reduced the rate of reflective cracking in both the 2- and 4-in.-thick asphaltic-concrete overlay sections. No conclusions can be drawn at this time with respect to the 6-in.-thick overlay section.

2. The best performance to date has been obtained with the waterproofing membranes.

3. Even when reflective cracking appears over joints with membrane treatment, the cracks appear to stay tighter than cracks over joints without membrane treatment.

4. Proper preparation of the existing concrete pavement and stabilization of slabs with large corner movements must be done in order to obtain maximum benefit from the joint treatment.

5. A minimum of 4-in.-thick asphaltic-concrete overlay should be used on jointed-concrete pavement, and the membrane treatment should be used to control the rate of reflective cracking.

6. The use of waterproofing membranes over concrete pavement joints before placing an asphalt overlay has been adopted as a standard practice in Georgia.

ACKNOWLEDGMENT

The data presented in this paper were obtained as part of Research Study 7502, Overlays for Plain Concrete Pavements, funded by FHWA and Georgia DOT.

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

Trade and manufacturers' names appear in this paper only because they are considered essential to the object of the document and do not constitute endorsement of a product by FHWA or Georgia DOT.

This paper does not constitute a standard, specification, or regulation.

Publication of this paper sponsored by Task Force on Engineering Fabrics.

Laboratory Testing of Fabric Interlayers for Asphalt Concrete Paving: Interim Report

ROGER D. SMITH

Because of the proliferation of paving products being presented as reflection crack retarders, the need developed for laboratory tests that can be used as a screening device to avoid the extensive costs and delays associated with full-scale field tests of all of these products. This need resulted in an FHWA-financed research project to generate laboratory tests for estimating the effect of various fabric interlayers on asphalt concrete (AC) overlay properties such as (a) water permeability, (b) susceptibility to flexural fatigue reflection cracking, (c) susceptibility to vertical shear fatigue reflection cracking, and (d) susceptibility to horizontal shear failure (slipping). Testing was also done to characterize popular fabrics in terms of physical and mechanical properties such as tensile strength, elongation, modulus, weight, thickness, and heat resistance. Possible correlations between these fabric properties and the above four overlay properties were investigated. In addition, methods for estimating the optimum asphalt tack-coat application rate for fabrics were developed. These research efforts have led to a more educated and selective use of fabrics in AC paving.

Laboratory test methods can be used to predict the relative in-service performance of fabric interlayers in asphalt concrete (AC) pavement overlays as well as the amount of asphalt tack coat to be used with each fabric type. To better understand the need and use of these test methods, the following items are described in this paper:

1. Basic causes of AC overlay cracking,
2. Popular theories of fabric interlayer effectiveness in reducing overlay cracking,
3. Earlier research efforts to predict interlayer effectiveness by using laboratory tests,
4. Measurement of physical and mechanical properties of 12 commercially produced fabrics,
5. Laboratory testing of AC specimens to investigate the effectiveness of fabric interlayers in thwarting the common causes of overlay reflection cracking, and
6. Attempted correlations between the physical and mechanical properties of the fabrics and their performance in the above tests.

BACKGROUND INFORMATION

The reflection of cracks from old distressed pavement through relatively new AC overlays significantly decreases the service life of these overlays. Numerous fabric materials--primarily polyesters and polypropylenes, as well as rubber-asphalt combinations--are being proposed as interlayers to retard this reflection cracking, but no laboratory procedures have been developed to evaluate the validity of these claims. Simple laboratory tests are therefore needed for the

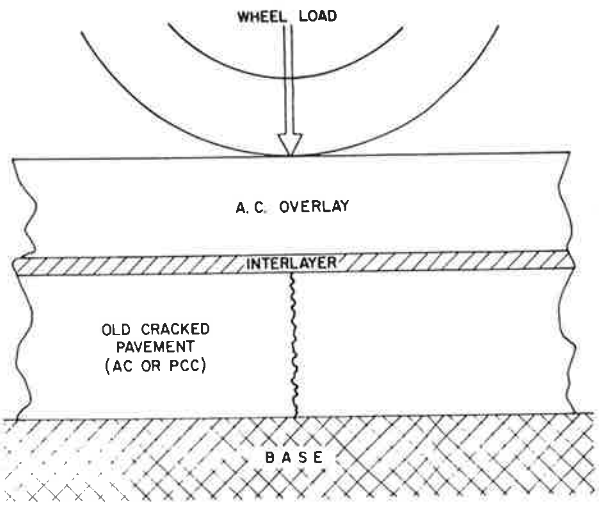
1. Analysis of the mechanisms by which reflection cracking occurs,
2. Estimation of the benefits of using various interlayers,
3. Definition of which interlayer properties correlate to crack retardation, and
4. Avoidance of the extensive costs and delays that are associated with full-scale field testing of inappropriate materials.

Reflection cracking is the propagation of cracks from an existing surfacing of portland cement concrete (PCC) or AC through the resurfacing layer. This problem is serious. Many different remedies have been tried (with varying degrees of success) to eliminate or deter such cracking.

Reflection cracking develops from movement of the pavement under the overlay (Figure 1). It can be caused by several mechanisms, such as

1. Differential vertical movement at a crack or slab joint in the old pavement, which induces a vertical shear stress in the overlay;
2. Horizontal movement associated with tempera-

Figure 1. Pavement overlay components.



ture or moisture changes in the old pavement, which induces tensile stress in the overlay; or

3. Live load flexural stress in the overlay, which tends to concentrate directly over discontinuities.

Since the advent of paving with fabric interlayers in the early 1970s, many claims have been made as to the benefits and problems that might be expected from this relatively new and unconventional paving technique. There were claims of fabric being nothing short of a cure-all for all types of overlay cracking, and many researchers began assigning a structural equivalency (in terms of AC thickness) to fabric for all applications. This meant that thinner overlays could be used, thereby resulting in added benefits where vertical controls existed. However, over the years, as a result of many field test sections, it has become apparent that the use of fabric interlayers in AC overlays is not always cost effective.

To better understand what role fabric might play in AC overlay work, a brief discussion of the mechanics of overlay cracking and the popular theories of how fabric might work are presented below.

Overlay Cracking Mechanisms

Reflection cracking of AC overlays has several primary causes:

1. Flexural fatigue is caused by high wheel load deflections that tend to be concentrated at localized structural inadequacies in the supporting material or at a crack in an underlying pavement structure;
2. Thermal strains that develop in the old pavement, especially PCC slabs during diurnal temperature cycles, can be transmitted to the overlay if the interlayer bond is strong enough; and
3. Various degrees of differential vertical movement (Δ-vert) at discontinuities (such as joints or cracks) in the underlying pavement can occur under heavy wheel loads, especially when the underlying pavement is curled.

Fabric Theory

Several theories have been advanced that support the claim of the ability of fabric to deter reflection cracking.

1. Stress-relieving interlayer theory: This hypothesis is that the fabric simply acts as a containment reservoir for the heavy asphalt tack coat and thereby provides a soft, ductile zone that has a blunting effect on a crack tip advancing into it. The stresses concentrated at the tip of the crack are thereby dissipated and the advance is halted.
2. Slip plane theory: This theory holds that a fabric interlayer system will fail in shear (in the plane of the fabric) before transferring any significant amount of stress from the old pavement (underlayer) to the overlay. This hypothesis applies primarily to overlay cracking that results from tensile stress induced by a cracked or jointed underlayer responding to thermal or moisture changes, such as in the case of a PCC pavement overlaid by AC.
3. Tensile reinforcement theory: This theory holds that the fabric has a reinforcing effect on the AC overlay in a manner similar to the effect of steel tensile reinforcement (rebar) in PCC structures.
4. Waterproofing theory: It is also commonly believed that fabric makes an overlay more impermeable; therefore, base and subase material are not subject to weakening by hydraulic action. This protection results in the overlay being subjected to less local deflections and an overall less-severe flexural fatigue effect.

Other Research

Before this current study, these four theories had been investigated by controlled laboratory testing in only a limited fashion, as discussed below.

