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A Functionally Optimized Hot-Mix Asphalt Wearing Course: Part I: Preliminary Results

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A Functionally Optimized Hot-Mix Asphalt Wearing Course: Part I: Preliminary Results

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This report provides the preliminary findings of a study financed with state Enhanced Pavement Program funds; the cost to date of the project is $108,268.

Abstract

The purpose of this report was to highlight the preliminary findings of the design, production, placement, and early life performance of a new generation open-graded surface course (also referred to as porous friction course [PFC]) for use in Virginia. The primary objective of the larger research project is the design of a functionally optimized hot-mix asphalt wearing course. This report documents important aspects of the mix design and construction and the initial functional quality of the new surface. General observations associated with the trial section and normal production and placement activities are accompanied by a summary of the quality characteristics of the material. Special emphasis is placed on the very early life functional characteristics of the new wearing course. Among these key characteristics are ride quality, skid resistance, and tire-pavement noise.

Observations made during trial production and placement led to "lighter" recommended application rates and reduced temperatures. Preliminary functional tests indicated that the PFC is exhibiting exceptional early-age skid resistance, incentive-quality smoothness, and low tire-pavement noise. On the basis of initial cost and early-life functional performance, the PFC is cost-competitive with traditional mixes placed at traditional application rates (when those mixes are used for functional rather than structural improvement).

The report includes (as an appendix) a revised special provision for PFC that incorporates the recommendations pertaining to mix production and placement. It encourages Virginia Department of Transportation pavement engineers to consider a PFC when lower noise, exceptional skid resistance, and good ride quality are desired and additional structure is not necessary. However, it also cautions against widespread application of the technology until at least a final report on performance can be issued. The projected completion date for this report is winter 2010.

In the absence of long-term performance data, the costs and benefits assessment is focused on initial costs and initial performance criteria. As a wearing course only, the PFC is $0.28 per square yard cheaper than a comparable dense-graded mix ($5.08 versus $5.36) if both mixes are placed at the normally recommended application rates. The PFC further offers the quantified benefits of much greater skid resistance and noticeably lower noise production. The additional advantages of reduced splash and spray are acknowledged but not quantified.

FINAL REPORT

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ABSTRACT

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INTRODUCTION

Regardless of the structure that underlies a traveled surface, the degree to which a transportation facility serves its intended purpose has everything to do with how it interacts with its users. When the surface is integral to the structure (i.e., a bridge deck or full-depth hydraulic cement concrete pavement), this interaction is heavily influenced by how the surface is finished (e.g., brooming, grooving, or tining). When the surface is placed separately from the primary structural elements, the interaction between the user and the facility has much to do with the composition and placement of the final wearing course.

During the design of a long-life multilayer bituminous-based system, a pavement engineer is striving for a durable overall structure with periodic replacement of a sacrificial wearing course. The design of this wearing course is where the materials/pavement engineer should consider how the pavement system will interact with its users, i.e., its ride quality, skid resistance and noise. If the engineer chooses to "cap" the pavement structure with an asphalt concrete wearing course, he or she has three primary options: a dense-graded mix, a gap-graded mix, or an open-graded mix:

1. *Dense-graded asphalt mixes* are the most common surface mixes used in Virginia. In these mixtures, the coarse and fine aggregates are proportioned to provide a relatively uniform blend of stone sizes. The design depends on all sizes of stone particles interacting together to provide the mix structure with just enough asphalt cement and air voids to make the mix durable and stable.

2. *Gap-graded mixes* have fewer mid-sized aggregate particles, leaving room instead for more liquid (which generally promotes a longer fatigue life). Without the mid-size particles, the structure relies more heavily on the stone-on-stone skeleton of the

coarse aggregates. The nature of this structural skeleton makes stone quality and shape very important, which contributes to higher prices for raw materials. The most widely used gap-graded mixes are stone-matrix asphalt (SMA).

3. *Open-graded mixes* work with the most limited assortment of stone sizes. In most cases, these mixes use one moderately sized coarse aggregate source. With few fines or intermediate-sized stone, open-graded mixes are very porous (18% to 25% in-place voids). This porosity can be put to work through use of these mixtures in two very different pavement applications: as a drainage layer within the pavement structure, and as a free-draining wearing course. Although these mixes are expected to be stable, designers rarely credit them with much structural contribution.

As a wearing course, open-graded mixes offer the most complete assortment of functional benefits. Their free-draining nature reduces the ability of water to pond at the tire-pavement interface, thus reducing hydroplaning potential and splash/spray. Improved surface draining also reduces wet-night glare and promotes better marker visibility. The porosity that permits good surface drainage is also among the most important influences on the generation and propagation of noise at the tire-pavement interface. Properly placed and seated, open-graded wearing courses also provide an added opportunity to improve the overall ride quality of a pavement.

Past Problems with Open-Graded Surface Mixes

In spite of the numerous benefits of open-graded surface mixes, there are good reasons for being cautious when it comes to their widespread application in Virginia. For the most part, the apprehension stems from Virginia's experiences with similar mixes. Some of the older-generation "popcorn" mixes were dry (relatively low liquid asphalt content) and subject to premature and rapid failure by raveling. Those mixes that did have higher asphalt contents would perform very well, but once the mixes oxidized, raveling would occur quickly. In both cases, these mixes did not have the benefit of polymerization, i.e., the addition of polymers to make asphalt more flexible and durable. Some mixes that did perform as anticipated under wet conditions were reportedly prone to developing "black ice" when "wet" approached "wet-freeze" conditions. This created winter maintenance problems in treating the pavements.

"Black icing" and durability are safety and performance issues of the mix itself, but the most serious of reported past issues associated with open-graded surface mixes was the accelerated failure of underlying layers. Although rarely well documented, the presence of an open-graded surface mix was widely reported to exacerbate the stripping susceptibility of underlying dense-graded layers. The commonly offered hypothesis credited the heavy tack/bonding component of open-graded mixes with trapping water within the lower layers. The elimination of "evaporative drainage" ultimately led to premature and deep pavement failures.

Recent Advances

The last significant use of open-graded surface mixes in Virginia dates back to the 1980s. Since that time, there have been numerous advances in materials, design, production, and placement technologies that should support better present-day performance. From a materials standpoint, higher quality and/or polymerized binders combined with the use of liquid-suspending fibers make it possible to produce and place stable mixes with a much higher liquid asphalt content. The combination of consistent production, short-term storage, hauling, and placement with a low risk of liquid drain-down potentially eliminates the premature raveling failures of the past. In addition, the Virginia Department of Transportation (VDOT) now requires the use of anti-stripping additives in all underlying layers of hot-mix asphalt, which should deter stripping.

