of the asphaltic concrete courses under dry and wet conditions. Because pavements usually develop more distress under wet than under dry conditions, the wet strength was considered to be important.

Several sections of Interstate roads were investigated. The most extensive testing was conducted on sections of I-64 and I-85. In 1979, 34 and 30 cores were removed from I-64 and I-85, respectively. The cores were subjected to indirect tensile tests, as described later, to gain an indication of the overall strength and the loss in strength caused by moisture. In addition, a visual determination of stripping was made.

Viscosity and penetration measurements were made according to ASTM D2170 and ASTM D5, respectively,