Germann and Lytton (1) of the Texas Transportation Institute investigated the fatigue life of AC that contained a fabric interlayer in the straight (axial) tensile loading mode. Their study dealt with theories 1 and 3, and their research revealed that beams containing fabric exhibited axial tensile fatigue lives several times those with no fabric. Although they recognized that the fabric's contribution to the AC tensile strength was not sufficient to prevent initial cracking, they did claim that the fabric was beneficial in slowing the rate of crack growth by preventing the crack from opening up to those displacements necessary for crack growth. They also reported that the fabrics withstood the strain of crack opening without rupture, which is an important consideration in the waterproofing theory mentioned previously.

Perhaps the earliest laboratory flexural testing of AC beams with fabric was done in 1972 by Draper and Gagle (2) of the Phillips Petroleum Company. Although their investigation dealt with the effects of Petromat on flexural yield strength (as opposed to fatigue life), it did disclose marked improvement (300 to 800 percent) in that property in beams containing Petromat compared to beams with a tack coat only.

Majidzadeh of Ohio State University (3) performed research testing with respect to theory 1. He concluded that, for low-stress situations, a fabric interlayer placed at the lower third point of an AC beam increased its flexural fatigue life by more than 1,000 percent. Also, with respect to theory 2 (the rebar theory), his research revealed that the fabric interlayer was of virtually no value in increasing the fracture toughness of an AC beam specimen, and probably of little value in resisting the high tensile strains associated with thermally induced movements.

The Iowa Department of Transportation (4) attempted some laboratory flexural fatigue testing of sand-asphalt beams with and without various fabric

Table 1. Fabric properties.

Fabric	Weight (oz/yd²)	Thickness[a] (mils)	Grab Tensile[b] (mils)		Elongation[b] (%)		Secant Modulus[c] (psi)	
			Machine Direction	Cross-Machine Direction	Machine Direction	Cross-Machine Direction	Machine Direction	Cross-Machine Direction
Reepav 376 (Dupont)	3.0	14	110	79	63	64	4,650	3,250
Nicofab B50 (Nicolon)	4.9	68	80	133	100	79	1,339	552
Amoco 4545 (Amoco)	6.6	40	142	147	73	104	1,890	1,480
Trevira 1117 (Hoechst)	4.4	51	162	119	82	111	1,666	810
Petromat (Phillip Fibers)	4.5	40	81	132	85	74	2,294	1,483
Bidim C-22 (Monsanto)	3.2	51	125	98	90	98	1,878	871
Bidim C-34 (Monsanto)	9.6	77	178	151	57	73	1,939	1,731
TrueTex MG75 (True Temper)	6.5	56	170	98	96	97	1,936	666
TrueTex MG100 (True Temper)	6.5	88	174	114	94	116	896	414
Duraglass B-65 (Johns-Manville)	9.8	77	126	116	3	3	–[d]	–[d]
Q-Trans-50 (Quline)	7.0	105	93	142	173	107	350	160
Fibretex 200 (Crown-Zellerbach)	6.0	73	183	126	145	175	1,025	368

Note: All values are from Transportation Laboratory (TransLab) testing.
[a]ASTM 461.
[b]ASTM 1117; 1-in. grip.
[c]At 50 percent strain, unless tearing occurs.
[d]Tear.

interlayers. This testing involved four different fabric brands: Petromat, Bidim C-28, TrueTex MG75, and Reepav T-323. This research revealed that the fatigue lives of beams with fabric were from two to four times that of control beams without fabric.

Another laboratory effort in the area of fabric interlayer effects on the flexural fatigue lives of AC beams (0.5 in. maximum) was undertaken by the E.I. DuPont Company (5), the producers of Reepav. This study, in addition to Reepav, also involved Petromat and Bidim. The testing indicated that the fatigue life of fabric was 2 to 22 times greater than the fatigue life of beams without fabric.

With respect to theory 4, a limited amount of permeability testing of cores from new AC pavement containing Petromat interlayers was performed by Bushey (6) of the California Department of Transportation (Caltrans) by using a vacuum pump arrangement. These early tests indicated that a Petromat interlayer could reduce the water permeability of AC. The study also revealed that, in the presence of AC cracking, the Petromat fabric did not appear to rupture, which suggested that even after the overlay has cracked, the fabric can act as a water barrier. More recent field observations by Caltrans personnel suggest that fabric can rupture at crack locations if strains (vertical or horizontal) are sufficient.

Other controlled research in the area of fabric permeability was done by the E.I. DuPont Company (5). This testing, which involved subjecting asphalt-saturated fabric specimens to a hydrostatic head of water, indicated that five test fabrics, with sufficient asphalt saturation, could form an adequate moisture barrier. These results may be of limited significance, however, because no effort was made to simulate the effects of imbedment in an AC pavement structure. However, the results did demonstrate that thin fabrics can provide an impermeable layer by using much less asphalt tack coat than thicker fabrics.

RESEARCH TESTING

Laboratory testing performed as part of this research project involved 12 brands of nonwoven fabric from 10 different manufacturers. These fabrics are listed in Table 1. Also tested were two woven, asphalt-backed membranes--Bituthene and Polyguard. All test specimens of a given fabric brand were cut from the same large parent sample, which represented one roll of production fabric. In all areas of testing, specimens without any interlayer treatment (control specimens) were also tested.

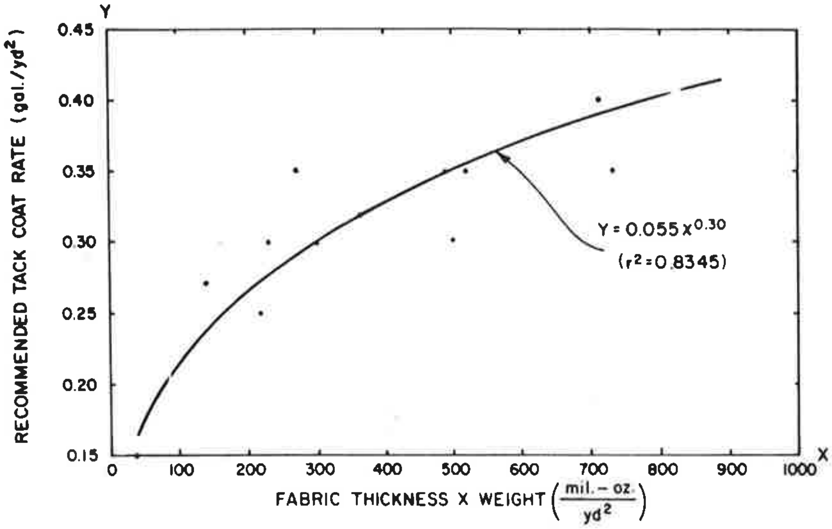
The various test procedures described in this section were designed with the primary objective being to reasonably simulate in-service conditions and mimic some critical behavior or failure mechanism inherent in AC overlays.

Fabric Property Measurements

Measurements of the physical properties of all test fabrics were made by TransLab's Commodities Unit. A total of eight fabric properties were measured, and the results are given in Table 1.

Although most of these fabric property tests are explained by their ASTM test method reference, it is believed that the secant modulus property should be explained further. Secant modulus, as used in this paper, is simply the slope of the stress versus strain plot for tensile loading of a 3x5-in. fabric specimen by using 3x5-in. grips and a 1-in. guage length. This slope value, for purposes of this paper, is defined as the ratio of stress (pounds per square inch) to strain (percent) at the point of 50 percent strain. Because the 3x5-in. specimens in this study used a guage length (grip separation) of 1 in., the secant modulus was simply the stress at 0.5-in. elongation divided by 0.50. The values given in Table 1 are the average of three tests at a loading rate of 12 in./min.

Figure 2. Recommended tack-coat rate versus fabric weight x thickness.



Estimation of Tack Coat Requirements

In order for any pavement interlayer system to be successful, it must achieve satisfactory bonding with both the overlay and the existing pavement or underlayer. In the case of a fabric interlayer, this proper bonding should depend on the tack coat that penetrates the fabric from its underside and provides sufficient excess on the fabric's top surface to effect proper bonding with the underside of the overlay. In order for this situation to be realized, three things must occur:

1. The tack coat must be made liquid (melted) enough to enable it to invade the fabric,
2. The tack coat must stay liquid long enough for its migration through the fabric to occur, and
3. External compressive pressure must usually be applied to the system when the tack asphalt is still liquid in order to provide a sponging effect on the fabric.

