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Installation and Initial Evaluation of Paving Fabric Interlayers for Mitigating Reflective Cracking in Pavements

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16. Abstract:

Propagation of cracks from existing pavements into a new asphalt concrete overlay (reflective cracking) is a major problem for both rigid and flexible pavements. Reflective cracking in pavements compromises ride quality and reduces the service life of the pavement. Reflective cracking of the asphalt layer over jointed concrete pavement is a perennial problem in Virginia and elsewhere. State transportation agencies continue to try various available treatment methods to delay or prevent reflective cracking with corrective or restorative maintenance. Some of those treatments include using paving fabric as an interlayer. Virginia has anecdotal experience with paving fabric interlayers, but little well-documented history with which to assess performance.

The objective of this study was to establish a performance baseline for fabric interlayers in conjunction with asphalt concrete overlays on existing flexible, rigid, and composite pavements by documenting the installation and initial field performance of several projects in Virginia. Two types of interlayer fabric were used. One of the interlayers needed an asphalt leveling course for placement based on the manufacturer's specifications. As expected, all of the sections with interlayers are performing well. However, most of the sections were placed in 2017 and 2018, and hence the performance data are preliminary. These sections need to be monitored continuously to track pavement distress and performance over time. The cost of using interlayers in pavement ranged from $6.0 to $8.0 per square yard, depending on the type of fabric and installation method. Long-term performance data are needed to assess the benefit-cost effectiveness of using paving fabric interlayers in pavements.

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FINAL REPORT

INSTALLATION AND INITIAL EVALUATION OF PAVING FABRIC INTERLAYERS FOR MITIGATING REFLECTIVE CRACKING IN PAVEMENTS

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ABSTRACT

Propagation of cracks from existing pavements into a new asphalt concrete overlay (reflective cracking) is a major problem for both rigid and flexible pavements. Reflective cracking in pavements compromises ride quality and reduces the service life of the pavement. Reflective cracking of the asphalt layer over jointed concrete pavement is a perennial problem in Virginia and elsewhere. State transportation agencies continue to try various available treatment methods to delay or prevent reflective cracking with corrective or restorative maintenance. Some of those treatments include using paving fabric as an interlayer. Virginia has anecdotal experience with paving fabric interlayers, but little well-documented history with which to assess performance.

The objective of this study was to establish a performance baseline for fabric interlayers in conjunction with asphalt concrete overlays on existing flexible, rigid, and composite pavements by documenting the installation and initial field performance of several projects in Virginia. Two types of interlayer fabric were used. One of the interlayers needed an asphalt leveling course for placement based on the manufacturer's specifications. As expected, all of the sections with interlayers are performing well. However, most of the sections were placed in 2017 and 2018, and hence the performance data are preliminary. These sections need to be monitored continuously to track pavement distress and performance over time. The cost of using interlayers in pavement ranged from $6.0 to $8.0 per square yard, depending on the type of fabric and installation method. Long-term performance data are needed to assess the benefit-cost effectiveness of using paving fabric interlayers in pavements.

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INTRODUCTION

Propagation of cracks from existing pavements into new asphalt concrete (AC) overlays (reflective cracking) is a major problem for both rigid and flexible pavements. Reflective cracking of the asphalt layer placed over jointed concrete pavement (JCP) is a perennial problem in Virginia and elsewhere. It is a result of horizontal and vertical movements at the joints and cracks in the underlying JCP. Temperature changes cause the slabs to contract and expand, causing horizontal movements at the joints, whereas traffic loadings and inadequate base support produce differential vertical movements, causing shear and bending stress in the AC overlay. Cracks in continuously reinforced concrete pavements (CRCPs) are held tight by the reinforcing steel, and thus transverse cracks and crack width can be reduced and, in general, reflection of transverse cracks through the asphalt overlay is less of an issue than with JCP.

The Virginia Department of Transportation (VDOT) maintains 5,540 lane-miles of interstate and 21,997 lane-miles of primary network. On the interstate network, 1,069 lane-miles of roadway are asphalt over JPC (designated bituminous over jointed concrete, BOJ) and 768 lane-miles are asphalt over CRCP (designated bituminous over continuously reinforced concrete, BOC). On the primary network, 1,184 lane-miles are BOJ and 118 lane-miles are BOC.

Reflective cracking is a serious challenge associated with corrective and restorative maintenance; it leads to premature failure of the overlay and allows water infiltration through the cracks, which causes stripping in AC layers and weakening and deterioration in the base and subgrade (Elseifi and Bandaru, 2011). Further reflective cracking in pavements compromises ride quality and reduces the service life of the pavement. State transportation agencies are trying various available treatment methods to delay or prevent reflective cracking in rehabilitated pavements. The key to delaying reflective cracking is to reduce the stresses and strains produced in the asphalt overlays.

Treatments that are used to reduce or prevent reflective cracking include use of paving fabric as an interlayer, which can be used to reinforce asphalt overlays by carrying tensile stress and to provide a waterproof barrier (Amini, 2005). VDOT has limited experience with paving fabric interlayers and thus no performance data are available. Previous studies on the effectiveness of paving fabric interlayers as crack control treatments have shown mixed results, and the findings indicate that the performance of these products depends on many factors including the installation procedures and condition of the existing pavement (Button and Lytton, 2007; Dhakal et al., 2016). The technologies continue to advance, and a wide variety of new interlayer systems are now available. However, field trials and further performance monitoring are needed to ensure that interlayers have real performance advantages for overlays of existing cracked and jointed concrete and asphalt pavements.

PURPOSE AND SCOPE

The purpose of this study was to establish a performance baseline for fabric interlayers in conjunction with AC overlays on existing flexible, rigid, and composite pavements by documenting the installation and initial field performance of several projects in Virginia. Another objective was to conduct a review of the contemporary literature about paving fabric interlayers. This performance baseline study and future performance monitoring of the sections will permit an effective revision to VDOT specifications for pavement interlayers, addressing uses, benefits, applications, and limitations.

METHODS

Literature Review

Literature related to paving fabric interlayers was identified by searching various databases related to transportation engineering such as the Transport Research International Documentation (TRID) database. The identified literature was then reviewed to summarize the findings from the relevant previous work.

Field Trials

The field trials were conducted on asphalt, concrete, and composite pavements (BOJ). Field trials on asphalt pavements are shown in Table 1, and those for concrete and composite pavements are shown in Table 2. Field trials on asphalt pavements included a control section (without interlayer). The field trial on the composite pavement on State Route (SR) 143 Southbound (SB) also included a short control section (0.3 miles long). In Table 2, SR 30 Eastbound (EB) had the exposed jointed concrete surface; the rest were composite pavements.

Table 1. Field Trial on Asphalt Pavements

District/County	Route Name	MP From	MP To	Asphalt Mix Type	Year of Placement
Lynchburg/Appomattox	Route 611	1,000 ft from intersection of SR 26 and Route 611		SM 9.5D	2016
Salem/Henry	US 58 EB	18.372	21.08	SM 9.5D	2018

MP = mile post; SM = surface mixture; EB = eastbound.

Table 2. Field Trial on Concrete and Composite Pavements (BOJ)

District/County	Route Name	MP From	MP To	Asphalt Mix Type	Year of Placement
Hampton Roads/ York	SR 143 NB and SB	5.65	6.71	SM 9.5D	2017
Hampton Roads/ York	US 17 SB	4.80	6.63	SM 12.5D	2017
Hampton Roads/ Sussex	US 460 EB and US 460 WB	11.52	14.62	SM 12.5D	2018
Hampton Roads/ James City	SR 30 EB	3.84	4.89	SM 9.5D	2018
Hampton Roads/ Accomack	US 13 NB	17.40	18.03	SM 12.5D	2018

BOJ = bituminous over jointed concrete; MP = mile post; NB = northbound; SB = southbound; SM = surface mixture; EB = eastbound; WB = westbound.

Documentation of Installation and Construction

The placement of interlayer and construction were documented for the projects identified in Tables 1 and 2. The researchers observed the installation of paving fabric and noted placement-related details such as surface preparation, propensity to wrinkle, and overlaps. Application rates of asphalt binder/emulsion were recorded, as were key fabric properties. Samples of the asphalt mixtures used to surface the interlayer product were also collected from the projects for further testing.

Laboratory Performance Testing of Asphalt Mixtures

The properties of the overlying asphalt layer are important to the performance of the overall system. Therefore, asphalt mixtures used for the overlay were characterized using a series of standard laboratory performance tests.

Dynamic Modulus

Dynamic modulus tests were performed using the Asphalt Mixture Performance Tester (AMPT) with a 25 to 100 kN loading capacity in accordance with AASHTO TP 79, Standard Method of Test for Determining the Dynamic Modulus and Flow Number for Asphalt Mixtures Using the Asphalt Mixture Performance Tester (AMPT). Tests on laboratory-produced specimens were performed on 100-mm-diameter by 150-mm-high specimens. The specimen air-void contents were 7 ± 0.5%. All dynamic modulus tests were conducted in the uniaxial mode without confinement. Stress versus strain values were captured continuously and used to calculate dynamic modulus.