There are also more contemporary paving materials and equipment that allow for high-quality, heavy, rapid, and uniform tacking that provides for a good, impervious bond without creating a tack-tracking mess. From a materials perspective, the highly polymerized and specialized emulsions with short set times are working very well.

PROBLEM STATEMENT

The functional advantages of free-draining surface courses are attractive, but in the absence of an actual surface under real traffic, it is impossible to substantiate and quantify those benefits. Further, many of the functional benefits of these surfaces are known to diminish with time in service, but it is difficult to say how long the splash, spray, and noise reduction will last under typical Virginia traffic and maintenance (especially winter) activities.

Unfortunately, the problem that appeared most detrimental yet elusive in the past, i.e., stripping of the underlying layers, remains the most difficult to address today. Modern mixes, those that would underlie today’s open-graded mixes, contain hydrated lime or other anti-stripping agents, which should reduce their susceptibility to moisture damage. Under the worst of conditions, however, the best materials will eventually strip and fail. This issue must be addressed before the benefits of the open-graded surface mixes can be equitably compared to their costs and before any widespread application should be considered.

PURPOSE AND SCOPE

The purpose of this study was to oversee the design, production, placement, and early life performance of a new generation open-graded surface course (also referred to as porous friction course [PFC]). This report of the preliminary findings of this study covers aspects of the project that start with design and construction and continue through the determination of the initial functional quality of the new installation. General observations associated with the trial section and normal production and placement activities are accompanied by a summary of the material quality characteristics. Special emphasis, however, is on documenting the very early life functional characteristics of the new wearing course. Among these key characteristics are ride quality, skid resistance, and tire-pavement noise.

METHODS

Demonstration Project

Site Characteristics

The site for the demonstration installation needed to meet several important criteria:

- a relatively high volume of traffic with a typical mix of passenger vehicles and trucks traveling at speeds in excess of 35 mph
- no major drainage (internal or surface) issues
- good overall cross-section and subsurface drainage structures (open-graded drainage layer and longitudinal under-drains with outlets)
- constructed of materials that were not naturally susceptible to moisture damage.

The project that received this functionally optimized wearing course was a stretch of State Route (SR) 234 near Manassas, Virginia. The road is a four-lane divided primary route. The test section is approximately 8,200 ft in length and runs between Balls Ford Road and Sudley Manor Drive. The project is part of a bypass-type facility that carries traffic around Manassas to and from I-66. The intersections at each end of the project are signalized, but the travel speeds between those intersections are 45 mph (plus).

Acoustic control sections (approximately 1,000 ft in length) were established between Wellington Road and Sudley Manor Drive south of the paving project. These sections are at a sufficient distance (1,000 ft) from the intersection to avoid conflicting with noise contributors associated with operation at the intersection (deceleration). The surface material at these control sections is a typical dense-graded mix that was placed in 2000. At the time of testing, the surface appeared oxidized and was beginning to “coarsen” under the approximately 8 years of weather and traffic.

Mix Design and Construction Specification

The mix was designed, produced, and placed in accordance with VDOT’s Special Provision for Porous Friction Course (VDOT, 2007a). The general characteristics of this special provision call for a minimum of 5.75% liquid asphalt cement, 0.3% cellulose fiber, a 9.5 mm nominal maximum size aggregate, and a minimum of 16% air voids. The liquid asphalt was required to meet the binder grading of PG 70-28 with a minimum elastic recovery of 70%. The trial mix was also subjected to a durability test, the Cantabro abrasion loss test (described in ASTM D7064), which permitted a maximum material loss of 20%. The approved job mix is included as Appendix A.

The PFC was to be applied at a rate of approximately 110 lb/yd^2 (1 in thickness) and "seated" with a 10-ton roller operated in a static mode only. A minimum of five roller passes was required to compact the PFC. The special provision did not specify a minimum density requirement.

Conventional Mix Comparison Sites

In addition to the control section (just discussed), VDOT's 2008 plant mix resurfacing schedule provided uniquely qualified comparison sites with more conventional mixes. Specifically, a dense-graded surface mix (VDOT designation SM-9.5D) and a stone-matrix asphalt mix (SMA-9.5 [70-22]) were placed during the same construction season within close proximity to the trial PFC and by the same paving contractor. The PFC and SMA were produced at the same plant, and the SM-9.5D was produced at another plant. These mixes also incorporated the same top-size aggregate. The dense-graded mix, SM-9.5D, is actually contiguous to the PFC trial section and runs between the PFC and I-66. The SMA mix was placed approximately 10 miles from the demonstration site on a similarly trafficked facility near Warrenton, Virginia (US15/29 Warrenton Bypass).

These conventional mix sites may eventually be relevant for traditional service life studies, but their most immediate value to this study was as comparison surfaces for functional character. With this in mind, friction and acoustic tests were performed on all three sections and ride quality was measured on the two projects (PFC and SMA) that were subject to VDOT's Special Provision for Rideability (VDOT, 2008). The functional tests are described in more detail later in this report.

Although not crucial to baseline functional character, the traffic characteristics of the PFC and the two comparison sites are summarized in Table 1. These data (VDOT, 2007b) become very relevant as functional character changes with age.

Table 1. Traffic Characteristics of Sites

Mix and Site	Link Length (mi)	Average Annual Daily Traffic	Percentage of Trucks and Busses
PFC 9.5, SR 234	2.00	35,000	9
SMA 9.5, US 15/29	0.44	42,000	10
SM 9.5D, SR 234	2.44	42,000	9

Data are from VDOT (2007b).

Materials Sampling and Testing

The produced material was sampled and tested as with any other hot-mix material placed on a VDOT facility. The standard gradation and volumetric tests were conducted by the contractor, VDOT's Culpeper District, and VDOT's central laboratory at Elko. A summary of the trial section and production mix results was provided by staff of the Culpeper District Materials Section.

Functional Testing

The Part II report for this study will summarize key surface characteristics at four milestones for the project:

1. prior to placement of the PFC (i.e., the original surface)
2. approximately 2 months after the placement of the new surface
3. after approximately 4 additional months under traffic (and a winter of maintenance)
4. after approximately 1 year in service.