For this situation to occur, it is apparent that inputs of heat and pressure are necessary. The heat demand must be met by heat from the overlay mix that is adjusted for the overlay thickness, the temperature of the underlayer, and the air temperature and wind speed during paving. The required pressure will be supplied from the deadweight of the overlay and the compactive effort on the overlay.

Testing Discussion

In designing a routine laboratory test for a fabric's asphalt saturation potential (ASP), it is prudent to simulate the probable worst-case field conditions, namely:

1. Low temperature of existing pavement = 40°F;
2. Thin overlay = 0.10 ft;
3. Relatively cool overlay mix = 250°F;
4. Minimal rolling effort = 3 passes of a 12-ton roller; and
5. Heat availability and dwell time = 5 min.

The details of this test cannot be presented here, but basically the test involves placing a 250°F AC briquette (4 in. in diameter) on top of a fabric, under which is an asphalt (AR-4000) film of known thickness (which represents a known tack-coat rate). The briquette is loaded to simulate rolling forces, and the fabric is inspected for degree of saturation.

Recommended tack coat rates for the fabric's tested are given in the table below:

Fabric	Lightest Tack-Coat Rate Found to be Acceptable (gal/yd²)
Amoco 4545	0.35
Bidim C-22	0.25
Bidim C-34	0.35
TrueTex MG75	0.30
TrueTex MG100	0.35
Trevira 1117	0.30
Nicofab B50	0.30
Petromat	0.25
Reepav 376	0.15
Q-Trans-50	0.35
Fibretex 200	0.30

An investigation was made of possible correlations that might exist between the recommended tack rate (from melt-through testing) and various fabric properties. It was hypothesized that the tack-coat demand of a fabric would depend largely on two fabric properties: weight and thickness. After unsuccessful attempts to establish a meaningful correlation with either of these properties individually, a reasonably valid (r^2 = 0.8345) correlation was observed to exist with their product (weight x thickness). This relation is given in Equation 1 and shown in Figure 2:

$$RTC = 0.055\ TW^{0.30} \quad (1)$$

where

RTC = recommended tack-coat rate (gal/yd²),
T = fabric thickness (mils), and
W = fabric weight (oz/yd²).

Note that the RTC values calculated from fabric weight and thickness by using Equation 1 should be taken as estimates, and values should be rounded to the nearest 0.05 gal/yd² to be consistent with the accuracies of field application techniques.

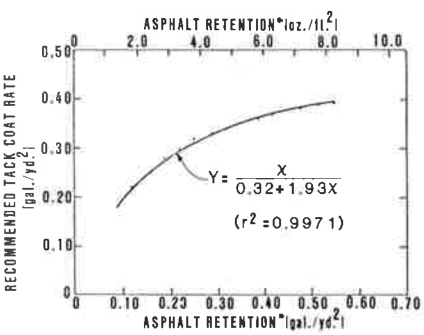
Other Tests for Estimating Tack Coat Requirements

Recognizing the need for a simpler test than the one just described, an investigation was made of a test developed earlier by the Texas State Department of Highways and Public Transportation (7).

The asphalt retention values obtained by using the Texas test had satisfactory correlations with TransLab RTC determinations, as shown in Figure 3. However, the Texas method for determining tack-coat rate, although simple, was not considered an acceptable test method because it did not simulate field conditions. For example, some of the fabric samples shrunk as much as 50 percent in their linear dimensions while in the 285°F oven. This is not comparable to field conditions, where the fabric would be restrained from shrinking. Also, the Texas test did not consider the role of roller pressure or AC mix weight and heat in accomplishing the saturation. It was therefore decided that TransLab should develop its own simple test, with an objective being that any such test should have satisfactory correlation with RTC values obtained from the melt-through test.

The TransLab motor oil retention test was developed to meet this need. In this test, a piece of the fabric is soaked in 20W motor oil at 70°F for 2 min, then removed and placed on an inclined (7.5°) surface. Next, a 3350-g steel cylinder is rolled down the incline 6 times to remove some of the excess oil on the fabric (Figure 4). The weight of the oil retained in the fabric is determined and a recommended tack rate is estimated by using the TransLab correlation shown in Figure 5. (Note that in Figure 5 the tack-coat rate includes 0.05 gal/yd² to fill voids in the surface that receives the tack coat.)

Figure 3. Recommended tack rate versus asphalt retention.



Interlayer Permeability

This study involved the development of a laboratory test for measuring the permeability of AC that contains fabric interlayers and also involved measuring and comparing the permeabilities in AC of 14 paving fabrics. Also measured were permeabilities of an interlayer of asphalt tack coat only (without fabric) and of control specimens (i.e., no interlayer treatment of any kind). Although not yet attempted, permeability tests of pavement cores that contain cracks are also planned.

Another aspect of this study involved determining whether AC aggregate punches through the fabric interlayer during compaction, and whether such punch-through necessarily leads to higher permeability.

In order to make the permeability information obtained in these laboratory tests applicable to field conditions, the specimen was made to model an AC pavement that contains fabric. This model was a 4-in.-diameter DGAC (type A, 0.75-in. maximum aggregate, 5.3 percent AR-4000 asphalt binder) briquette that was 2 in. in height and had a paving fabric sandwiched at middepth (see Figure 6).

The water permeability test apparatus (Figure 7) developed by Chevron was selected for simplicity after trying other less-realistic methods that involved waxed briquettes and vacuum pumps. A

Figure 4. Motor oil retention test setup.

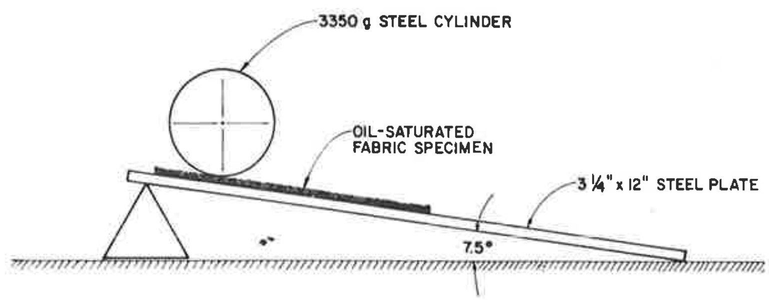
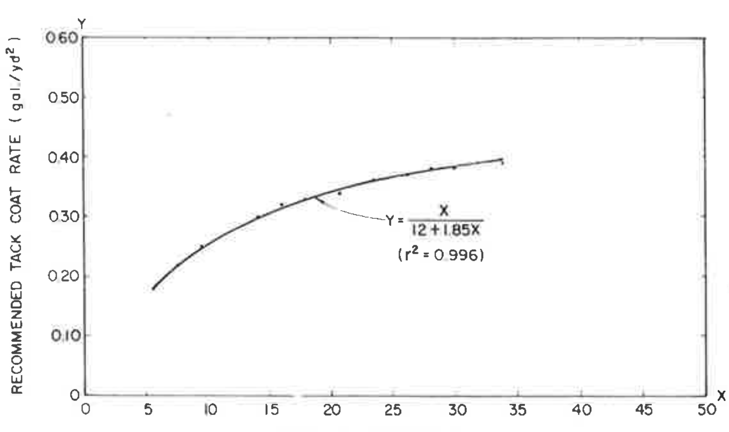
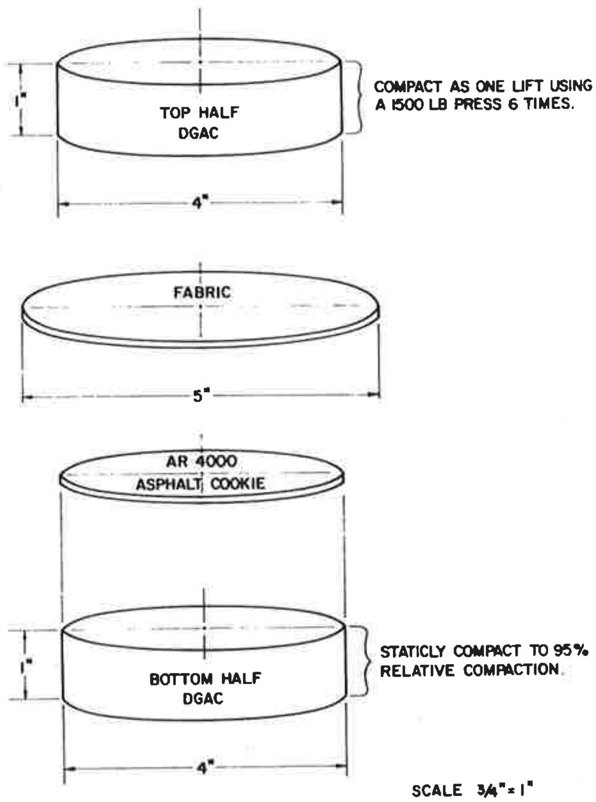


Figure 5. Recommended tack-coat rate versus motor oil retention.



falling-head permeability test was run with an initial head of 8 in. Readings were made in milliliters of the flow at 5, 10, 30, and 60 min. Aerosol was used in the water as a wetting agent at a ratio of 95 mL to 5 gal of water. This minimized the tension of the surface water as it passed through the briquette. This test was repeated at least twice per specimen; each time the dome-to-briquette joint was retaped. All values are reported in Table 2.