Flow Number (FN) Test

FN tests were performed using the AMPT. Tests were conducted at 54°C. The test temperature is the design high pavement temperature at 50% reliability as determined using Long-term Pavement Performance Binder (LTPPBind) software at locations in central Virginia.

A repeated haversine axial compressive load pulse of 0.1 second every 1.0 second was applied to the specimens. The specimen air-void contents were 7.0 ± 0.5%. The tests were performed in the unconfined mode using a deviator stress of 600 kPa. The tests were continued for 10,000 cycles or a permanent strain of 5%, whichever occurred first. During the test, permanent strain (εp) versus the number of loading cycles was recorded automatically, and the results were used to estimate the FN. The FN was determined numerically as the cycle number at which the strain rate is at a minimum based on the Francken model.

Asphalt Pavement Analyzer (APA) Test

The APA test was conducted in accordance with Virginia Test Method 110 (VDOT, 2014). APA tests were conducted on gyratory compacted specimens at a test temperature of 64ºC on specimens having 7.0% air voids. The APA test used an applied load of 100 lb and a hose pressure of 100 psi. The rut depth resulting after 8,000 cycles of load applications was reported. It included the average rut depth of the four replicates for each mixture type.

Ideal Cracking Test (IDEAL-CT)

The Indirect Tensile Asphalt Cracking Test (IDEAL-CT) for cracking resistance has been proposed by researchers at the Texas Transportation Institute (Zhou et al., 2017). According to Zhou et al., this test shows promise in relating a laboratory-measured index to field performance, reasonable repeatability, and simplicity by requiring no cutting, drilling, gluing, or notching of the specimen. The IDEAL-CT is typically run at 25ºC with 150-mm-diameter and 62-mm-high cylindrical specimens and a loading rate of 50 mm/min. This test uses a gyratory compactor to prepare specimens compacted to 7% air voids that is placed in a Marshall load frame (or similar load frame) and loaded to failure in the indirect tensile mode. The load-displacement curve is used to determine the CT Index, a crack susceptibility indicator.

Texas Overlay Test

The Texas overlay test was performed in accordance with TX-248-F-2019 (Texas Department of Transportation [DOT], 2019) to assess the susceptibility of mixtures to reflective cracking. All specimens were within 7.0 ± 1.0% air voids. The test was conducted in the displacement-control mode until failure occurred at a loading rate of one cycle per 10 seconds with a maximum displacement of 0.63 mm at 25 ± 0.5°C. The number of cycles to failure is defined as the number of cycles to reach a 93% drop in initial load.

Semi-Circular Bend (SCB) Test

An additional cracking test, the SCB Illinois Flexibility Index Test (I-FIT), was conducted in accordance with AASHTO TP 124-16, Standard Method of Test for Determining the Fracture Potential of Asphalt Mixtures Using Semicircular Bend Geometry (SCB) at Intermediate Temperature (AASHTO, 2017). Tests were conducted at ambient laboratory temperature (~21ºC). All specimens were within 7.0 ± 0.5% air voids.

Cantabro Mass Loss Test

The Cantabro mass loss test was conducted in accordance with AASHTO TP 108-14, Standard Method of Test for Abrasion Loss of Asphalt Mixture Specimens (AASHTO, 2017). The test was performed by placing one compacted specimen in a Los Angeles abrasion test drum and subjecting it to 300 drum revolutions in the absence of the abrasion charges. Mass loss is calculated at the end of the experiment. Relative loss is considered a durability indicator.

Shear and Tensile Bond Strengths of Field Cores

Shear and tensile bond strengths of the fabric interface from three projects were measured using 4-in field cores (Virginia Test Method 127). Eight cores were taken from each project. More details for the test methods can be found in an earlier report by McGhee and Clark (2009).

Performance Monitoring

Distress data for the existing pavement (i.e., prior to fabric interlayer and overlay application) and performance data after fabric placement and overlay construction were collected from VDOT's Pavement Management System (PMS). The field performance of several sections were evaluated through field visits. The asphalt surface distresses that were collected from VDOT's PMS included transverse cracking, longitudinal cracking, reflective transverse cracking, reflective longitudinal cracking, alligator cracking, longitudinal joint cracking, patching, potholes, delamination, bleeding, and rutting. In VDOT's PMS, three condition indices are used to rate pavement sections based on the observed distresses. The first is the load related distress rating (LDR), which measures pavement distresses caused by traffic loading. The second is the non-load related distress rating (NDR), which measures pavement distresses that are not load related, such as those caused by environmental or climatic conditions. These two condition indices range from 0 to 100, where 100 signifies a pavement having no distresses. The third is the Critical Condition Index (CCI), which is the lesser of the LDR and the NDR. In addition to storing the individual distress data, VDOT's PMS calculates and stores the LDR, the NDR, the CCI, and the International Roughness Index (IRI) for all sections.

RESULTS AND DISCUSSION

Literature Review

A detailed literature review is presented in the Appendix. A summary of that review is presented here.

The use of paving fabrics in a properly designed structural section is expected to reinforce asphalt overlays by carrying tensile stress and providing a waterproof barrier, thus mitigating reflective cracking from the underlying pavement. The fabrics are usually designed to be saturated with paving asphalt and can be effective in addressing block and alligator cracking as well as oxidized pavement surfaces (Miner and Davis, 2010). No improvement in performance is likely to occur if wide transverse thermal and shrinkage cracks are present (Cleveland et al., 2002). In the case of JCP or CRCP, it is recommended that fabrics be placed on a smooth surface usually provided by placing a level-up AC course over the concrete pavement. This level-up course will help the fabrics in reducing reflective cracking (Cleveland et al., 2002). Normally, only dense-graded, well-compacted, and low permeability AC mixtures are recommended as overlays over pavement interlayers.

Amini and Wen (2016) monitored the long-term field performance of paving fabric interlayer systems to evaluate their effectiveness and performance. Sections having paving fabrics had improved performance in terms of preventing and delaying cracking as well as waterproofing when compared with unreinforced sections. Pasquini et al. (2015) evaluated laboratory and field studies carried out to investigate the reflective cracking resistance of geocomposite-reinforced asphalt systems. They concluded that the enhanced properties of the selected geocomposites provided stress relief, thus reducing the reflective cracking phenomenon. The Montana DOT evaluated various pavement fabric and mat applications in terms of effectiveness for potential use in future road construction projects to retard reflective cracking (Abernathy, 2013). All sections in the Montana DOT study have shown progressive transverse cracking issues since construction, leading to the conclusion that none of the paving fabrics treatments delayed cracking as compared to the control section. Darling and Woolstencroft (2000) evaluated the performance of fiberglass geogrid for retarding reflective cracking. Two field projects were considered for the implementation of fiberglass geogrid with adhesive: US 190 in Hammond, Louisiana (a rural two-lane secondary highway), and US 96 in Lumberton, Texas (a five-lane highway). The performance of both projects have been followed for 4 years, and the results indicate that fiberglass grid may be a good means to reduce/retard reflective cracking (Darling and Woolstencroft, 2000). Elseifi and Bandaru (2011) also provided a detailed literature review about the performance of paving fabric as interlayers.

Installation

Route 611, Lynchburg District

On April 4, 2016, a high-strength fiberglass, temperature-resistant composite reinforcing grid with bituminous coating was placed on Route 611 near its intersection with SR 26. Located near a local stone quarry, Route 611 has a high volume of dump truck and tractor-trailer traffic. The interlayer (designated "Type A" in this report) used on Route 611 was designed with the following characteristics: strain at nominal tensile strength ≤ 3%; tensile strength = 100kN/m; bitumen content of coating > 60%; mesh size = 30 mm x 30 mm; etc. Type A also included an ultra-lightweight nonwoven fabric, which facilitates installation.

The interlayer arrived in 328-ft (100-m) rolls and was placed for a total length of 1,000 linear feet on both lanes for full-width coverage. Both lanes were paved on the same day, and traffic was allowed on one lane while paving was done on another lane. The interlayer fabric, which was pre-coated with bitumen, was roughly 1 mm thick. An asphalt surface mixture having a nominal maximum aggregate size (NMAS) of 9.5 mm was placed above the interlayer at a thickness of 1.5 in. For this particular application, a leveling course was not needed. However, slippage cracks found at the beginning of the project triggered pre-placement surface milling for approximately 130 ft (Figure 1). Surface debris was removed and the pavement was thoroughly swept before installation. Figure 2 shows the interlayer placement procedure. First, an asphalt binder (PG 64S-22) was used as a tack coat. An application rate of 0.13 gal/yd^2 (applied at a temperature of 310^{o}F) was used for the milled surface, and an application rate of 0.11 gal/yd^2 was used for the unmilled surface. Second, the interlayer was placed immediately following the tack coat application using a laydown machine, as shown in Figure 2. The interlayer overlapped 4 in along the transverse joint (overlap between rolls), as shown in Figure 3. Third, the asphalt overlay was placed (Figure 4). Also, as shown in Figure 4, 6 in of additional interlayer width (each lane was approximately 10 ft wide and interlayer that was 10 ft, 6 in wide was installed) was provided for longitudinal joint overlap.