This report provides a summary of testing from the first two of those milestones. The results of the 1-year assessment will be used to determine whether longer term monitoring will be necessary. If warranted, any recommended followup monitoring will be prescribed in the Part II report.

Ride Quality

Among the special provisions included in this demonstration project was VDOT's Special Provision for Rideability (VDOT, 2008). The original surface and new surface ride quality testing was conducted by VDOT's Non-Destructive Testing Unit in accordance with Virginia Test Method 106. As per the requirements of the Special Provision for Rideability, the new-surface profiling was conducted within 30 days of project completion.

Skid Resistance

VDOT's Non-Destructive Testing Unit also performed surface friction testing. This testing was conducted with a lock-wheeled friction tester (ASTM E274) using a smooth tire (ASTM E524). To permit a more representative measure of skid resistance, the friction testing was not conducted until the new surface was under traffic for approximately 2 months. The two conventional mix comparison sites were tested at the same time. These sites had also been exposed to several months of traffic prior to testing.

Tire-Pavement Noise

The most non-conventional functional testing conducted for the project targeted the noise properties at the tire-pavement interface. These tests were conducted in accordance with the American Association of State Highway and Transportation Officials' (AASHTO) Standard Method of Test for Measurement of Tire/Pavement Noise Using the On-Board Sound Intensity (OBSI) Method (AASHTO TP 76-08) (AASHTO, 2008). The OBSI testing was arranged through a task order contract with the Federal Highway Administration (FHWA) (FHWA Contract DTFH61-04-R-00009, Task Order 13). Pre-overlay measurements and measurements at approximately 2 months in service were made by The Transtec Group from Austin, Texas, in cooperation with Illingworth & Rodkin (the full reports of these measurements are available from the authors upon request). Testing of the conventional mix comparison surfaces was administered separately (by arrangement directly with the Virginia Transportation Research Council [VTRC]) but was conducted at the same time as the tests for the PFC and accompanying acoustic control section.

RESULTS AND DISCUSSION

Construction

Modification for Tack Coat and Paver

The special provision (VDOT, 2007a) as provided in the contract documents called for the use of a polymer-modified emulsion applied with a spray-bar paver to ensure a good waterproof bond between the PFC and the existing surface. Prior to construction, the contractor submitted a value engineering proposal (VEP) to replace the polymer-modified emulsion and use of a spray-bar paver required in the special provision. In the VEP, the contractor proposed using a heavy application of trackless tack coat material (0.12 gal/yd^2) and a conventional asphalt paver. Given the recent success VDOT had experienced using trackless tack for bonding and the expectation that the heavier application rate would suffice to ensure the waterproofing membrane, the VEP was accepted and this paving process was used.

Trial Section

To identify construction issues prior to production and paving, the contract required the contractor to construct a 300-ton trial section. This trial section was located at the northern end of the project in the southbound travel lane. Trial production went very smoothly. However, during placement of the section, three major issues were identified:

1. *Because of the aggregate structure of the PFC, very little roll down was achieved.* The 110 lb/yd^2 specified in the contract resulted in a thickness of approximately 1¼ in. Therefore, to place the PFC at the desired 1-in thickness, the application rate had to be reduced. The final target application rate was adjusted to approximately 94 lb/yd^2. With the reduction in the application rate, the PFC quantities specified in the contract were much greater than the final produced tonnage.

2. *With the minimal roll down, it was difficult to transition from the mainline overlay to the existing paved shoulder that was not overlaid.* In addition, the stiffness and stickiness of the PG 70-28 liquid and the lack of fines in the mix precluded hand work that appeared necessary to “feather” the outside edge. This led to an undesirable “lip” and concerns with safety at the corresponding drop-off. To address this concern, an additional 2 ft of paving was placed on the shoulder to move the lip further from the edge of the travel lane. The reduced application rate also promoted a more desirable feathering to the shoulder.

3. *For traffic marking, VDOT used 6-in- wide B-VI tape.* This tape was placed on the pavement's surface once the final rolling was completed. Because of the minimum production temperature of the PFC (315º F) and the use of the PG 70-28 liquid asphalt, the new mat was cooling very slowly and making it difficult for the striping subcontractor to apply the tape. On the control section, a water truck was used to cool the PFC to allow the application of the tape. For the remainder of the project, the minimum production temperature was reduced by 15º to 25º F. These lower production temperatures resulted in lower placement and compaction temperatures, which permitted the striping subcontractor to place the tape in a timely manner. The temperature changes necessary to facilitate the traffic marking application resulted in no observable difficulties with haul, placement, and compaction.

Production

Full production and placement took place during night-paving operations. Placement of the first three lanes started late evening on August 24, 2008, and ran through early morning of August 27. The fourth and final lane was completed overnight the following week on September 2 and 3. Originally, the contractor planned to complete the paving in 1 week; however, rain and events at a local concert venue extended the time to complete the project.

Materials Sampling and Testing

Materials sampling and testing was conducted by the producer, the Culpeper District Materials Section, and VDOT's central materials laboratory. A cursory review of the laboratory results from each source suggested no consistent outliers, so all data were combined to examine the traditional mix production characteristics. Table 2 summarizes the night-by-night gradation, liquid asphalt cement (AC) content, and volumetric properties during full production.

With the exception of the first night's production, the 2,700 tons of PFC produced for this project were consistent. The liquid AC content on the first night was below the specified minimum AC content (5.75%). However, on the final three nights, the AC content was consistent and complied with the specifications. For the design sieves, the variability (coefficient of variation) in gradation was less than 7% and for mix volumetrics less than 4%. Given the porosity of the PFC, the CoreLok device (ASTM D6752) was used by the contractor and VDOT to determine bulk specific gravity.

Table 2. Production Gradation and Volumetric Data

Night	1/2 in	3/8 in	No. 4	No. 8	No. 200	AC	VTM	VFA	VMA	VCA_{mix}
Night 1	100.0	88.3	33.9	11.3	3.2	5.48	19.1	37.5	30.6	38.0
Night 2	100.0	89.2	35.7	11.4	3.0	5.86	18.3	40.7	30.7	38.2
Night 3	100.0	89.1	32.4	11.3	3.1	5.82	18.9	40.0	31.4	38.3
Night 4	100.0	89.1	31.2	11.2	3.1	5.80	17.9	40.7	30.2	37.3

AC = proportion (%) liquid asphalt cement by weight of mix, VTM = voids in total mix, VFA = voids filled with asphalt, VMA = voids in the mineral aggregate, VCA_{mix} = voids in the coarse aggregate.