Figure 6. Permeability test specimen.



After testing, the briquettes were placed in a 140°F oven and broken down to allow retrieval of the fabric "cookie." The fabric was checked for aggregate punch-through and lack of asphalt saturation.

Correlation between the light transmission and the measured permeability was then investigated based on the assumption that the recovered fabrics that exhibited greater light transmission (aggregate punch-through) would yield higher permeability values, but no such correlation was observed. Small discrete holes, apparently made by sharp edges of aggregate, were noticed on some fabrics, but these fabrics did not necessarily exhibit high permeabilities. This suggests that the openings within the fabric are plugged or otherwise blocked (at least partly) when the fabric is tightly sandwiched in the AC test specimen, and that aggregate punch-through is probably not a major contributor to high permeability.

An investigation was also made into possible correlations between laboratory-measured permeabilities and the following fabric properties: thickness, ultimate strength in weaker direction, and fabric modulus at 50 percent strain. No acceptable correlation(s) was found to exist.

Even though no explanation is offered, note that the following fabrics consistently provided very low interlayer permeability: Reepav 376, Bituthene, and Duraglass B-65.

Although some interlayers performed better than others, note that all interlayer treatments provided a significant reduction in permeability. Even those specimens with only the heavy tack-coat interlayer (no fabric) exhibited, for the most part, very low permeability. This suggests that the primary role of the fabric (from the standpoint of permeability) may be to distribute and secure the tack asphalt as a continuous, uniform membrane within the AC mat. (Note that field experiments by Caltrans have thus far failed to corroborate these laboratory permeability test findings.)

Figure 7. Water permeability apparatus.

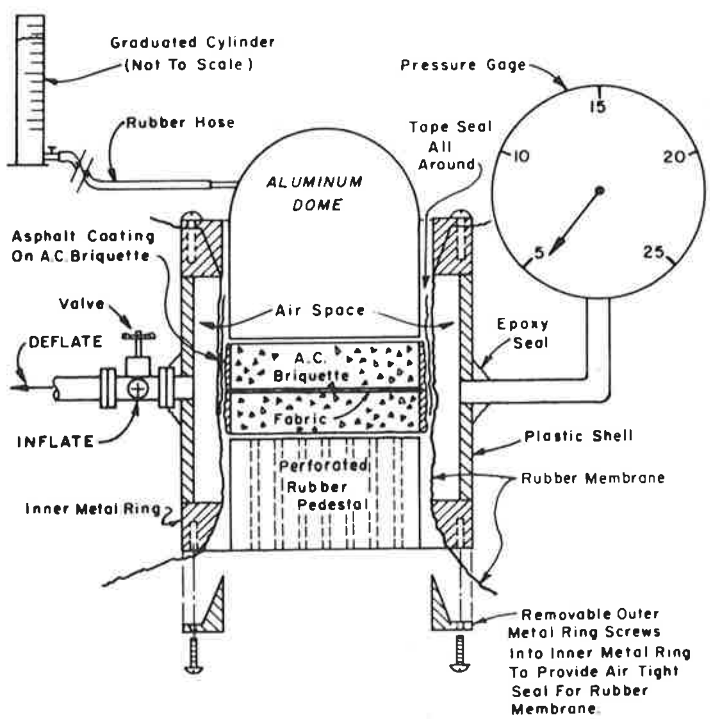


Table 2. Permeability test results.

Interlayer Type	5 Minutes			10 Minutes		
	Specimen A	Specimen B	Specimen C	Specimen A	Specimen B	Specimen C
Petromat	10, 120	100, 60	180, 140	10, 180	140, 110	240, 220
Bidim C-22	125, 90	∞, ∞, ∞	290, 280, ∞[a]	210, 160	∞, ∞, ∞	350, 380, ∞[a]
Bidim C-34	130, 70	270, 150	100, 100	200, 120	290, 230	140, 175
TrueTex MG75	20, 20	100, 40, 10[a]	70, 45	50, 30	200, 70, 20[a]	100, 80
TrueTex MG100	85, 50	240, 30, 10[a]	100, 30, 40[a]	150, 80	350, 60, 20[a]	150, 60, 70[a]
Duraglass B-65	15, 20	30, 10	20, 0	30, 30	60, 20	30, 0
Q-Trans-50	70, 80	30, 20	100, 55	130, 130	60, 30	150, 110
Fibretex 200	90, 70	5, 0	230, 50, 120[a]	160, 110	25, 5	310, 120, 90[a]
Reepav 376	0, 0	0, 0	20, 5	5,0	5, 0	30, 10
Nicofab B50	100, 50	110, 60	220, 130, 45[a]	170, 90	180, 70	300, 95, 200[a]
Amoco 4545	210, 30, 30[a]	20, 10	255, 70, 180[a]	260, 50, 50[a]	35, 10	320, 135, 290[a]
Trevira 1117	—[b], —[b]	—[b], —[b]	100, 220, 130[a]	—[b], —[b]	—[b], —[b]	310, 170, 210[a]
Bituthene	0, 0	0, 0	0, 0	0, 0	0, 0	0, 10
Polyguard	0, 0	0, 10	30, 60	5, 0	10, 10	75, 130
Tack coat only	0, 0	120, 150	20, 0	0, 0	190, 260	30, 0
Control	∞, ∞	—[b], —[b]	∞, ∞	∞, ∞	—[b], —[b]	∞, ∞

Note: All values shown are in milliliters of head drop.
[a]Third replicate test where repeatability was poor.
[b]Not tested in this specimen group.

Flexural Fatigue

Because of the severe stress-concentrating effect of a crack in an underlying pavement, flexural fatigue reflection cracking can occur with the repeated application of normal truck loads. Popular theories that attempt to explain why fabric might delay reflection cracking in these fatigue situations are as follows:

1. The fabric acts as a tensile element (similar to a reinforcing bar in PCC) to resist tensile crack formation and possibly even to reduce wheel load deflection; and
2. The tip of the old crack is effectively blunted by the relatively soft asphalt and fabric interlayer; thus the energy of the crack is dissipated and further growth is curtailed, or at least delayed.

Testing Discussion

To simulate the action of a rolling wheel load, a pneumatic flex-fatigue machine (Figure 8) was designed and built at TransLab to subject an AC beam specimen (Figure 9) to a realistically critical degree of bending. This machine simulates a rolling wheel load by applying the load by a series of four loading feet that "walk" across the beam in sequence (Figure 10).

At the same time that the flexural load is being applied, the beam specimen is subjected to an axial tensile load to simulate thermal-induced stress and create a realistic combined stress condition that should assure crack advancement through the entire beam cross section. The support for the beam specimen consisted of a simply-supported aluminum T-beam, on top of which was a 0.25-in.-thick rubber pad. This pad allowed Δ-vert movement in the specimen between loading feet.

The beam specimen itself (3x3x12 in.) consists of a top and bottom layer each 1.5 in. thick (Figure 9). In an effort to simulate age-hardened asphalt, Chemcrete was used for the top half of the beam. The bottom half was made of conventional AC (0.5-in. maximum aggregate). Fabric interlayers incorporated an appropriate AR-4000 asphalt tack coat.