Figure 1. Slippage Cracks and Milled Surface on Route 611

Figure 2. Interlayer Placement on Route 611

Figure 3. Longitudinal Interlayer Overlap (Route 611)

Figure 4. Asphalt Overlay Placement

The remaining 3 miles of the overlay project, contiguous to the 1,000-ft test section, did not contain the interlayer and served as an experimental control section. In the control section, a conventional tack coat application rate of 0.09 gal/yd^2 (using a CRS-1H emulsion) was used, as shown in Figure 5.

Figure 5. Tack Application at the Control Section

US 58, Salem District

Type A interlayer (high-strength fiberglass) was also used on US 58 in the Salem District in October 2018. The placement and paving procedures (PG 64S-22 asphalt binder was used as a tack coat at an application rate of 0.13 gal/yd^2) were similar to those for Route 611 except the existing asphalt surface was milled to a depth of 2 in before the interlayer was placed. An asphalt mixture, SM 9.5D, was placed above the interlayer at a thickness of 2 in.

SR 143 NB and SB, York County

Another Type A interlayer was placed over a JCP on SR 143 in York County in August 2017. This installation also involved milling existing asphalt pavement and adding a 1.5-in overlay of an asphalt surface mixture having a 9.5 mm NMAS (VDOT designation SM-9.5D). Asphalt binder (PG 64S-22) was used as the tack coat at an application rate of 0.13 gal/yd^2. Figure 6 shows the existing surface, milled surface, and placed fabric. Paving fabric was placed on both the inside and outside lanes, and 6 in of longitudinal overlap was provided.

US 17 SB, York County

Type A interlayer fabric was used on US 17, but directly on an existing composite pavement (asphalt pavement over jointed concrete); a 2-in overlay of an asphalt surface mixture having a 12.5 mm NMAS (VDOT designation SM-12.5D) was placed in October 2017. An asphalt binder tack coat application rate of 0.11 gal/yd^2 was used. Both lanes were overlaid with paving fabric, and a 6-in longitudinal overlap was used. Figure 7 shows the fabric placement on US 17.

US 460, Wakefield

A different type of fabric (designated "Type B" in this report) was placed on US 460 in October 2018. Type B fabric is composed of high-strength glass filament yarns woven into a grid and coated with resin (Figure 8). According to the manufacturer, the coating enhances the bond between layers of asphalt. Type B fabric properties include tensile strength = 100kN/m (560 lb/in); grid size = 12 mm x 12 mm; etc.

Figure 6. Fabric Placement on Route 143

Figure 7. Fabric Placement on US 17

Figure 8. Interlayer Used on US 460

The fabric roll length was 328 ft, but the width was 5 ft. The project was 1.12 miles long with a 2-in asphalt overlay on top. The placement procedure was also different than with the Type A projects. The surface was milled first, and a leveling course with asphalt mixture (3/4-in-thick SM 12.5D mixture) was installed. Fabric was placed on the leveling course once the asphalt mixture cooled down to 100°F. The fabric was rolled into place using steel rollers (Figure 9). An initial trial with pneumatic tire rollers did not work because the roller picked up the fabric. Next, an asphalt emulsion was applied on top of the fabric, and then the asphalt overlay was placed on top of that (Figure 10). A 6-in longitudinal overlap (alongside and next longitudinal roll) was provided for the next roll of fabric. A dust-free surface is very important for this fabric placement. Care should be taken when driving the emulsion truck over the fabric to avoid tearing/bunching/pickup. Because of the 5-ft width of each roll, multiple overlaps resulted in a slower installation rate. The additional use of a leveling course also reduced the construction speed.

Figure 9. Interlayer Placement on US 460

Figure 10. Emulsion Application and Overlay on US 460

SR 30, York County

A second Type B interlayer was placed on SR 30 in York County in October 2018 on exposed JCP. Concrete patching was first conducted on deteriorated surfaces (approximate total quantity of 1,000 yd^2), and joint sealant was installed in existing joints. As with the US 460 project, application of the fabric was preceded by a leveling course, which consisted of a nominally 1-in-thick asphalt surface mixture having an NMAS of 4.75 mm (VDOT designation SM-4.75). This mixture incorporated 30% reclaimed asphalt pavement (RAP), 24% natural sand, and an asphalt content of 6.3% PG 64S-22. The percentage passing the No. 4, No. 16, and No. 200 sieves was 92%, 54%, and 9.1%, respectively. SM 4.75 mixtures were produced in accordance with VDOT's special provision for SM 4.75 mix design (VDOT, 2016).

The fabric was once again placed and rolled-in using a steel drum roller, followed by an application of asphalt emulsion and a 1.5-in-thick asphalt overlay (VDOT designation SM-9.5D). Figure 11 shows the fabric placement steps. From the upper left of Figure 11, a hump can be seen, which shows that the joint reflection of the concrete pavement already appeared on the 1-in SM 4.75 layer.

US 13, Accomack County

A third Type A interlayer was installed on US 13 in Accomack County (in October 2018) using installation procedures similar to those for Route 611. Existing pavement was milled to a depth of 2 in. An SM 12.5 D asphalt mixture was used at a thickness of 2 in.

Figure 11. Interlayer and Overlay Placement on SR 30

Laboratory Evaluation of Asphalt Mixtures

Volumetric and Gradation Analysis

Asphalt mixtures were collected from six of the seven projects (mixture was not collected from the US 13 project). Volumetric and gradation analyses were performed for all sampled mixtures. Gyratory pulls, 150 mm in diameter, were compacted to 50 gyrations for volumetric determination in accordance with VDOT specifications. Data collected and compiled for each mixture included asphalt content and gradation; voids in total mixture (VTM); voids in mineral aggregate (VMA); voids filled with asphalt (VFA); dust/asphalt ratio; and effective binder content (P_{be}). Volumetric and gradation results, presented in Tables 3 and 4, indicated that all mixtures met VDOT specification requirements.

Table 3. Volumetric Properties of the Asphalt Mixtures Studied

Project	**Route 611**	**SR 143**	**US 17**	**US 460**	**US 58**	**SR 30**
Mix Type	**SM 9.5D**	**SM 9.5D**	**SM 12.5D**	**SM 12.5D**	**SM 9.5D**	**SM 9.5D**
Mix ID	**16-1006**	**17-1022**	**17-1029**	**18-1058**	**18-1060**	**18-1073**
%AC	5.83	6.44	5.23	5.38	5.84	6.11
%Air voids (V_a)	3.2	3.8	3.6	3.9	3.5	3.0
%VMA	16.6	18.8	15.8	16.2	15.3	17.3
%VFA	80.6	79.6	77.3	75.7	77.1	82.9
Dust/asphalt ratio	1.25	1.25	0.96	1.00	0.81	0.79
Effective % Binder (P_{be})	5.59	6.43	5.17	5.37	4.98	6.11
Effective film thickness (F_{be})	8.8	8.9	9.6	9.6	9.7	11.7

SM = surface mixture; AC = asphalt content; VMA = voids in mineral aggregate, VFA = voids filled with asphalt,

Table 4. Gradation Analysis of All Mixtures

Project	**Route 611**	**SR 143**	**US 17**	**US 460**	**US 58**	**SR 30**
Mix Type	**SM 9.5D**	**SM 9.5D**	**SM 12.5D**	**SM 12.5D**	**SM 9.5D**	**SM 9.5D**
Mix ID	**16-1006**	**17-1022**	**17-1029**	**18-1058**	**18-1060**	**18-1073**
Sieve	% passing (average)					
$^3/_4$ in (19.0 mm)	100.0	100.0	100.0	99.8	100.0	100.0
$^1/_2$ in (12.5 mm)	99.9	99.8	96.6	98.4	99.6	99.8
$^3/_8$ in (9.5 mm)	96.8	93.8	83.3	89.3	92.7	94.3
No. 4 (4.75 mm)	64.1	66.5	49.8	57.7	62.2	59.3
No. 8 (2.36 mm)	43.4	49.6	38.0	43.5	40.9	40.0
No. 16 (1.18 mm)	31.7	39.2	31.8	35.5	30.9	30.7
No. 30 (600 µm)	22.8	29.2	24.6	23.1	22.7	22.1
No. 50 (300 µm)	14.9	17.9	14.5	12.5	13.9	13.5
No. 100 (150 µm)	9.6	10.5	7.5	8.1	7.9	7.6
No. 200 (75 µm)	6.96	8.05	4.99	5.37	4.04	4.80

SM = surface mixture.

Laboratory Performance

Dynamic Modulus

Dynamic modulus is one of the inputs required in AASHTOWare Pavement ME Design and is a measure of mixture stiffness. These data will be useful for future calibrations of pavement sections with interlayers. Figures 12 and 13 show dynamic modulus test results in semi-log and log-log scale. The figures show that modulus values are different for high and intermediate temperatures. Mixture 18-1058 showed the highest stiffness among all mixtures. Modulus differences among mixtures are due to changes in binder content and binder stiffness. With all mixtures using nearly 30% RAP, the stiffness of the RAP binder is also affecting the dynamic modulus.