Functional Testing

Ride Quality

Table 3 summarizes the original surface ride quality for the PFC and final surface ride quality for the PFC and SMA projects. The final surface IRIs were similar for the two projects, with both earning substantial incentives for smoothness. The improvement for the PFC project was particularly impressive considering the thin application rate (approximately 1 in; the SMA was approximately 1½ in thick).

Table 3. Ride Quality

Mix and Site	Lane	IRI Before (in/mi)	IRI After (in/mi)	Improvement (%)
PFC 9.5, SR 234	SBL1	81	40	51
	SBL2	81	44	46
	NBL1	73	39	47
	NBL2	78	42	46
SMA 9.5, US 15/29	SBL1		46	
	SBL2		40	

IRI = International Roughness Index.
VDOT's Special Provision for Rideability (VDOT, 2008) exempts single-lift paving from smoothness disincentives if the "improvement" in IRI is at least 30%. The SMA mix was placed on a new intermediate course, which eliminates the percent improvement exemption; no before testing for IRI was conducted.

Skid Resistance

The new-surface frictional character of the PFC and the comparison surfaces is summarized in Table 4. Each friction test covered approximately the same length of surface (approximately 1.0 sec of "lock-up" on a pre-wetted surface at 40 mph). The number of tests was varied to provide good site coverage. The number of individual lock-ups, as well as the average smooth tire friction value and the standard deviation of the sample set, is shown.

In many respects, the PFC is most nearly equivalent to the SMA. Both technologies incorporate a robust coarse aggregate structure with a relatively high ratio of liquid AC to rock. Functionally, this coarse aggregate structure usually provides an adequate macrotexture (features greater than 0.5 mm in size), generally noticeably "rougher" than for dense-graded mixes. The high liquid AC content (important to durability) also leads to a higher stone film thickness. This higher film thickness temporarily encapsulates the microtexture (features less than 0.5 mm in

Table 4. Skid Resistance

Mix and Site	Lane	No. of Tests	SN40S, Average	SN40S, Standard Deviation
PFC 9.5, SR 234	SBL1	9	47.0	1.2
	SBL2	9	41.4	2.0
	NBL1	9	46.1	1.0
	NBL2	10	41.8	1.4
SMA 9.5, US 15/29	SBL1	17	33.3	1.7
SM 9.5D, SR 234	NBL1	11	30.9	3.5
	SBL1	12	32.3	2.4

SN40S = 40 mph smooth tire friction value using a locked-wheeled unit in accordance with ASTM E274 .

size) of the coarse aggregates and often leads to lower friction numbers very early in life despite a fairly pronounced macrotexture. Fortunately, under normal to heavy traffic (all of these sites), this film wears away quickly and supplies acceptable friction values within just a few weeks. The timing for the functional testing was designed to allow every section to undergo more than sufficient traffic to avoid any friction issues related to heavy film. Nonetheless, the comparatively lower friction number in both passing lanes (Lane 2) for the PFC is likely due to a lower cumulative traffic volume at the time of testing.

It is not entirely clear at this point why the PFC holds such an overall advantage in skid resistance. It almost certainly relates to the ability of the mix to manage surface water through higher macrotexture and porosity, as microtexture (a property of the coarse aggregate) should be essentially the same for each of the three mixes.

Tire-Pavement Noise

The final functional test sought to characterize noise properties of the various surfaces and materials. This testing produced two sets of test results (before and after) for the demonstration site and nearby "acoustic control" section (see Table 5). Table 5 summarizes lane-by-lane results for the comparison sites.

In order to discuss the meaning of these results, it is first necessary to review some of the fundamentals of noise. An excellent source for a practical background on tire-pavement noise is *The Little Book of Quieter Pavements* (Rasmussen et al., 2007). This resource explains that air pressure changes (sound) are converted to and reported in decibels, which uses a logarithmic scale. When decibels are used to describe the perception of loudness, an increase of 10 dB in

Table 5. Tire-Pavement Noise

Mix and Site	Lane/Surface	OBSI, dB(A)
PFC 9.5 Demo, SR 234	SBL1/Pre-Overlay	105.5
	SBL1/PFC	97.4
	SBL2/Pre-Overlay	106.6
	SBL2/PFC	99.3
	NBL1/Pre-Overlay	104
	NBL1/PFC	99.6
	NBL2/Pre-Overlay	104
	NBL2/PFC	99.1
Control, SR 234	SBL1/Pre-Demo	106.4
	SBL1/Post-Demo	106.1
	NBL1/Pre-Demo	104.8
	NBL1/Post-Demo	104.5
SMA 9.5, US 15/29	SBL1/SMA 9.5	102.0
	SBL2/SMA 9.5	101.6
SM 9.5D, SR 234	SBL1/SM-9.5D	101.5
	SBL2/SM-9.5D	101.4
	NBL1/SM-9.5D	101.7
	NBL2/SM-9.5D	100.6

OBSI = On-Board Sound Intensity; dB(A) = a measure of "loudness" in which output has been weighted (A-weighted) to emphasize frequencies to which people are most sensitive; shaded rows reflect data from the most recent series of tests.

sound pressure level is usually about twice as loud. A common rule of thumb is that a 1 to 3dB change is just noticeable for most people, whereas a change of 5dB is much more definite.

The results shown in Table 5 suggest that the tire-pavement noise of the original pavement was improved considerably with the installation of the PFC: more than 6 dB(A) quieter on average. The advantage of PFC over the other new surfaces is much less distinct. There is the perceptible (i.e., "just noticeable") difference of about 3 dB(A) between the PFC and the SMA and slightly less difference, about 2.5 dB(A), between the PFC and the dense-graded mix.