A 0.125-in.-wide saw cut was then made in the bottom half of the beam specimen to a depth that left a remaining thickness of 1.75 in. This saw cut simulated a crack in an underlying pavement and was positioned between the middle two loading feet in order to permit differential vertical movement (Δ-vert) and vertical shear stress development in the remaining beam cross section. It is believed that the use of a loading scheme that allowed this vertical shear stress development, in conjunction with flexural and axial tensile stresses, was a big step toward realism in laboratory fatigue testing of AC.

The force exerted by the loading feet on the beam was chosen to produce a maximum radius of curvature in the beam of approximately 125 ft. Early work by Dehlen (8) had found this to be a critical degree of curvature beyond which cracking could be expected in 1- to 2-in.-thick AC pavement. The load cycling frequency was 12 cycles/min (5 sec/cycle), as shown in Figure 11. Degree of curvature in the beam specimen was measured and recorded each time crack length was measured. The device used for measuring curvature is shown in Figure 12.

The axial tensile load applied to the beam specimen during the fatigue loading was 35 lb, which resulted from a machine setting of 5 psi-gauge-pressure (psig). The intent in selecting the magnitude of the tensile load was to use a low-range load that would ensure elimination of any top fiber compressive stress in the beam and promote cracking full-through the beam top half.

Throughout the course of each beam test, continuous autographic plots of flexural and axial loads versus time were complied. Each specimen's plot provided a complete record of loading history.

Crack length measurements were made on the front and back faces of the specimen at regular intervals of 200 to 400 cycles by using a divider and an engineer's scale. The average of these two values was used in all analyses. Visibility of the crack was enhanced by coating both faces of the specimen with white spackling compound. The test was considered finished when the crack reached the top surface on both faces. All tests were run at room temperature, which varied within a range of 68° to 74°F.

Three beam specimens were tested for each interlayer treatment. Interlayer treatments tested were limited to various fabrics (a total of 12) and a heavy asphalt tack coat without fabric. Several control specimens (no interlayer treatment) were also tested.

Results

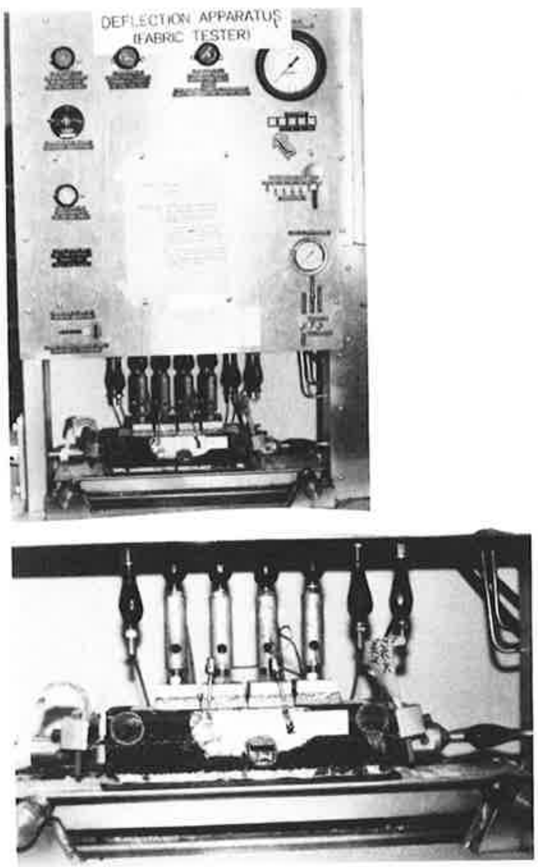
For each beam tested, a plot of crack length (c) versus number of loading cycles (N) was constructured. An average curve was constructed from the valid tests for each interlayer treatment. These average plots are shown in Figure 13.

Beam specimen top-half mix properties were considered the most likely cause of the inconsistent fatigue performance. Therefore, a normalization study was undertaken wherein the mix properties (Table 3) of several identical beam specimens without fabric were determined in hope of divulging normalizing factors that could be used to correct the c versus N curves.

Because none of these normalizing efforts was successful, it was concluded that the error must be random and could possibly have resulted from differences in aggregate arrangement and orientation. For simplicity of presentation, an average c versus N plot was constructed for valid tests of each interlayer treatment. The average plots are presented in Figure 13.

At the start of this project it was considered a top priority to maintain realism in all testing. A conventional AC mix was therefore used with extreme precaution taken to ensure consistency in mix variables and, it was hoped, to minimize this random type of error. It now appears that in order to avoid this error and to enable isolation of interlayer effects on fatigue life, further testing will be required by using a more homogeneous beam specimen. Therefore, a phase 2 fatigue investigation will be undertaken that involves beams made of a homogeneous sand-asphalt mix. In this study, as in phase 1, a hardened Chemcrete binder will be used to simulate aged AC pavement.

Figure 8. Flexural fatigue machine.



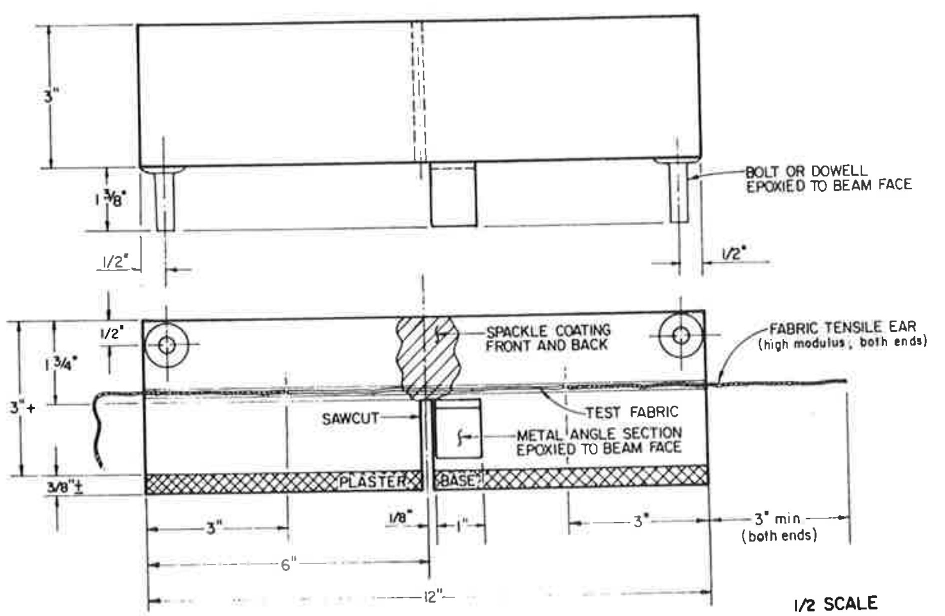
Interlayer Shear Strength

Whenever an AC overlay is placed on a discontinuous existing pavement--especially on PCC slab pavement--it will be subjected to tensile stresses induced by longand short-term thermal strain in the underlying pavement (1). Long-term strains are those associated with the slabs' slow thermal (expansion-contraction) response to seasonal changes, whereas short-term strains are those that result from diurnal slab curling cycles (8). These two effects are additive and time-varying to produce a net stress inducement in an overlay that can often cause reflection cracking.

Axial tensile stress can only be induced in the overlay if it is transferred across the interface between overlay and PCC slab. A condition of tight intimate bonding at this interface would theoretically provide the potential for 100 percent strain transfer. This condition should be realized at low temperatures.

An investigation was undertaken to determine the relation between interlayer shear strength and temperature for AC specimens with and without inter-

Figure 9. Flexural fatigue beam specimen.



layer treatments. This information could then be used in the

1. Determination of the relative potentials for stress relief in the various interlayers,
2. Assessment of the relative effects of the various interlayers on the horizontal shear strength and slippage potential of the AC, and
3. Indication of the degree that overlay bond is affected by various interlayers.

Also, by using this shear strength information, an analysis can be made of the potential for slipping under wheel loads (9,10).