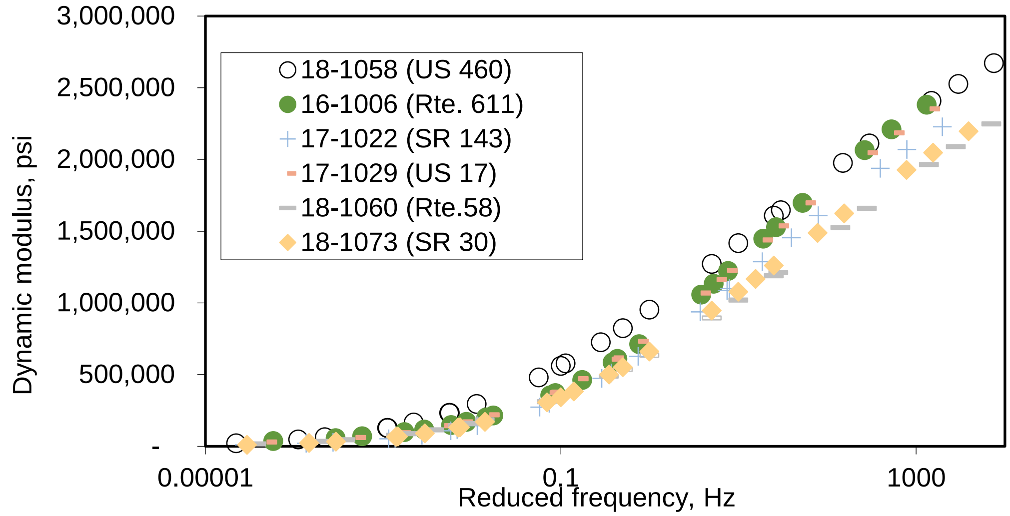

Figure 12. Dynamic Modulus Results (semi-log Scale)

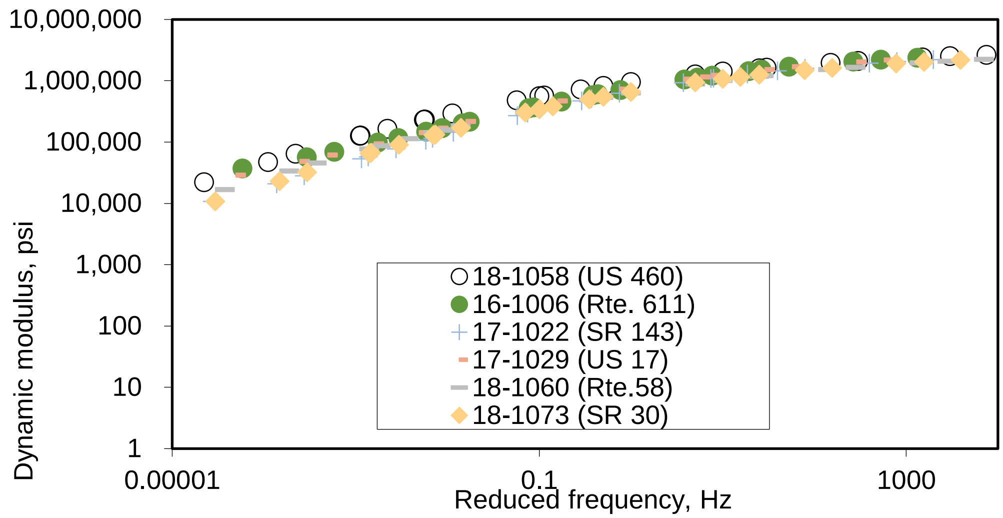

Figure 13. Dynamic Modulus Results (log-log Scale)

Cracking

Cracking and durability tests including the IDEAL-CT, SCB, and Texas overlay tests are used to evaluate a mixture's ability to resist cracking; the Cantabro mass loss test is performed as a measure of mixture durability. As Virginia works toward laboratory performance parameters that match field performance, having these test results for these mixtures will be helpful for future studies. Table 5 shows the cracking test results. Higher CT Index values indicate a better ability of mixtures to resist cracking. VDOT regular mixtures (SM 9.5 and 12.5) had shown an average CT Index value of 80 as part of a previous study (Diefenderfer and Bowers, 2019). VDOT currently uses a criterion of CT_{index} greater than 70 as part of an ongoing balanced mix design (BMD) effort. Two mixtures (17-1029 and 18-1058) did not meet this criterion, indicating possible cracking susceptibility.

Table 5. Cracking and Cantabro Mass Loss Test Results

Mix ID	Mix Type	Design Asphalt Content (%)	Production Asphalt Content (%)	RAP (%)	IDEAL-CT CT_{index}		SCB I-FIT		Overlay Cycles		Cantabro Mass Loss (Avg.)
					Avg.	COV	Avg.	COV	Avg.	COV	
16-1006	SM 9.5D	5.6%	5.8%	30%	77	4.7%	4.4	15.3%	324	30.2%	5.6%
17-1022	SM 9.5D	5.7%	6.4%	30%	81	16.9%	3.6	42.3%	165	26.3%	6.1%
17-1029	SM 9.5D	5.4%	5.2%	30%	62	16.1%	2.9	5.9%	205	40.4%	7.7%
18-1058	SM 12.5D	5.60%	5.3%	30%	32	12.9%	Brittle	-	18	64%	6.6%
18-1060	SM 9.5D	6.2%	5.8%	26%	73	15.4%	-	-	315	32.6%	5.4%
18-1073	SM 9.5D	5.7%	6.1%	30%	73	7.5%	3.2	1.6%	86	50.4%	4.4%

RAP = reclaimed asphalt pavement; SCB = semi-circular bend test; COV = coefficient of variation; SM = surface mixture; - = not available.

The Flexibility Index (FI) is determined through an SCB test. A higher FI is indicative of a mixture exhibiting a more ductile failure, and a lower FI indicates a more brittle failure. Al-Qadi et al. (2015) found that FI values varied from 15 to 1 for the best and poorest performing laboratory-produced mixtures, respectively. FIs for most of the mixtures tested in this study were less than 5, with one mixture (18-1058) showing brittle behavior (unmeasurable FI). This mixture also showed a higher dynamic modulus.

Conceptually, the Texas overlay test speaks most directly to reflective cracking, as the number of overlay test cycles to failure is expected to indicate a mixture's ability to resist reflective cracking. The New Jersey DOT currently recommends more than 150 cycles to failure in the overlay test for high-RAP surface mixtures with a PG 64-22 binder (New Jersey DOT, 2007), whereas the Texas DOT's 2014 specification requires a minimum of 300 cycles to failure for their thin overlay mixtures (Texas DOT, 2016). For most of the mixtures tested here, the overlay test cycles were less than 300.

Although a brittle or at least cracking-susceptible overlay is not an ideal element of a reflective cracking mitigation system, its use may serve to accelerate what is learned about the other components in these trials. That is, as long as these installations include good controls, the cracking-susceptible surface mixtures will help discriminate among any performance differences much sooner than would cracking-resistant overlays.

Durability

Table 5 also shows that the Cantabro average mass loss was less than 7.5% for most of the mixtures (17-1029 showed 7.7%). VDOT's provisional limit on mass loss for BMD trials is less than 7.5%, so durability issues are not expected for these mixtures.

Rutting Susceptibility

FN and rutting measurements using the APA test indicate a mixture's ability to resist rutting. Field rutting data results will also help to validate these tests. The FN and APA test results are shown in Table 6. The minimum FN criterion (unconfined condition) developed during NCHRP Project 9-43 for traffic levels of 3 to 10 million equivalent single axle loads is 50 cycles (Bonaquist, 2011). Higher FN values indicate a higher rut resistance of the mixture. For most of the mixtures, the FN was above 50, indicating resistance to rutting.

Table 6. Flow Number and APA Rut Depth

Mix ID	Mix Type	Production Asphalt Content (%)	RAP (%)	Flow Number (Unconfined Test), Avg.	APA Rut Depth, Avg. (mm)
16-1006	SM 9.5D	5.8%	30%	881	3.1
17-1022	SM 9.5D	6.4%	30%	226	4.1
17-1029	SM 9.5D	5.2%	30%	303	3.4
18-1058	SM 12.5D	5.3%	30%	285	6.0
18-1060	SM 9.5D	5.8%	26%	158	5.0
18-1073	SM 9.5D	6.1%	30%	62	5.3

APA = asphalt pavement analyzer; RAP = reclaimed asphalt pavement; SM = surface mixture.

Table 6 also shows that APA results and rut depth were less than 6 mm for all mixtures. VDOT's provisional limit on APA rut depth for BMD trials is less than 8 mm.

Shear and Tensile Bond Strengths of Field Cores

One of the keys to good interlayer installation (and ultimately performance) is establishing a good bond between the various layer components. To examine bond strength, cores were taken (eight cores from each project) 3 weeks after each project was completed for three of the Type A installations (Route 611, SR 143, and US 17). Figure 13 shows cores from the interlayer and the control section from the Route 611 project. Cores were also taken from the Route 611 project after 1 year in service. Table 7 shows the bond strength results for Route 611. The interlayer section showed lower bond strength compared to the control section (without an interlayer) at 3 weeks in service, a trend that is also evident after 1 year. In both the control and interlayer sections, shear strength had decreased and tensile strength had increased when core test results of initial and 1-year tests were compared.