CONCLUSIONS

- *Consolidation through compaction (i.e., roll-down) is significantly reduced with a PFC as compared with dense-graded mixes*. The stone-to-stone aggregate structure, the relatively low compactive effort used, and the corresponding high void level of these mixes result in "lighter" relative lifts.
- *Lowering the placement temperatures to correspond with the recommendation of the liquid asphalt supplier facilitated timely application of striping and did not adversely affect other haul, placement, and finishing activities.*
- *A heavy application of a non-tracking tack material does not appear to impact adversely the placement and initial bond of a PFC.* It is too soon to speculate as to whether long-term performance will be jeopardized by permitting this approach in lieu of the approach whereby polymerized tack material is applied with a spray-bar paver.
- *The PFC has exceptional early-age skid resistance*. At this point, friction is the characteristic whereby the PFC has the most quantifiable functional advantage over the two "conventional" mixes (the SM-9.5D and the SMA-9.5[70-22]). The SN40S for the PFC averages about 44, and those for the two comparison surfaces average in the low 30s.
- *Significant improvements in ride quality (compared with the original surface) are possible through a relatively thin lift of a PFC*. Final surface IRI values averaged in the very low 40s with a consistent improvement of nearly 50% over the original surface.
- *Comparatively speaking (and very early in life), the PFC is an acoustically superior hot-mix asphalt wearing surface.* Its application effected a significant improvement in tire-pavement noise as compared with the original (and weathered) dense-graded surface. Although much less pronounced, the early-age noise levels of the PFC are also noticeably lower than that of dense-graded and gap-graded (SMA) mixes of similar age and construction.
- *On a basis of initial cost and early-life functional performance, the PFC is at least a cost-competitive if not a superior alternative to traditional mixes that are placed at traditional*

application rates unless the application has structural implications. However, until longer-term performance data are available, this conclusion cannot be extrapolated beyond a first-cost comparison.

RECOMMENDATIONS

1. *VDOT's Materials Division in concert with VTRC should modify VDOT's original Special Provision for Porous Friction Course to provide the following:*

    - *an option for tack coat that incorporates a non-tracking tack material in lieu of the originally prescribed emulsion and a conventional paving machine as an alternative to the spray-bar paver*

    - *recommended application rates that account for the reduced roll-down characteristic of a PFC*

    - *a laydown temperature that conforms to the recommendation of the asphalt liquid supplier (to facilitate timely application of marking tape).*

    It should be noted that the recommended special provision was crafted and made available as soon as the necessary elements became apparent. The modified (and current) special provision is provided as Appendix B.

2. *VDOT pavement engineers, managers, and district coordinators should consider using a PFC when low noise, good ride quality, and exceptional skid resistance are the primary objectives.* A PFC is not recommended as the sole element in an application in which additional structure is necessary.

3. *VDOT pavement engineers, managers, and district coordinators should consider using a PFC on a limited basis, at least until more is known about its longer term performance in Virginia.* At the very least, widespread use of PFCs is discouraged until the final report on this demonstration project can be issued, currently anticipated for winter 2010.

4. *VTRC should initiate and conduct a performance (to include costs) comparison of thin wearing course options for Virginia.* This research project should include thin applications of dense-graded mixes, less common surface mixes such as a PFC, and lower cost alternatives such as latex-modified slurry seals and microsurfacing.

COSTS AND BENEFITS ASSESSMENT

It would be inappropriate at this point to speculate on the long-term benefits of using a PFC. It is likewise difficult to compare the relative benefits provided by the alternative and more conventional mixes. It is possible, however, to review the initial costs and discuss how they have translated into early-age functional benefits. To that end, Table 6 provides basic information from the winning bids for the three mixes investigated in this study.

It is important to emphasize that the PFC was designed as a functional mix only. The assumption with its application was that the existing pavement required no structural improvement. Since the SM-9.5D (the comparison dense-graded mix) was also placed on the same original project and presumably the same pavement structure (with the same structural adequacy), it is theoretically possible to compare those two initial costs and benefits directly. At the given application rates, the PFC is a better buy (by $0.28 per square yard) than the dense-graded mix. An economic comparison to other strictly "functional fixes" (e.g., slurry seals and microsurfacing) also makes sense in this instance and should be pursued through a more comprehensive study of the performance of thin wearing course options.

Although the per-square-yard cost of the PFC is nearly $1 less expensive than the SMA, the same assumption regarding structural adequacy cannot be made here. On the US 15/29 project, the structural advantage of the SMA, not to mention a demonstrated advantage in material service life (McGhee and Clark, 2007), is very important. It may also be important to point out that the bid price for this particular SMA mixture was very reasonable in comparison to most that were advertised around Virginia for the past several years. SMA averaged more than $100/ton through most of 2007 and early 2008 (Kiefer, 2008); therefore, in most places, the per-surface-area price difference would have been more dramatic. Had this finer SMA been used as more of a functional wearing course, the pavement engineer might have been well advised to consider the PFC or a similar alternative at the thinner application rate as a cost-effective alternative.

If safety is the overriding concern when a wearing course is selected (more a European philosophy than a domestic one for now), the largest "bang for the buck" for early-age skid resistance certainly comes with the PFC. In fact, smooth-tire friction is where the PFC currently holds the most quantifiable advantage over the two more conventional mixes. In addition, although not easy to quantify, there is a noticeable difference in the splash and spray characteristics of the PFC, which results in improved visibility during rain events.

Table 6. Material Bid Prices for Mixes Investigated in This Study

Material	Application Rate (lb/yd^2)	Price		Contract Quantity (tons)
		Ton ($)	Square Yard ($)	
PFC 9.5 (70-28)	94	108	5.08[a]	3,231[b]
SM-9.5D	165	65	5.36	14,171
SMA-9.5(70-22)	165	73.5	6.06	29,051

[a] Does not incorporate the lump-sum reduction from the Value Engineering Proposal ($13,804).
[b] Final placed quantity of 2,733 tons.

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APPENDIX A

STATEMENT OF ASPHALT CONCRETE OR CENTRAL-MIX AGGREGATE JOB-MIX FORMULA

Contractor Design Mix No. ______________________ Design Lab No. ________

Date ____________ Job Mix ID No. ________ Calendar Yr. ____________ TSR Test No. ________

Type Mix / Size Aggregate ______________________________

Producer Name & Plant Location ______________________ Phone ____________

MATERIALS					(Size) Kind (Type)	Source
Approval Phase	A	B*	C			
Aggregate				%		
Aggregate				%		
Rap				%		
Sand				%		
Screening				%		
Lime				%		
Asphalt Cement				%	(72) PG 70-28	
Fiber				%		
Additives:				%		

Job-Mix Sieves	Total % Passing		Tolerance % + or -	Acceptance Range Average of ___ Test(s)		End of Year Average	Design/Spec. Range
	Lab JMF	Production JMF					
Approval Phase	A	B*		A	B	C	
1/2	100	100	0	100	100		100
3/8	88	88	4	84-92	84-92		85-100
#4	31	33*	3	28-34	30-36*		20-40
#8	10	10	3	7-13	7-13		5-10
#200	3	3	2	1-5	1-5		2-4
Asphalt (%)	6.0	5.8	.30	5.7-6.3	5.5-6.1		5.75-7.25