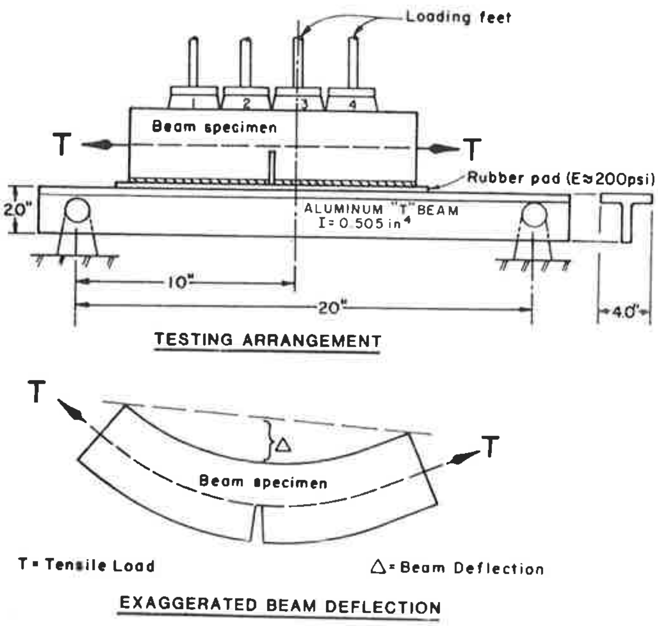
For the testing procedure of interlayer shear strength, 3x3x12-in. AC beam specimens from the flexural fatigue testing were cut roughly into quarters lengthwise. Two beams of each interlayer type were quartered to produce eight specimens with shear areas approximately 3x2.75 in. All shear tests were done on the apparatus shown in Figure 14, which was used in conjunction with a Baldwin 6,000-lb testing machine.

The bottom half of the specimen was clamped securely so that no rotational movement could take place. A vertical load was applied to the other (top) half of the specimen so that a shear force was created on the interlayer. A plot of head movement versus load was made for each specimen by using an X-Y plotter. The shear test was performed at five temperatures (-20°, 0°, 20°, 60°, and 100°F) at a shear rate of 0.05 in./min.

The ultimate shear load was recorded and divided by the interlayer cross-sectional shear area to obtain the ultimate shear strength. Shear strength versus temperature was then plotted for each interlayer. Finally, the average curve for each interlayer treatment was plotted to facilitate direct comparisons (Figure 15).

The following observations were made from the test results:

Figure 10. Flexural fatigue testing arrangement.



NOTE :

Beam specimen is positioned so that loading feet 2 and 3 straddle the sawcut. This results in the specimen not being exactly centered on the support beam.

Figure 11. Loading cycle diagram for flexural fatigue test.

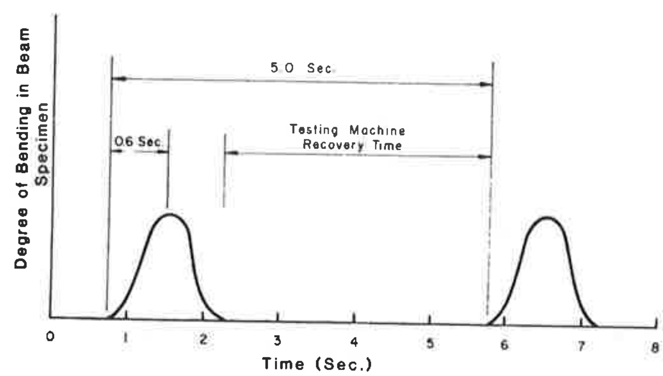


Figure 12. Measurement of degree of bending in beam specimen.

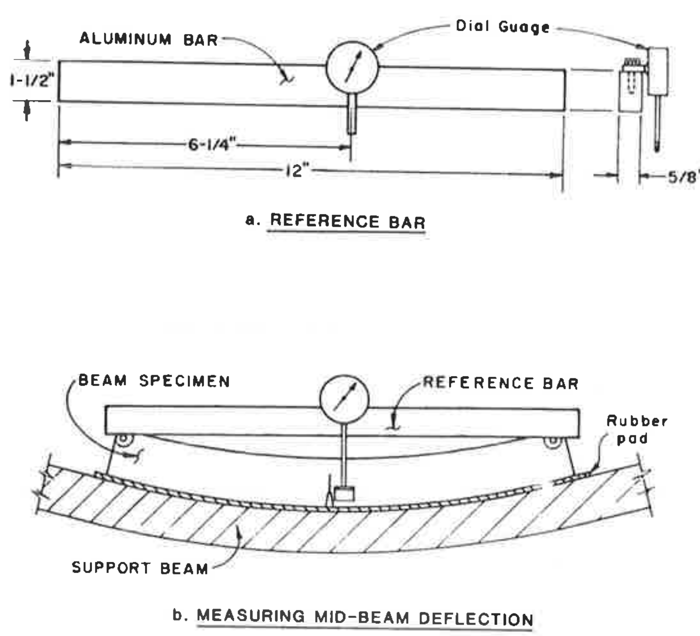


Figure 13. Averaged c versus N curves for each interlayer type.

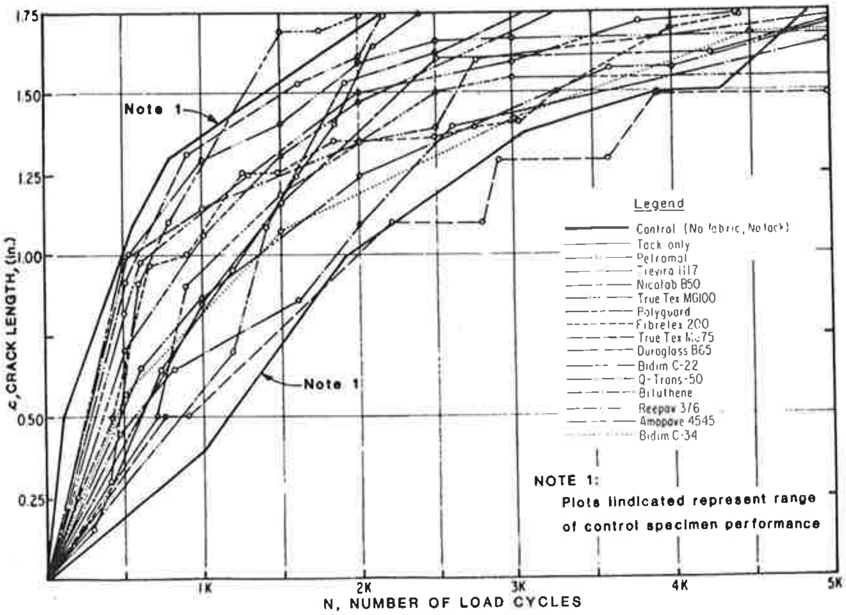


Table 3. Data used in normalization effort.

			Properties of Top Half of Beam Specimen			
Specimen No.	Interlayer Treatment	Load Cycles at c = 1.0 in.	Micro-viscosity[a] (MP)	Shear Suscepta-bility[a]	Bond Strength[b] (psi)	Air Voids[c] (%)
43	None	1,500	1,020	0.37	940	5
41	None	1,100	178	0.30	1,022	4
42	None	600	265	0.53	898	5
54	None	1,900	670	0.32	980	4
61	None	2,000	186	0.32	850	4
38	None	1,300	1,580	0.21	786	5
69	None	600	225	0.34	841	4
50	None	1,400	1,080	0.33	844	4
78	TrueTex (MG75)	1,900	680	0.42	1,005	6
79	TrueTex (MG75)	4,100	900	0.23	862	4
80	TrueTex (MG75)	600	920	0.32	944	6

[a]California test method 348.
[b]AASHTO test T177-68 (1978).
[c]California test method 367.

1. For thin fabrics (Reepav and Petromat), the beam-to-beam difference was minimal, which suggested that 100 percent melt-through always occurred.

2. For thick fabrics (TrueTex MG75, Q-Trans-50, and Bidim C-34), the beam-to-beam shear strength difference was higher, which suggested that partial saturation can occur, thereby resulting in less satisfactory bonding and lower horizontal shear strengths.

3. Fabric interlayers reduced the shear strength of the AC by approximately 50 percent at any temperature (-20° to +100°F).

4. Membranes with a rubberized asphalt backing (Bituthene and Polyguard) did not weaken in shear by embrittling at low temperatures (down to -20°F).

5. Shear strength did not appear to be related to the weight or thickness of the fabric (assuming 100 percent saturation).