Initial bond strengths (after 3 weeks) for SR 143 and US 17 are shown in Tables 8 and 9, respectively. On SR 143, the interlayer was placed on a milled surface, whereas on US 17 it was placed directly on the existing surface. The interlayers placed on milled surfaces showed a higher shear strength compared to those on the unmilled surfaces. In addition to the prospects for increased mechanical interlock, the milled surface applications included a higher application rate of tack coat.

Figure 13. Cores from Route 611 Project: (left) from interlayer section; (right) from control section

Table 7. Bond Strength Results for Route 611

Location		Initial	1 Year
Control section	Shear strength (psi), Avg.	163	123
	Tensile strength (psi), Avg.	37	61
With paving fabric	Shear strength (psi), Avg.	87	63
	Tensile strength (psi), Avg.	29	40

Table 8. Bond Strength Results for SR 143

Sample No.		Initial
With paving fabric	Shear strength (psi), Avg.	174
	Tensile strength (psi), Avg.	48

Table 9. Bond Strength Results for US 17

Sample No.		Initial
With paving fabric	Shear strength (psi), Avg.	80
	Tensile strength (psi), Avg.	47

According to VDOT specifications for non-tracking tack coat (referee system), shear strength should be >100 psi for a milled surface and > 50 psi for a non-milled surface. For tensile strength, the values should be > 40 psi for a milled surface and > 30 psi for a non-milled surface. All bond strength results met the VDOT criteria for shear and tensile bond strengths.

In-Service Performance

Most of the interlayer sections were placed in 2017 and 2018 (except for Route 611, which was placed in 2016), and hence in-service performance data are preliminary. The condition of the existing pavement before the interlayer was installed is an important contributor to an evaluation of a reflective cracking mitigation method. To assess the preconstruction condition, data were extracted from VDOT’s PMS and summarized for the trial sections in Tables 10 and 11 for the sections placed in 2017 and 2018, respectively. Table 12 summarizes the condition state for the control section on SR 143. Tables 10 and 11 also show the most recent post-installation condition indices. As expected this soon after construction, all sections are performing well.

Condition indices such as the CCI alone do not capture the increase in reflective cracks over time and do not isolate other deterioration such as rutting and fatigue cracking. A detailed example of distress data collection for future performance analysis is shown in Table 13. Detailed distress data (including severity) along with traffic and past performance of the section will be used to assess the effectiveness of interlayer systems in mitigating reflective cracking. A visual performance evaluation was conducted for Route 611 and US 58, and no cracking was found on either the control sections or where interlayers were used.

Table 10. Performance of Pavements With Interlayer Placed in 2017

Project	County	County Beginning MP	County Ending MP	Data Year	Pavement Type	No. Travel Lanes	Lane Width (ft)	CCI	LDR	NDR	IRI Avg. (in/mi)
SR 143 NB	York	5.65	6.71	2016	BOJ	2	10.90	57	79	57	140
				2017				55	73	55	160
				2018				**100**	**100**	**100**	**101**
				2019				**95**	**99**	**95**	**116**
SR 143 SB	York	**5.63**	**6.71**	2016	BOJ	2	**10.50**	55	82	55	166
				2017				56	76	56	165
				2018				**100**	**100**	**100**	**131**
				2019				**100**	**100**	**100**	**137**
US 17 SB	York	6.14	6.57	2016	BOJ	2	**11.10**	82	82	82	77
		6.14	6.57	2017				69	78	69	78
		5.26	**6.63**	**2018**				**96**	**96**	**99**	**94**
		5.26	**6.63**	**2019**				**92**	**92**	**99**	**103**

Bold text indicates performance after interlayer placement. MP = mile post; CCI = Critical Condition Index; LDR = load related distress rating; NDR = non-load related distress rating; IRI = International Roughness Index; NB = northbound; BOJ = bituminous over jointed concrete; SB = southbound.

Table 11. Performance of Pavements With Interlayer Placed in 2018

Project	County	County Beginning MP	County Ending MP	Data Year	Pavement Type	No. Travel Lanes	Lane Width (ft)	CCI	LDR	NDR	IRI Avg. (in/mi)
US 460 EB	Sussex	13.24	14.62	**2019**	BOJ	2	10.60	**100**	**100**	**100**	**115**
US 460 WB		13.24	14.62	**2019**	BOJ	2 2	10.60	**88**	**97**	**88**	**103**
SR 30 EB	James City	3.84	4.89	2016	JRCP	2	9.90	54	54	-	145
				2017				59	59	-	146
				2018				59	59	-	140
				2019	BOJ			**100**	**100**	**100**	**90**
US 13 NB	Accomack	17.0	18.02	2016	BOJ	4	11.3	71	78	75	76
				2017				67	81	68	72
				2018				60	74	61	75
				2019				**100**	**100**	**100**	**63**

Bold text indicates performance after interlayer placement. MP = mile post; CCI = Critical Condition Index; LDR = load related distress rating; NDR = non-load related distress rating; IRI = International Roughness Index; EB = eastbound; BOJ = bituminous over jointed concrete; WB = westbound; JRCP = jointed reinforced concrete pavement; NB = northbound.

Table 12. Performance of Control Section (SR 143)

Project	County	County Beginning MP	County Ending MP	Data Year	Pavement Type	No. Travel Lanes	Lane Width (ft)	CCI	LDR	NDR	IRI Avg. (in/mi)
SR 143 SB (control section)	York	6.07	6.37	2018	BOJ	2	10.90	64	83	68	202
				2019				**100**	**100**	**100**	**124**

Bold text indicates performance after interlayer placement. MP = mile post; CCI = Critical Condition Index; LDR = load related distress rating; NDR = non-load related distress rating; IRI = International Roughness Index; SB = southbound; BOJ = bituminous over jointed concrete.

Table 13. Detailed Distress Data for Sections Placed in 2017

Route Name	Data Year	Transverse Cracking Severity 1 (linear ft)	Transverse Cracking Severity 2 (linear ft)	Long. Cracking Severity 1 (linear ft)	Long. Cracking Severity 2 (linear ft)	Alligator Cracking Severity 1 (ft^2)	Alligator Cracking Severity 2 (ft^2)	Alligator Cracking Severity 3 (ft^2)	Rut Depth (in)
SR00143NB	2016	3496	62	773	5	2553	672	0	0.12
	2017	3513	786	985	507	2390	1497	0	0.15
	2018	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0.10**
	2019	**0**	**0**	**0**	**0**	**41**	**0**	**0**	**0.10**
SR00143SB	2016	3719	5	194	0	2197	456	0	0.13
	2017	2018	1056	351	127	2557	1010	0	0.14
	2018	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0.09**
	2019	**0**	**0**	**0**	**0**	**3**	**0**	**0**	**0.09**
US00017SB	2016	3589	24	0	0	2294	2	0	0.16
	2017	4431	581	467	13	3231	125	0	0.18
	2018	**30**	**0**	**7**	**0**	**35**	**9**	**0**	**0.11**
	2019	**39**	**0**	**0**	**0**	**49**	**2**	**0**	**0.16**

Bold text indicates performance after interlayer placement. Long. = longitudinal.

Summary of Findings

- The literature review found that interlayers may extend the life of asphalt overlay when they are installed properly on the correct pavement but their historical track record is mixed at best.
- The placement methods for interlayers used in this study differed and depended on the type of fabric used. Some interlayers need a leveling course for placement based on the manufacturer's specifications.
- The interlayer material/technology suppliers recommend different tack coat application rates for milled and non-milled surfaces.
- The interlayer fabric width and the use of a leveling course (or not) significantly affects the speed at which an interlayer system can be installed.
- Laboratory performance tests showed that some of the mixtures used to complete (and cover) the interlayer system were susceptible to cracking.
- Laboratory performance tests showed that these same mixtures were likely rut resistant.
- Although meeting VDOT's minimum requirements for bond strength, the shear and tensile strength test results were lower in the interlayer sections than in the control sections.
- The bond strengths (shear and tensile) for interlayer systems were higher on milled surfaces. This may have been due to the higher application rate of tack coat and/or increased mechanical interlock.
- As expected, all sections are performing well. Since most of the sections were placed in 2017 and 2018, performance data are preliminary.

CONCLUSIONS

- *Placement methods of different interlayers differ and depend on the specifications of the interlayer material / technology supplier.*
- *The length and width of interlayer materials (and the resulting need for overlapping) profoundly affect the speed with which interlayer systems can be installed.*
- *An adequate bond between the fabric interlayer and adjacent pavement layers (existing pavement and new overlay) should not be assumed. Lower bond strength results were found for the interlayer sections as compared to control sections. However, bond strengths met current VDOT criteria for shear and tensile bond strengths.*

- *Continued monitoring of performance will be needed to quantify any benefit of interlayer use in pavements.*

RECOMMENDATIONS

1. *VDOT's Materials Division should consider the following changes in the specifications for fabric interlayers for pavements:*

   - *a minimum width requirement (lane width plus overlap) for the interlayer fabric stock in order to avoid multiple overlaps and optimize installation speed*

   - *a bond strength emphasis consistent with current "referee system" requirements for tack coat applications (according to VDOT specifications for tack coat [referee system], shear strength should be >100 psi for a milled surface and >50 psi for a non-milled surface).*

2. *The Virginia Transportation Research Council (VTRC) should continue to monitor the performance of the sections in this study to evaluate the cost-effectiveness of interlayers in mitigating reflective cracking.*

IMPLEMENTATION AND BENEFITS

Implementation

With regard to the minimum width requirement in Recommendation 1, VDOT's Materials Division will discuss the specification change request with industry and other stakeholders and will make changes by August 2021. With regard to the bond strength emphasis in Recommendation 1, a reference to Section 310 tack coat (which includes the referee system for bond strength) will be included in the VDOT interlayer specification by August 2021.