Lay Down Temperatures	300 - 330 °F(°C)	Muffle Furnace Correction Factor:	.50
		Field Correction Factor ($G_{se} - G_{sb}$):	
Lab Compaction Temperatures	290 - _____ °F (°C)	Pill Weight:	4300
		SMA Mixes	
		VCA_{DRC}:	42.5
Producer Technician's Certification Number	Poole / Maddox	G_{CA}:	2.943

APPENDIX B

VDOT'S REVISED SPECIAL PROVISION FOR POROUS FRICTION COURSE

VIRGINIA DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISION FOR
POROUS FRICTION COURSE

October 1, 2008

I. DESCRIPTION

This work shall consist of furnishing a Porous Friction Course (PFC) bituminous mixture in accordance with Sections 211 and 315 of the Specifications and this Special Provision.

II. MATERIALS

(a) **Coarse Aggregate:** Coarse aggregate shall conform to the following requirements:

1. Los Angeles Abrasion	AASHTO T96	40% max.
2. Flat and Elongated Particles Measured on No. 4 retained, max. to min.	ASTM D4791 VTM-121	
3:1		25% max.
5:1		10% max.
3. Magnesium Sulfate Soundness Loss 5 cycles	AASHTO T104	15% max.
4. Particles retained on the No. 4 sieve shall have at least	ASTM D5821	
one fractured face		100% min.
two fractured faces		90% min.
5. Absorption	AASHTO T85	2% max.

The aggregate properties specified are for each stockpile of coarse aggregate material designated on the job mix form (TL-127). The material contained in each stockpile shall meet the minimum or maximum criteria specified, except that Flat and Elongated testing will be performed on Porous Friction Course Plant Sample and acceptance shall be in accordance with Section V herein.

Use of slag will not be permitted.

(b) **Fine Aggregate:** shall conform to the requirements of Section 202 of the Specifications, except for grading, which shall be tested according to AASHTO T 304 (Method A) with a value of not less than 40 percent and a sand equivalent value of not less than 45 (AASHTO T 176).

(c) **Asphalt Binder:** Asphalt binders shall be Performance Graded Binder Polymer modified PG 70-28 conforming to the requirements of mix designation (M), as designated by the Department, with an Elastic Recovery of 70% or greater. The supplier shall certify to the Department that the binder meets all the properties of that grade as shown in AASHTO M320 (Provisional Specification MP-1) for Performance Graded Asphalt Binder. This certification shall be based on testing performed on samples of binder provided to the Contractor for incorporation into the mixture. Certification based on testing performed on laboratory-produced binders will not be acceptable.

During mixture production, testing to determine the binder PG grade will be performed by the Department on samples taken from storage at the hot mix asphalt plant as directed by the Engineer. The Contractor shall be responsible for obtaining the sample of binder when requested. In the event that it is determined that the binder does not meet the requirements of the specified PG grade, production shall be stopped until further testing indicates that the problem has been corrected.

(d) **Mineral Filler:** shall conform to the requirements of Section 201 of the Specifications. At the time of use, it shall be sufficiently dry to flow freely and be essentially free from agglomerations.

(e) **Fiber Additive:** Cellulose fiber in either loose or pelletized form shall be used. The minimum dosage rates for cellulose is 0.3 percent by weight of total mixture. During production, the Department may require the fiber additive be increased if visual inspection or draindown testing on plant produced material indicates that draindown in excess of 0.3 percent by weight of the mix is occurring as determined by VTM-100. Allowable tolerances of fiber dosage shall be ± 10 percent of the required fiber weight.

Fibers will be accepted based on the manufacturer's certification. Fibers shall conform to the following:

CELLULOSE FIBER PROPERTIES

Sieve Analysis			
Method A			
Alpine Sieve[1] Analysis:			
Fiber Length:		0.25 inch	(maximum)
Passing	No. 100 Sieve	70%	(± 10%)
Method B			
Mesh Screen[2] Analysis:			
Fiber Length:		0.25 inch	(maximum)
Passing	No. 20 Sieve	85%	(± 10%)
	No. 40 Sieve	65%	(± 10%)
	No. 140 Sieve	30%	(± 10%)
Ash Content[3]		18%	(± 5%) non-volatile
pH[4]		7.5	(± 1.0)
Oil Absorption[5]		5.0	(± 1.0) (times fiber weight)
Moisture Content[6]		< 5%	

[1]Method A: Alpine Sieve Analysis. This test is performed using an Alpine Air Jet Sieve (Type 200 LS). A representative five-gram sample of fiber is sieved for 14 minutes at a controlled vacuum of 22 inches (± 3 inches) of water. The portion remaining on the screen is weighed.

[2]Method B: Mesh Screen Analysis. This test is performed using standard Nos. 20, 40, 60, 80, 100, and 140 sieves, nylon brushes and a shaker. A representative 10-gram sample of fiber is sieved, using a shaker and two nylon brushes on each screen.

The amount retained on each sieve is weighed and the percentage passing calculated.

[3]Ash Content: A representative 2-3 gram sample of fiber is placed in a tared crucible and heated between 1100 ^{o} F and 1200^{o} F for not less than two hours. The crucible and ash are cooled in a desiccator and reweighed.

[4]pH Test: Five grams of fiber is added to 3.5 oz. (100 ml) of distilled water, stirred and let set for 30 minutes. The pH is determined with a probe calibrated with pH 7.0 buffer.

[5]Oil Absorption Test: Five grams of fiber is accurately weighed and suspended in an excess of mineral spirits for not less than five minutes to ensure total saturation. It is then placed in a screen mesh strainer (approximately 0.5 square millimeter hole size) and shaken on a wrist action shaker for ten minutes (approximately 1 ¼ inch motion at 20 shakes/minute). The shaken mass is then transferred without touching, to a tared container and weighed. Results are reported as the amount (number or times its own weight) the fibers are able to absorb.

[6]Moisture Content: Ten grams of fiber is weighed and placed in a 250° F forced air oven for two hours. The sample is then reweighed immediately upon removal from the oven.

NOTE: When using pelletized fiber, the dosage rate shall be adjusted to meet the specified minimum dosage rates for cellulose fiber. Pelletized fiber consists of cellulose fiber and a binder. The specified minimum dosage rates are based on fiber content only. Therefore, the amount of pelletized fiber added shall typically be higher than loose fiber.