6. At temperatures greater than 100°F, all of the fabric interlayers tested had virtually no shear strength.

Differential Vertical Movement

Differential vertical movement (Δ-vert) at underlayer discontinuities (such as joints or cracks in overlaid PCC pavement) has long been known to be a major cause of reflection cracking in AC overlays (11,12). Therefore an attempt was made to design a laboratory fatigue test whereby an aged AC specimen could be subjected to a vertical shear fatigue mode of loading. Specimens would be tested with and without interlayer treatments in an effort to understand what effect, if any, an interlayer such as fabric will have on an overlay's resistance to this type of reflection cracking.

Developmental testing by using the apparatus in Figure 16 is continuing at this time. Due to the erratic test behavior witnessed thus far, it is suspected that further refinements of the test method will be required, including the use of a specimen more than 2 in. thick.

Fabric Heat Resistance

Claims have been made that polypropylene fabrics, such as Petromat and Fibretex 200, are severely affected by temperatures greater than 300°F. Earlier tests that involved exposing a polypropylene fabric sample to oven temperatures around 300°F showed the fabric to shrink considerably, embrittle, and even disintegrate in some cases. Oven testing, however, does not simulate the true conditions a paving fabric will experience in service. First, soaking the fabric specimen in a hot oven provides a more severe thermal exposure than would be realized by a fabric under a hot overlay mix that is rapidly cooling, at least in the immediate area of contact with the fabric. Second, in the overlay situation, the fabric quickly becomes saturated with the asphalt tack coat, which effectively insulates individual fiber strands from thermal extremes. Finally, the severe shrinkage of the fabric that is observed in oven testing is not realized in an overlay structure where the surrounding AC mat and the fabric's large area create a condition of full restraint. A simple test was therefore devised in an attempt to better simulate in-service conditions that a fabric experiences.

In TransLab's testing, a 6x6x2-in.-thick block of 325°F dense-graded AC (confined in a wood mold) was placed on a fabric specimen approximately 1 ft² resting on a wooden base block. No tack coat was used. A 1,500-lb load was then applied to the top of the hot AC block and held for 1 min. After removing the load and AC block, the fabric specimen was visually inspected for changes.

Petromat and Fibretex 200, the two polypropylene fabrics tested, showed no visible signs of damage or dimensional change. Some additional fusing of the individual fiber strands appears to be the only sign of change. This could possibly lead to a slight change of tensile strength or secant modulus.

Based on these findings, together with field observations, it was concluded that the claims of polypropylene's degradation as a result of heat exposure are not applicable to pavement overlay situations.

INTERIM CONCLUSIONS

Estimating Tack-Coat Requirements

1. The tack-coat application rate required by a paving fabric can be estimated if fabric thickness and weight are known or by using a simple motor oil retention test.
2. Saturation of the fabric by the asphalt tack coat usually requires the presence of heat and pressure.

Flexural Fatigue

1. In closely controlled fatigue testing of AC specimens, the random error associated with aggregate position and orientation is sufficient to mask fabric-related differences in fatigue life.
2. Paving fabrics do not appear to reduce the initial deflection of AC beams in laboratory testing. This suggests that a fabric interlayer is not a significant tensile reinforcing element in an AC pavement.
3. Fatigue crack growth through the AC beam specimens did not appear to be delayed by fabric interlayers.

Interlayer Shear Strength

1. The shear strength of interlayers that involve nonwoven fabrics is maximum in the 0° to +20°F range and virtually zero at more than +100°F.
2. Fabric interlayers reduced the horizontal shear strength of the AC by approximately 50 percent at any test temperature.
3. Membrane interlayers that have a rubber-asphalt backing (Bituthene and Polyguard) do not weaken in shear by embrittlement at low temperatures (down to -20°F).
4. Interlayer shear strength could not be correlated to fabric weight or thickness.

Interlayer Permeability

1. Fabric and asphalt interlayers can provide drastic reductions in the water permeability of AC.
2. An asphalt interlayer without fabric also provides a drastic reduction in the water permeability of AC.
3. Punch-through of the fabric by sharp-edged aggregate does not lead to increased permeability. The fabric interlayers apparently have a self-sealing effect.
4. No correlation was observed between a fabric's permeability as an AC interlayer and its physical and mechanical properties.

Figure 14. Interlayer shear test setup.

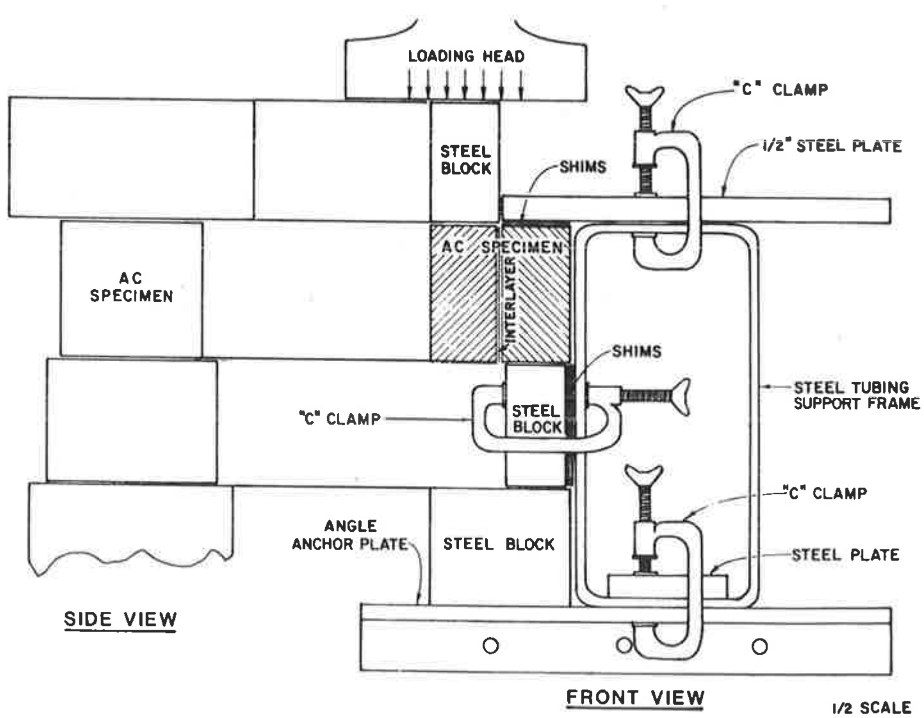


Figure 15. Average interlayer shear strength versus temperature.