With regard to Recommendation 2, VTRC will monitor the performance of the sections for the benefit-cost analysis. This work will also address cost-effectiveness of paving fabric interlayer systems perhaps to include recommendations concerning more systemic use.

Benefits

Implementing the recommendations of this study will help assess the cost-effectiveness of interlayers in pavements. Another area for which state agencies need help is including interlayers in mechanistic-empirical pavement design (MEPDG). In general, pavement design based on the nationally calibrated MEPDG did not consider pavements with interlayers. Future performance monitoring (Recommendation 2) of the test sections in this study will help local calibration efforts to verify and validate the MEPDG transfer functions for pavement with interlayers.

These sections need to be monitored continually to track pavement distress and performance over time. The cost of using interlayers in pavement can range from $6.00 to $8.00 per square yard, depending on the type of fabric and installation method used. Long-term performance data are needed to assess the benefit-cost of interlayer use in pavements.

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APPENDIX

LITERATURE REVIEW

Evaluation of Paving Fabric Interlayers for Preventing Reflective Cracking in Pavements

Over the last 35 years, highway agencies have changed their emphasis from the construction of new roads to the maintenance and rehabilitation of existing infrastructure. Hot mix asphalt (HMA) overlays are commonly applied on existing pavements when pavement conditions have reached an unacceptable level of service. As a consequence, the reflection of cracks from existing pavements becomes a major type of distress influencing the life of HMA overlays and controlling their long-term performance. Reflective cracking is a serious challenge associated with pavement rehabilitation; it leads to premature failure of the overlay, allows moisture infiltration through the cracks into the mixture and the supporting layers, and promotes the stripping of the asphalt binder from the aggregates. It can also reduce the strength of the base and subgrade materials, which could lead to the total failure of the flexible pavement structure (Habbouche et al., 2019). As the need grows for new rehabilitation methods to improve the performance of overlays against reflective cracking, agencies are trying various available treatment methods to delay or prevent reflective cracking in rehabilitated pavements including a thickness increase of the HMA overlay (Loria, 2008); the use of stress-absorbing membrane interlayers) (Baek and Al-Qadi, 2009); the use of stress relief courses (Baek and Al-Qadi, 2009; Dave et al., 2010); the use of fabric and geotextile membranes (Habbouche et al., 2017); etc.

Paving fabrics have been manufactured since the mid-1960s and have been successfully used in the United States for more than 40 years. Numerous significant environmental contributions were made with the use of these paving fabrics to maintain roadways including the reduction of energy needed to manufacture, transport, and pave HMA overlays (Miner and Davis, 2010). Paving fabrics should be placed on a structurally sound existing pavement with an approximate remaining service life of at least 5 years for satisfactory performance when applied in flexible pavements. The use of paving fabrics in a properly design structural section is expected to reinforce asphalt overlays by carrying tensile stress and providing a waterproof barrier, thus leading to mitigation of reflective cracking from the underlying pavement. These fabrics are usually designed to be saturated with liquid paving asphalt and can be effective in addressing block and alligator cracking as well as oxidized pavement surfaces (Miner and Davis, 2010). No improvement in performance is likely to occur if wide transverse thermal and shrinkage cracks are present (Cleveland et al., 2002).

For rigid pavements, the rocking upward and downward movement of the underlying portland cement concrete slab will cause the existing cracks or joint to reflect upward through the HMA overlay. In the case of JCP or CRCP, it is recommended that fabrics be placed on a smooth surface usually provided by placing an HMA leveling course over the concrete pavement. This leveling course will help the fabrics in reducing reflective cracking (Cleveland et al., 2002). For JCP, measures should be taken to minimize joint and crack movements. According to the *AASHTO Guide for Design of Pavement Structures* (AASHTO, 1993), the effectiveness of using geotextiles to control reflective cracking in HMA overlays over JCP is questionable and depends on the actions that precede the placement of the grid. Cracks in the concrete larger than 1/8 in should be sealed. A seal coat should be applied to seal smaller cracks and guarantee a good adhesion to the existing concrete. In some cases, a high-modulus product is recommended to be placed in strips only over the joints (Cleveland et al., 2002). Other techniques may be used to treat the existing concrete; the California DOT reported that the use of paving fabric on a crack and seat rigid pavement can efficiently help address any potential reflective cracking (Miner and Davis, 2010).

Material Characterization of Paving Fabrics

Paving fabrics are manufactured with polypropylene and polyester. Polypropylene begins to melt at a temperature of about 325°F; therefore, the temperature of the paving mixture should not exceed 325°F when it contacts paving fabrics. According to VDOT's *2016 Road and Bridge Supplemental Specifications,* Section 318, products with polypropylene fabrics (i.e., pavement interlayers) must not be used if the HMA temperature exceeds 350°F. Industries have recently started blending polypropylene with waste polyester obtained from recycled plastic soft drink bottles making these fabrics environmentally beneficial. This introduction is an example of how industry addresses the ongoing needs to "go green" of public works agencies.

Several products can be considered with geosynthetic paving interlayers such as fabrics, grids, composites, and membranes. Fabrics manufactured using polypropylene or polyester are most common. Nonwoven paving fabrics are known to exhibit relatively low moduli and thus can mobilize only limited stress at limited strains. Mixed results related to the reduction of reflective cracking were observed upon use of nonwoven fabrics. According to some DOT engineers, their use can help reduce water intrusion, which can help maintain the pavement smoothness (Cleveland et al., 2002).

Thicker fabrics should theoretically result in lower stress at the tip of a crack. The full thickness of the nonwoven fabric should be saturated with asphalt, and the maximum weight for a paving fabric should be carefully improvised to allow proper asphalt saturation in the field. Multiple lightweight fabrics with appropriate qualities may be recommended by numerous manufacturers. Therefore, advice should be sought from an agency's materials and construction divisions. The use of full-width fabrics is usually limited to flexible pavements with extensive random cracking (especially alligator cracking), indicating structural failure. Grids are expected to carry more stress at low strain levels when compared with fabrics because of their higher moduli. The grid should have a sufficient stiffness (tightly stretched or slightly pretensioned) to act as an overlay reinforcement. Composites, which may offer the benefits of both fabrics and grids, are recommended for use on pavements where both reinforcement and waterproofing are desired. Finally, membranes, which are relatively expensive, especially the heavy duty ones, should serve as a waterproofing tool and a stress-relieving interlayer (Cleveland et al., 2002).

Paving fabrics are known for several important properties including weight, tensile strength, elongation, and asphalt retention. Paving fabrics can be subdivided into three categories; light duty, standard, and heavy duty. The light duty paving fabrics are usually used with AC overlays or chip seals on low volume, slightly distressed roads in a moderate climate. The standard paving fabrics are most commonly used on most local agencies' projects with AC overlays or chip seals in accordance with AASHTO M 288. The heavy duty paving fabrics are used for severely distressed and highly trafficked roads in harsh climate conditions. The liquid paving asphalt tack coat, once applied, is retained by the paving fabrics, resulting in a paving fabric interlayer system. Multiple benefits are expected from the use of paving fabrics such as extension of a roadway structural and functional performance life, reduction in maintenance needs and associated traffic disruption, and reduction of energy needed for construction and maintenance operations.

Several aspects should be taken into consideration when synthetic products are ordered (e.g., pavement fabric layer). The width of rolls should be specified to accommodate the pavement lane width or any plans for placement. Significant loss of time, excessive construction joints, and waste of material can result from ordering an improper roll width. In addition, the roll weight should be considered to avoid the roll sagging, thus producing wrinkles during placement of geosynthetics. Careful consideration should also be given to storage of synthetics, especially to avoid misshapen rolls. Precipitation, sparks/flames, chemicals, extended exposure to sunlight, and temperatures exceeding 160°F should be avoided while storing pavement fabric layers. The polymer component of the fabric is susceptible to degrading upon prolonged exposure to sunlight (Cleveland et al., 2002).

Multiple factors may influence the in-place costs of geosynthetics in general and pavement fabric layers in particular such as the specific product used, quantity to be placed, tack coat requirements, local experience with installing the product, local labor costs, and general condition of the marketplace. The in-place cost of fabrics has fallen significantly since the early 1980s (Cleveland et al., 2002). According to Barksdale (1991) in *NCHRP Synthesis 171*, the in-place cost of a full-width paving fabric was roughly equivalent to the cost of about 0.5 to 0.6 in of AC.