(f) **RAP:** Use of RAP will not be permitted.

(g) **Tack Coat:** Unless otherwise directed in the contract, two options for placing the tack coat are available.

Option 1: A tack coat of asphalt emulsion meeting the requirements specified herein or other emulsion approved by the Engineer shall be applied prior to placement of the asphalt concrete. The tack coat shall be placed within 10 seconds of placement of porous friction course unless otherwise directed by the Engineer. At no time should any part of the paving machine come into contact with the tack coat before the porous friction course is applied. The emulsion shall be uniformly applied with a paver spray bar, except hand spray equipment may be used in areas inaccessible to the paver spray bar as directed by the Engineer inaccessible areas are exempt from the 10-second criterion. The emulsion asphalt shall be applied at a temperature recommended by the supplier at a starting rate of 0.25 gallons per square yard +/-0.02 unless otherwise approved by the Engineer.

Test on Emulsion	Method	Min	Max
Viscosity at 77° F, SSF	AASHTO T59	20	100
Sieve Test, % (Note 1)	AASHTO T59	—	0.05
24 hour storage stability, % (Note 2)	AASHTO T59	—	1
Residue from distillation at 400° F, % (Note 3)	AASHTO T59	63	
Oil portion from distillation ml of oil			2

per 100g emulsion			
Demulsibility, % 35 ml 0.02 N CaCl2 or 35 ml 0.8% dioctyl sodium sulfosuccinate	AASHTO T59	60	
Test on Residue From Distillation			
		Min	Max
Elastic Recovery, % (Note 4)	AASHTO T301	60	—
Penetration @ 77° F, 100 g, 5 sec. dmm.	AASHTO T49	60	150

Note 1: The sieve test is waived if successful application of the material has been achieved in the field.
Note 2: After standing undisturbed for 24 hours, the surface shall show no white, milky colored substance, but shall be a smooth homogeneous color throughout.
Note 3: AASHTO T59 with modifications to include a 400° F +/- 10° F maximum temperature to be held for a period of 15 minutes.
Note 4: With exception that the elongation is 20 cm and the test temperature is 50° F.

Option 2: A tack coat of asphalt emulsion meeting the requirements specified in Special Provision for Nontracking Tack Coat shall be applied prior to placement of the PFC. The emulsion shall be uniformly applied with a spray bar paver or a mechanical distributor, except hand spray equipment may be used in areas inaccessible. The asphalt emulsion shall be applied at a temperature recommended by the supplier at a starting rate of 0.12 gallons per square yard +/-0.02 unless otherwise approved by the Engineer.

III. MIX FORMULA

The Contractor shall submit for the Engineer's approval, a job mix formula within the following design ranges of percent passing each sieve size as noted in Table A. In addition, the PFC mixture shall conform to all the requirements in Table B. One percent hydrated lime will be required as an antistripping additive. An alternative antistripping additive can only be used if permitted by the Engineer.

TABLE A - PFC DESIGN RANGE

Percentage by Weight Passing Square Mesh Sieves (in)

	¾	**1/2**	**3/8**	**No. 4**	**No. 8**	**No. 200**
PFC 9.5	100	100	85-100	20-40	5-10	2-4
PFC 12.5	100	90-100	55-75	15-25	5-10	2-4

TABLE B - PFC Mixture Requirements

Mix Type	AC %	Drain-down %	VCA Design and Production	Design Gyrations	Air Voids %	Cantabro Abrasion loss %	TSR %
PFC12.5/ PFC 9.5	5.75-7.25	0.3 max	$<VCA_{DRC}$	50	16 min	20 max	80 min

Draindown testing shall be in accordance with VTM-100 Determination of Draindown Characteristics in Uncompacted Asphalt Mixtures.

The Voids in Coarse Aggregates (VCA) of the Dry Rodded Condition (DRC) and mix shall be determined in accordance with VTM-99.

The specimen size shall be 4 inches (100 mm) diameter and between 2.4 inches to 2.6 inches (61 mm and 66 mm) tall for Cantabro Abrasion testing. AASHTO T312 shall be used to prepare the specimen for testing.

The air voids shall be calculated using the CoreLok method for the bulk specific gravity of the compacted specimen.

The tensile strength ratio shall be determined using a modified AASHTO T283 procedure. Specimen shall be compacted to the design number of gyrations using AASHTO T312. The specimen shall be saturated by applying 26 inches of mercury vacuum for 10 minutes. The specimen shall be conditioned using one freeze-thaw cycle.

In addition to the job mix submittal, the Contractor shall submit ignition furnace calibration data in accordance with VTM-102 and aggregate property test results for the aggregate components or blend prepared by an approved testing laboratory.

IV. SURFACE PREPARATION

Prior to commencement of paving operations, the existing pavement surface shall be cleaned of all accumulated dust, mud, or other debris, that may affect the bond of the new overlay by the Contractor.

Pavement cracks or joints ¼ inch or more in width shall be cleaned and filled with a sealant material conforming to Type B of the Special Provision For Sealing Cracks in Asphalt Concrete Pavements or Hydraulic Cement Concrete Pavement. Pavement markers, thermoplastic pavement marking and tape pavement markings shall be removed prior to the commencement of paving operations. Pavement irregularities greater than 1 inch in depth shall be filled with a material approved by the Engineer.

Utility structures shall be protected and referenced prior to paving at no cost to the Department for location and adjustment (when necessary) after paving

V. ACCEPTANCE

A lot will be considered acceptable for gradation and asphalt content if the mean of the test results obtained is within the tolerance allowed from the job-mix formula. The Contractor shall check and report the percentage of F&E particles in the coarse aggregates of the mix during production. When the PFC material is sampled for acceptance (gradation and asphalt content), one of the four sublots must be selected for F&E particle verification. The F&E particle testing will be performed on the coarse aggregate material retained on the No. 4 sieve in accordance with VTM-121 after the gradation analysis is performed. At initial start-up of production, the F&E particles shall be determined for each of the first two lots of material produced and compared to the maximum limits specified in section II (a). If passing results are obtained on each sample in the first two lots, then F&E particle testing shall be performed on a frequency of every second lot of material produced (e.g., lots 4, 6, 8, etc.). If the results for the mix exceed the specified limits, the Contractor shall stop production and notify the Engineer. Production shall not resume until the Contractor has taken corrective action and the Engineer has approved the corrective action. Once production has resumed, the Contractor shall determine the F&E particles of the mix for two consecutive lots. If passing results are obtained for these two lots, the F&E particle testing frequency shall return to every second lot of material produced. In the event the Department determines that the mixture being produced does not conform to the approved job-mix formula and volumetric properties in Table A and B based on the Department's or Contractor's test results, the Contractor shall immediately make corrections to bring the mixture into conformance with the approved job-mix formula or cease paving with that mixture. Subsequent paving operations using either a revised or another job-mix formula that has not been verified for acceptance as described herein shall be limited to a test run of 300 tons maximum. No further paving using that specific mixture shall occur until the acceptability of the mixture being produced has been verified using the 300-ton constraint.