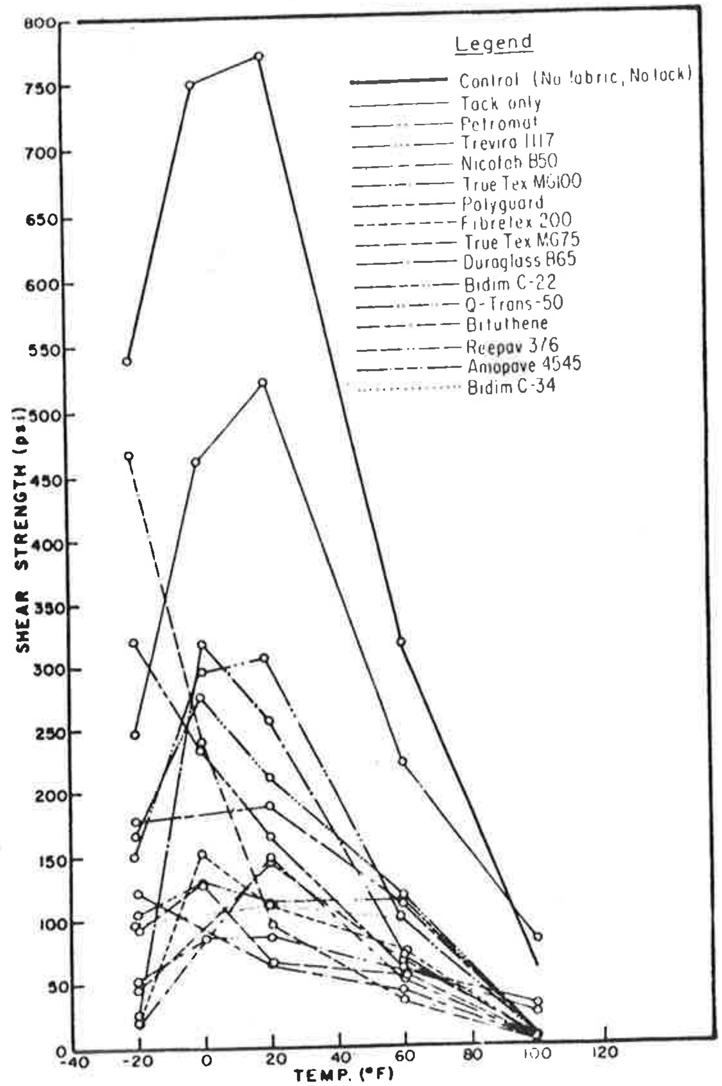
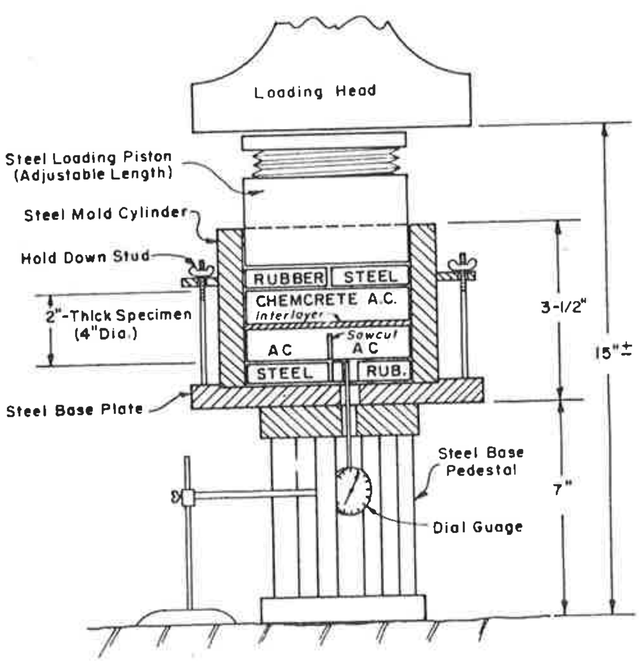


Figure 16. Shear fatigue test setup.



Differential Vertical Movement

Laboratory attempts to test the effect of Δ-vert on AC cracking were not successful. Therefore, a special gauge was developed for field measurement of Δ-vert.

Fabric Heat Resistance

Polypropylene and polyester fabrics do not appear to suffer adverse effects from being in contact with hot (325°F) AC mixes.

ACKNOWLEDGMENT

I wish to acknowledge the efforts of Tom Fellenz, assistant transportation engineer, Caltrans, who performed much of the specimen preparation, testing, and data analyses in connection with this study.

I also wish to acknowledge Brian Murray, associate transportation engineer, and Roy E. Steiner, machinist and instrument maker, for the design and construction of the flexural fatigue testing machine.

This research was funded as part of the Highway Research Program, FHWA.

Note that product brand names were used in this paper because of the comparative nature of the study and in the interest of presenting information meaningful to the reader.

REFERENCES

1. F.P. Germann and R.L. Lytton. Methodology for Predicting the Reflection Cracking Life of Asphalt Concrete Overlays. Texas Transportation Institute, Texas A&M Univ., College Station, Rept. 207-5, March 1979.
2. H.L. Draper and D.W. Gagle. Asphalt Pavement Laminated with Petromat Fabric. Phillips Petroleum Company, Greenville, SC, May 1972.
3. K. Majidzadeh. A Laboratory Investigation of the Use of Petromat for Optimization of Pavement Performance. Ohio State Univ., Columbus, Nov. 1976.
4. J.J. Roland. Beam Tests for Fabrics Used in Reduction of Reflection Cracking. Iowa Department of Transportation, Ames, April 1981.
5. C.D. Murray. Simulation Testing of Geotextile Membranes for Reflection Cracking. E.I. du Pont de Nemours and Company, Wilmington, DE, 1982.
6. R.W. Bushey. Experimental Overlays to Minimize Reflection Cracking. California Department of Transportation, Sacramento, Sept. 1976.
7. Fabric Underseal Specification. Texas State Department of Highways and Public Transportation, Austin, Item 3099, Feb. 1978.
8. G.L. Dehlen. Flexure of a Road Surfacing, Its Relation to Fatigue Cracking, and Factors Determining its Severity. HRB, Bull. 321, 1962, pp. 26-39.
9. C.L. Monismith and N.F. Coetzee. Reflection Cracking Analyses, Laboratory Studies, and Design Considerations. Univ. of California, Berkeley, 1980.
10. J.A. Epps and J.W. Button. The Slippage Question on Airport Pavements. Texas Transportation Institute, Texas A&M Univ., College Station, Interim Rept. RF 3424-2, 1979.
11. H.J. Treybig and others. Overlay Design and Reflection Cracking Analysis for Rigid Pavements. FHWA, Rept. FHWA-RD-77-66, 1977.
12. K.H. McGhee. Efforts to Reduce Reflective Cracking of Bituminous Concrete Overlays of Portland Cement Concrete Pavements. Virginia Highway and Transportation Council, Charlottesville, 1975.

Publication of this paper sponsored by Task Force on Engineering Fabrics.

Reflection Cracking Models: Review and Laboratory Evaluation of Engineering Fabrics

KAMRAN MAJIDZADEH, GEORGE J. ILVES, AND MICHAEL S. LUTHER

A review of recent theoretical models for analyzing reflection cracking in pavements is presented. Four models are applicable to asphalt overlays of jointed-concrete pavements, and one model deals with asphalt overlays of existing flexible pavements. Both mechanistic and phenomenological models are reviewed, together with a critique of each model's shortcomings. A two-dimensional finite-element analysis of flexible overlay stress for jointed-concrete slabs subjected to seasonal and daily temperature changes is presented. The analysis shows that, contrary to some existing models, curling temperature gradients (cold or slab surface relative to bottom) produce joint openings that induce only tension stress in the overlay. A technique is presented for equating daily (curling) thermal loads to seasonal thermal loads in terms of equivalent maximum overlay stress. The finite-element analysis suggests that a reflection cracking model must consider the ratio of loading and temperature dependency of the asphalt overlay modulus in any stress calculation. Laboratory testing is currently being conducted to verify reflection cracking models and assess performance of geotextiles and stress-absorbing membrane interlayer systems to reduce cracking.

Reflection cracking is the cracking of a resurface or overlay above underlying cracks or joints. It occurs in overlays of both flexible and rigid pavements and is a major cause of distress; it includes spalling, surface water infiltration to underlying layers, and a general reduction in structural stiffness. Reflective cracks require continued future maintenance for crack sealing and patching and thus are a significant expense item.

Reflection cracking is not a new engineering problem. Since the early 1950s many different materials, methods, and techniques have been tried to prevent or at least delay reflection cracking. Most of these efforts have been for an asphalt concrete (AC) overlay on existing portland cement concrete (PCC) slab applications, where existing cracks or joints are usually reflected through the overlay within a year (1). Early research recognized that the probable cause of reflection cracking was movement of some form in the underlying pavement at existing cracks and joints. This movement can result from both traffic- and environment-induced forces, and includes differential vertical movement, thermal- or moisture-induced expansion, contraction, or distortion (curling) at underlying joints and cracks.

Because the overlay is bonded to the existing pavement, movement at underlying joints or cracks induces stresses in the overlay. Sufficiently high stresses can cause fracture or cracking of the overlay. If the induced stresses do not exceed the yield strength of the overlay material, cracking could still develop as the result of cyclic load applications that produce fatigue fracture of the AC. Bond breakers, cushions, rubber-asphalt stress-absorbing membrane interlayers (SAMIs), fabrics, and stronger overlays modify the existing pavement and are among the methods that have been used in an attempt to mitigate the reflection cracking problem.

The literature indicates that reflection cracking studies and field experiment projects to date have generally been of an empirical nature, with little control or identification of the parameters known to affect cracking. Characterizing the existing pavement in terms of joint width, load transfer, crack spacing, crack and joint opening under known temperatures, and deflection under load are usually not part of such studies. Obviously, certain crack-prevention treatments are sensitive to some of these factors, as demonstrated in numerous field studies.