History of Design With Geosynthetics

Generally, the overlay for both flexible and rigid pavements should be designed as if the pavement interlayer were not present. When the presence of pavement interlayer is taken into consideration, the reduction in overlay thickness should be limited to less than 4 times the size of the largest aggregate in the HMA overlay mixture and/or not less than the minimum allowable thickness for a structural HMA overlay. The use of thin or inadequately compacted overlays should be avoided with fabrics, especially on high-volume facilities. Poorly compacted overlay can lead to accumulating water on top of the pavement interlayer, leading to stripping and freeze-thaw damage in the overlay. Well-compacted dense-graded mixtures with low permeability should be used as overlays over paving interlayers. Multiple steps were recommended by manufacturers when geosynthetics are considered in an overlay design for flexible pavement.

- *Evaluation of pavement condition.* A pavement condition survey is usually conducted to establish the type, severity, and extent of existing pavement distresses. Nondestructive techniques including, but not limited to, visual distress surveys, ground penetrating radar, and falling weight deflectometer testing are usually used to categorize the candidate pavements for rehabilitation using a combination of geosynthetic interlayer and overlays.

- *Evaluation of structural strength.* The structural strength of the existing pavement is usually assessed using nondestructive testing. In general, it is recommended that the existing pavement have more than 5 years of remaining service life.

- *Identification of base/subgrade failures.* Reflective cracking will not be significantly delayed by geosynthetics in areas experiencing base/subgrade failures. Limited base failures are usually repaired by removal and replacement. When base failures are diagnosed as extensive, rehabilitation alternatives other than using pavement interlayer should be considered.

- *Selection of overlay design and monitoring of the field performance.* An adequate overlay thickness should be designed to ensure a considerable and reasonable performance service life. It is highly desirable to record performance histories of pavements with interlayers during construction and the in-service life of the overlay.

The design for rigid pavement overlays with geosynthetics is generally similar to that previously described for flexible pavements. Vertical joint deflections should be evaluated, and grout injection or joint repairs should be considered if needed. Horizontal thermal joint movements should be monitored. Careful attention must be given to joints and slabs including cleaning and resealing, patching, grouting, and repair (Cleveland et al., 2002).

Laboratory Evaluation of Pavement Rehabilitated With Interlayers

The adherence of geotextile interlayer with asphalt overlay was investigated by Zhang et al. (2017) in terms of shear damage energy. Multiple factors such as tack coat type and content, paving technology, and service environment were considered. A strong positive correlation existed between the adherence and the anti-reflective cracking performance for geotextile interlayer (Zhang et al., 2017).

Wargo et al. (2017) compared the performance of fiberglass grid with composite interlayer systems through testing double-layer beam specimens under four-point notched bending beam fatigue loading. Five types of geosynthetics with different tack coats were used as interlayers: two paving matts (continuous fiberglass fibers coated in elastomeric compound embedded between two polyester textiles and a nonwoven blend of fiberglass and polyester fibers); one paving fabric made of nonwoven polypropylene; and two self-adhesive fiberglass grids impregnated with acrylic polymer resin (G12.5 and G25). A standard roller compactor was used to compact the slab (50 mm thickness). The tack coat and interlayer system were then placed on top of the compacted slab. Either asphalt binder or emulsion was used as the interface bonding agent. The second asphalt layer was then compacted on top of the first one, resulting in a layered slab with a total thickness of 100 mm. Three beams (each 54 mm thick) were cut from each slab. The top and bottom layers of each beam were 36 mm and 18 mm, respectively. The displacement control mode (Haversine displacements with zero and maximum deflection peaks at frequencies of 5 Hz and 10 Hz) was used to load the double-layer beam specimens. The test was conducted until full-depth cracking was observed. The effect of temperature on specimen behavior was also evaluated. The stiffness curves (load vs. displacement data) were plotted, and damage mechanisms were evaluated and compared through the digital image correlation technique. All geosynthetic interlayer systems showed a better fatigue performance when compared with the control unreinforced specimens. It was interesting to notice that the number of cycles to fatigue failure increased with the increase in temperature for non-grid specimens. However, the opposite was observed for grid specimens. The damage mechanisms were noticeably affected by the type of interlayer system used. Grid systems showed a better performance when the interface bond was stronger. The non-grid interlayers exhibited a more flexible interlayer that dissipated more energy at the interface and delayed the full vertical cracking of the beams when tested in the laboratory (Wargo et al., 2017).

Raab et al. (2017) evaluated the effect of three types of reinforcement systems on the performance of two layered asphalt pavements in terms of retarding reflective cracking. Various mesh opening sizes and different bond coatings were evaluated. The pavements were loaded with a down-scale and full-scale traffic load simulator and were compared in terms of performance with unreinforced pavements. The pavement deformations measured through sensors and visual inspections were used to monitor the crack formation and propagation of all evaluated pavements. The pavements were then cored and the collected specimens were tested using a direct shear apparatus to monitor the interlayer bonding strength. Two reinforcement systems showed successful results in delaying reflective cracking; only one system showed similar or worse performance when compared with unreinforced pavements (Raab et al., 2017).

Noory et al. (2017) evaluated the shear bonding and reflective crack propagation of reinforced overlays using geocomposite interlayer systems. Laboratory double-shear and pull-out tests were conducted to determine the shear bonding and pull-out strength of geocomposites in evaluated asphalt specimens. A power law model relating the crack propagation to the number of loading cycles was developed and verified. Geocomposites sliding on the asphalt layer were observed to contribute less than 40% to the overall shear bonding. Moreover, this study indicated that the temperature factor primarily controls the shear bonding between layers as well as initiation and propagation of reflective cracks. The tack coat application rate and geocomposite grid size were classified as less critical factors. Finally, this study revealed that an increase in shear bonding between the existing pavement and the new overlay can greatly increase the resistance to reflective cracking (Noory et al., 2017).

Solaimanian et al. (2016) evaluated the resistance of HMA overlays to reflective cracking using geocomposites and accelerated loading. The experiment included building two AC slabs over hydraulic cement: a control slab that did not include any reinforcement, and an experimental slab that included a geocomposite layer in the middle of the asphalt layer. A rapid setting tack coat was applied to the surface of each slab before placement of the asphalt layer. Each slab was composed of two sub-slabs separated with a noticeable joint: one slab laying on a stiff ground and the other laying on neoprene. This was performed to aggravate the vertical movement at the joint to simulate a reduction in the load transfer efficiency of the slabs. The slabs were loaded with model scale accelerated testing equipment. The loading configuration consisted of applying 225 lbf with an approximate tire pressure of 90 psi at a traffic speed of 7,200 axles per hour, delivering a moving speed of 5 mph for a total of 400,000 cycles. The asphalt overlay was investigated for signs of distress and cracking at specific cycle intervals. The control slab exhibited top-down cracking at the vicinity of the joint after 20,000 trafficking cycles. The experimental slab showed similar cracking after 150,000 cycles. These cracks started from the top but were very well aligned with the cracks in the underlying layer. The authors expected that a much higher number of load repetitions would have been needed to exhibit bottom-up reflective cracking in the asphalt layer (Solaimanian et al., 2016).

Delbono and Giudice (2014) investigated the adherence of a polymeric grid used as an interlayer in rehabilitated pavements. The laboratory experiment consisted of a standard concrete cylinder 100 mm in diameter and 50 mm high; two modified asphalt emulsions with different melting points identified as cationic to avoid any possible slow evaporation of the water; a grid based on polyester fibers attached to a nonwoven polypropylene geotextile with a mesh size of 40 x 40 mm; and conventional asphalt applied at different temperatures at the top. The material characterization of the evaluated geosynthetic included the determination of the softening points by ring and ball (ASTM D-36, 2006) and melting points (ASTM D-1525, 2000). The adherence tests were used by the method of shear stress and direct tensile, and the experiments confirmed that the geosynthetic can be convenient to prevent reflection of cracks from the base material toward the bearing layer (Delbono and Giudice, 2014).

Li et al. (2013) evaluated the performance of asphalt mixtures reinforced with paving fabric for cold regions such as Alaska and other northern U.S. states where pavements are more prone to distresses because of extreme climatic conditions. Three types of paving fabrics were evaluated in the laboratory: two biaxial fabrics (i.e., PGM-G100/100 and PGM-G50/50) and one multi-axial reinforced paving composite, PGM-G, which was newly developed at that time. The performance tests of asphalt mixtures included asphalt retention, grab strength, shear strength, permeability, and indirect tension. The addition of paving fabrics was found to increase the overall pavement structure stiffness, greatly reduce the permeability, and provide good resistance to low temperature cracking. The multi-axial PGM-G paving composite provided the best overall pavement performance (Li et al., 2013).