The production tolerances for the control sieves and asphalt content shall be as follows:

PROCESS TOLERANCE

Tolerance on each laboratory sieve (in) and Asphalt Content – Percent Plus and Minus

No. Tests	Top Size	1/2	3/8	No. 4	No. 8	No. 200	AC
1	0.0	8.0	8.0	6.0	6.0	4.0	0.60
2	0.0	5.7	5.7	4.3	4.3	2.8	0.43
3	0.0	4.4	4.4	3.3	3.3	2.2	0.33
4	0.0	4.0	4.0	3.0	3.0	2.0	0.30
8	0.0	2.8	2.8	2.1	2.1	1.4	0.21

VI. PFC MIXING PLANT

Plants used for the preparation of the PFC mixture shall conform to the following:

(a) **Handling Mineral Filler:** Adequate dry storage shall be provided for the mineral filler, that shall, at a minimum, consist of a waterproof cover that completely covers the stockpile at all times. Provisions shall be made for metering of the filler into the mixture uniformly and in the desired quantities. In a batch plant, mineral filler shall be added directly into the weigh hopper. In a drum plant, mineral filler shall be added directly onto the cold feed belt.

(b) **Fiber Addition:** Adequate dry storage shall be provided for the fiber additive, and provisions shall be made for accurately and uniformly metering fiber into the mixture at plus or minus 10 percent of the desired quantities.

Introduction of loose or pelletized fiber shall require a separate system that can accurately proportion, by weight, the required quantity of fiber in such a manner as to ensure consistent, uniform blending into the mixture at all rates of production and batch sizes. This supply system shall be interlocked with the other feeding devices of the plant system, and sensing devices shall provide for interruption of mixture production if the introduction of fiber fails.

Batch Plant: Loose fiber or pelletized fiber shall be added through a separate inlet directly into the weigh hopper above the pugmill. The addition of fiber should be timed to occur during the hot aggregate charging of the hopper. Adequate dry mixing time is required to ensure proper blending of the aggregate and fiber stabilizer. Therefore, dry mixing time shall typically be increased 5 to 15 seconds. Wet mixing time shall typically be increased at least 5 seconds for cellulose fibers, to ensure adequate blending with the asphalt cement.

When fiber is used, the fiber supply system shall include low level and no flow indicators and a printout of the date, time, and net batch weight of fiber.

Drum Mix Plant: When fiber is used, the fibers shall be added in such a manner as not to be entrained into the exhaust gases of the drum plant. The fiber supply system shall include low level and no flow indicators and a printout of status of feed rate in pounds/minute.

When pelletized fibers are used, they shall be added directly into the drum mixer through the RAP inlet or a specialized fiber inlet. Operation of the drum mixer shall be such as to ensure complete blending of the pelletized fiber into the mix.

(c) **Hot Mixture Storage:** When the hot mixture is not hauled immediately to the project and placed, suitable bins for storage shall be provided. Such bins shall be either surge bins to balance production capacity with hauling and placing capacity or storage bins, which are heated and insulated and which have a controlled atmosphere around the mixture. The holding times shall be within limitations imposed by the Engineer, based on laboratory tests of the stored mixture.

(d) **Mixing Temperatures:** Typical plant mixing temperature shall be 300° - 330° F and at no time shall the mixing temperature exceed 350° F.

VII. WEATHER RESTRICTIONS

Weather Restrictions: Placement of the PFC mixture shall be permitted only when the ambient and surface temperatures are 50° F or above.

VIII. PLACING AND FINISHING

Placing and Finishing: The application rates of the PFC will be as follows or as directed by the Engineer.

PFC 9.5	90 lb/yd^2
PFC 12.5	100 lb/yd^2

The hot mix asphalt shall be delivered to the paver hopper at a temperature conforming to the asphalt liquid supplier's recommendation and shall be measured in the paver hopper. The paver shall be capable of placing the hot mix asphalt at a speed of 30 feet per minute.

The Contractor shall plan his operation such that a continuous paving operation that provides for constant steady movement of the paver is maintained. In the event that excessive stop and go of the paver is occurring, production and laydown of the mixture may be stopped until the Contractor has made satisfactory changes in the production, hauling, and placement operations resulting in a constant steady movement of the paver.

Should visual examination by the Engineer reveal that the material in any load, or portion of the paved roadway is contaminated, segregated, or flushed with asphalt cement, that load, or portion of the paved roadway may be rejected without additional sampling of the material.

IX. ROLLING

Rolling: Immediately after the mixture has been spread and struck off, it shall be thoroughly and uniformly rolled. Rolling shall be accomplished with steel wheel roller(s) with a minimum weight of 10 tons. A minimum of two rollers shall be available at all times for rolling.

To minimize coarse aggregate fracture/breakage in the aggregate skeleton of PFC mixes, the use of vibratory rollers shall be in static mode only.

Rollers shall move at a uniform speed not to exceed 3 mph with the drive wheel nearest the paver. The PFC mixture shall receive a minimum of four roller passes before the surface temperature of the asphalt has reached 185° F.

To prevent adhesion of the mixture to the rollers, it shall be necessary to keep the wheels properly moistened with water possibly mixed with very small quantities of detergent or other approved material.

X. PREPAVING CONFERENCE.

Prior to the start of production, the Department should conduct a prepaving conference.

XII. MEASUREMENT AND PAYMENT

Porous Friction Course will be measured in tons and paid for at the contract unit price per ton, which shall include furnishing and application of tack coat, surface preparation, all materials, additives, labor, testing and equipment as described herein.

Payment will be made under:

Pay Item	Pay Unit
Porous Friction Course, PFC 12.5 (70-28)	Tons
Porous Friction Course, PFC 9.5 (70-28)	Tons