Evaluation of Field Pavement Rehabilitation Projects With Interlayers

Amini and Wen (2016) evaluated the effectiveness of using paving fabric interlayer systems through monitoring the long-term performance of corresponding field sections. Comprehensive testing, monitoring, and analysis programs were undertaken. Twelve 500-ft pavement sections of a two-lane highway were constructed and monitored for 7 years. Multiple factors were considered such as joint and crack movement in the underlying pavement, crack width, overlay thickness, variability of pavement strength, existing pavement condition, base/subgrade conditions, local climate, and traffic volume. The test sections were located in the City of Pearl, Rankin County, Mississippi, in the outside lane of US 80 in the westbound direction. The existing pavement exhibited many distresses including raveling and transverse cracking with the need for milling, sealing, and overlay. Falling weight deflectometer testing was performed, and all cracking data were collected by the Mississippi DOT prior to construction and every year afterward for 7 consecutive years. All test sections were constructed head to head and were thus subjected to the same traffic loading and climatic conditions. Several agencies have reported and indicated that placing fabric properly remains very important for the performance of the entire interlayer system. During construction and fabric installation, sand was spread on the fabric to absorb any inspected excess of bleeding tack coat; all wrinkles that could not be removed were cut, and small tears in the fabric were patched and milled down. An improved performance in terms of preventing and delaying cracking and waterproofing capability was observed for the paving fabric sections when compared with the unreinforced sections. In addition, an increase of the overlay thickness showed an enhancement of the pavement structure by reducing reflective cracking growth. The milling technique did not have a significant improved effect on the performance of all paving fabric and unreinforced sections. A cost-benefit analysis was conducted to compare all sections with different treatments and aspects. It was concluded that the overlay with the paving fabric section was the most efficient; however, more cracking data were needed at the time for a more accurate analysis (Amini and Wen, 2016).

Leiva-Padilla et al. (2016) evaluated reflective cracking in asphalt overlays reinforced with geotextiles through measurements and modeling of core samples extracted from an experimental test section built using geotextiles as an interlayer system prior to overlaying. The samples were evaluated in the laboratory by means of the overlay tester. The fracture mechanics and viscoelasticity properties were determined from indirect traction tests in order to define the cohesive zone model (damage) and dynamic modulus tests (viscoelastic Prony series parameters). The results helped describe the mechanical behavior associated with the reduction in the reflective cracking process when geotextile materials are used. An increase in fatigue life (up to 260%) was quantified because of the energy dissipation capabilities of the material. In addition, the crack propagation trend was observed generally to follow the geotextile-asphalt layer interface (Leiva-Padilla et al., 2016).

Pasquini et al. (2015) evaluated laboratory and field studies carried out to investigate the reflective cracking resistance of geocomposite-reinforced asphalt systems. The study was based on a real-scale field trial, 260 m long, constructed along an in-service motorway. Four geocomposites obtained by combining two types of membrane compound (plastomeric and elastomeric compound) and two types of reinforcing fiberglass grids (FG5.0 with 5.0 mm square mesh and FG12.5 with 12.5 mm square mesh) were then investigated. An additional unreinforced control section and a reinforced section with geocomposite (plastomeric membrane reinforced with a continuous fiberglass fabric) were also constructed for comparison purposes. The setup of these field trials allowed the evaluation of different aspects including the effectiveness of different types of geocomposite against reflective cracking and the possible applicability of such materials without a tack coat and/or on a milled surface. Cores were collected from these sections and evaluated in the laboratory by conducting the Ancona shear testing research and analysis and simulative reflective cracking tests. The outcomes of this comprehensive experimental research showed that the application of a reinforcement at the interface inevitably leads to debonding effects. Moreover, geocomposite appears suitable to be applied directly over milled surfaces. The application of a tack coat was found not to be necessary for geocomposite-reinforced interfaces. Finally, the enhanced properties of the selected geocomposites provided proper stress relieving, thus reducing reflective cracking phenomena (Pasquini et al., 2015).

The Montana DOT (Abernathy, 2013) evaluated the effectiveness of various pavement fabric and mat applications to retard reflective cracking. Eight experimental sections were initially designed: one control section and seven sections including the paving mats previously defined. Multiple paving mats were selected for trials including TruPave engineered paving mat (full lane application); PavePrep geocomposite membrane (spot treatment of transverse cracks); GlasPave 25 waterproofing paving mat (full lane application); and GlasGrid 8512 pavement reinforcement system (spot treatment of transverse cracks). These sections were placed in a severe environment (e.g., excessive freeze-thaw cycles, temperature extremes, etc.), which may accelerate cracking. Prior to construction, transverse, longitudinal, block, and alligator cracking were observed, indicating multiple issues below the pavement in terms of loss of support. Site visits to document new cracking were made frequently after construction. Cracking was observed near the shoulders in the fall of 2010 in all sections. All cracks were sealed during the 2012 site visit. No additional cracking was noticed on any test section during the 2013 site visit. All sections showed progressive transverse crack issues since construction, leading to the conclusion that none of the paving fabric treatments delayed cracking as compared to the control section (Abernathy, 2013).

Zhang et al. (2011) evaluated the use of an interface self-absorbing composite (ISAC) intermediate layer to prevent reflective cracking in semi-rigid asphalt pavement. By definition, the ISAC system is a sandwich type structure that includes generally three layers: low-strength geotextile, the middle viscoelastic membrane layer, and the high-strength geotextile upper layer. The laboratory evaluation showed that the ISAC composite interlayer increased the initial cracking number of the test piece and greatly delayed the cracking time, thus reducing the cracking extension velocity and improving the anti-reflection cracking lifetime of the pavement. A test specimen consisted of a mortar cement layer with a joint on top of a rubber plate and AC at the top with or without interlayer at the middle. The field experimental validation of ISAC included 12 consecutive pre-cutting joints in the semi-rigid base of cemented stable broken stone to establish six different comparison settings: fiberglass grid ISAC; polyester cloth ISAC; simplified fiberglass grid ISAC free of the geotextile cloth at the lower layer; single fiberglass grid; single polyester cloth; and one free of any anti-cracking interlayer. The structures with interlayers showed a more sound anti-cracking effect when compared with the one with no interlayer. Moreover, the section with the fiberglass grid ISAC exhibited a superior performance when compared with the polyester cloth ISAC composite interlayer (Zhang et al., 2011).

Darling and Woolstencrof (2000) evaluated the performance of fiberglass geogrid for retarding reflective cracking. Two field projects were considered for the implementation of fiberglass geogrid with adhesive: US 190 in Hammond, Louisiana (a rural two-lane secondary highway), and US 96 in Lumberton, Texas (a five-lane highway). The first part of the US 190 section consisted of a 10-in full-depth HMA layer on top of a cement-stabilized base. The second part consisted of 8.5-in portland cement concrete on top of a granular base with a 7.7-in-thick HMA overlay. This route exhibited a large number of transverse and longitudinal cracks because of the extensive axial loads. A rehabilitation alternative was recommended to bump the Present Serviceability Index. The rehabilitation consisted of stabilizing 8.5 in of in-place base, adding 1.5 in of HMA binder course followed by a fiberglass geogrid interlayer, and placing a 1.5-in HMA wearing course at the top. The repair procedures prior to grid installation consisted of milling 3 in off the existing asphalt and partially filling the severe transverse and longitudinal cracks with an emulsion tack product. The US 96 road (38 ft wide) initially consisted of a 2.65-in HMA overlay on top of a 11.8-in base. This highway was then widened on both sides with a 10-in-thick cement stabilized base and a 3-in-thick HMA overlay. As a rehabilitation alternative, a fiberglass grid was placed on top of 1.5-in leveling course and covered with a 1.5-in HMA wearing course. On both projects, an installation tractor was used to lay the grid onto the base course asphalt. The surface was kept clean prior to the grid installation. The grid installation commenced approximately 1 hour prior to paving for safety purposes. Both projects displayed several types of cracking: block, alligator, transverse, and longitudinal. Some of the cracks were load related; others were related to the shrinkage of the HMA surface because of hardening of the asphalt or daily temperature cycling. The performance of both projects showed promising results of using fiberglass grid as a means to retard reflective cracking (Darling and Woolstencrof, 2000).

Al-Qadi et al. (2002) evaluated the field performance of geocomposite membrane in flexible pavement systems in Virginia. The geocomposite membrane consisted of a 2 mm-thick low modulus polyvinyl chloride backed on both sides with 150 g/m^2 polyester nonwoven geotextile. Two sections at the Virginia Smart Road, labeled J and K, were instrumented and constructed to quantify the effectiveness of using geocomposite membrane to prevent moisture and to absorb strain energy. Prior to installation, the area to be covered with geocomposite membrane was carefully cleaned of any loose aggregates. No prime coat was used prior to the membrane installation on section J. For section K, the geocomposite membrane was installed after placement of two lifts of HMA base mixture with a 25.0 mm NMAS (BM-25.0). The membrane was then installed on the tack-coated area and compacted using a pneumatic tire roller. Another BM-25.0 lift was then placed, followed by placement of 0.75 in of surface mixture (SM 9.5D) and an open-graded friction course layer. Ground penetrating radar and time domain reflectometer moisture sensors were used to evaluate the effectiveness of the geocomposite membrane in abating water infiltration into the subbase layer. In addition, the potential of the geocomposite membrane to mitigate reflective cracking was investigated through the finite element analysis approach. Field cores and analyses of data collected by the falling weight deflectometer validated the effectiveness of geocomposite membrane in dissipating a large amount of energy around the cracked region and, by that, increasing the number of cycles for crack initiation by several orders of magnitude (Al-Qadi and El Seifi, 2002).

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