Florida Department of
TRANSPORTATION

Thickness and Binder Type Evaluation of a 4.75-mm Asphalt Mixture using Accelerated Pavement Testing

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EXECUTIVE SUMMARY

An increasing number of transportation agencies are investing in thin overlays consisting of small aggregate size asphalt mixtures to address routine maintenance needs and pavement preservation initiatives. Reported benefits of thin overlays include a smooth riding surface, reduced tire-pavement noise, and the ability to more easily maintain and control grade and cross-slope. The smallest aggregate size mixture the Florida Department of Transportation (FDOT) currently specifies is a 9.5-mm nominal maximum aggregate size (NMAS) mixture. When used as a dense graded friction course, the 9.5-mm NMAS mixture is placed in 1.0 inch lifts, which allows more flexibility and better optimization of milling depths, as well as structural or overbuild lift thickness to achieve a structurally appropriate and economical pavement. However, the ability to place an even thinner asphalt layer may potentially provide designers with more cost-effective alternatives. FDOT recently investigated the layer thickness of a 4.75-mm NMAS mixture using accelerated pavement testing (APT). During the APT study, overlay thicknesses of 0.5 inches, 0.75 inches, and 1.0 inch were placed with PG 67-22 (unmodified) and PG 76-22 (polymer modified) asphalt binders. Pavement instrumentation, laboratory data, and results from a field test section were also considered. This report documents the findings of the APT study and provides recommendations for the use and appropriate thickness of a 4.75-mm NMAS overlay.

BACKGROUND

Introduction

The use of a 4.75 mm nominal maximum aggregate size (NMAS) overlay has gained interest among many transportation agencies as a pavement maintenance or preservation technique. The Florida Department of Transportation (FDOT) recently placed several short sections of a 4.75 NMAS Superpave designed friction course (FC-4.75) as maintenance overlays and also constructed two sections as an experimental pavement preservation technique. Local agencies in Florida are also interested in the potential benefits of a thin FC-4.75 overlay due to the reported benefits. Benefits of thin 4.75 mm NMAS overlays found in literature include a smooth riding surface, reduced tire-pavement noise , and the ability to more easily maintain and control grade and cross-slope (Watson et al, 2014). Other benefits of mixtures with smaller aggregate sizes include good workability and decreased permeability (West et al., 2011). Perhaps one of the most important advantages to FDOT's pavement designers is that a thin lift or overlay allows flexibility and better optimization of milling depths, structural layers, and overbuild lifts to achieve structurally adequate and economical pavement sections. FDOT currently allows 1 inch lifts of Superpave designed 9.5-mm NMAS mixtures (SP-9.5). However, the ability to place an even thinner asphalt layer may potentially provide designers with more cost-effective alternatives. According to NCHRP Report 531, lift thicknesses should be three to four times the NMAS to achieve adequate compaction (Brown et al., 2004.). Considering this criteria, a 4.75-mm NMAS overlay could be placed thinner than 1 inch assuming it meets other requirements of a surface course such as resistance to rutting and cracking and adequate friction properties.

The National Center for Asphalt Technology (NCAT) conducted a survey in 2004 that found 11 states used a 4.75-mm mixture primarily as surface mixtures and leveling courses (West et al., 2011). Despite the extensive use by several states, documented performance of 4.75-mm NMAS mixtures is limited. The lack of performance studies is likely due to the predominant use of the mixture as surface courses for light volume roadways and as leveling courses. One of the first studies to examine the performance of 4.75-mm NMAS mixtures found that these mixtures had excessive laboratory rutting measured with the Asphalt Pavement Analyzer (APA) due to high asphalt contents (James et al., 2003). Kansas researchers observed that rutting performance is aggregate specific and higher binder grade may not improve performance using the Hamburg Wheel Tracking device (Rahman et al., 2010). A recent NCAT study revealed that rutting resistance of 4.75-mm mixtures assessed with the Mixture Verification Tester can be improved by increasing dust content, using high angularity aggregate, and using stiffer binders (West et al., 2011). However, it should be noted that laboratory testing of asphalt mixtures is typically conducted on specimens much thicker than what will typically be placed in the field. Stress conditions that a thin asphalt overlay is subjected to will likely be much different than what laboratory methods can measure.

Another concern that some agencies have is the potential for hydroplaning and friction loss (Williams, 2008 and Li et al., 2011). A recent FDOT study that analyzed crash statistics, geometrical data, pavement condition, and pavement surface types found that conditions for hydroplaning are more likely on dense-graded pavement surfaces (Gunaratne et al., 2012). Likewise, an NCHRP study linked surface texture to water film thickness and hydroplaning potential through the following relationship (Anderson et al., 1998).

$$WFT = \left[\frac{nLi}{36.1S^{0.5}}\right]^{0.5} - MTD$$

where

WFT = water film thickness (inch)
n = Manning's roughness coefficient
L = Drainage path length (inch)
i = Rainfall rate (inch/hour)
S = Slope of drainage path (mm/mm)
MTD = Mean texture depth (inch)

Considering the limitations of laboratory testing of 4.75 mm NMAS mixtures, full-scale field tests and accelerated pavement testing (APT) are perhaps the best methods to assess the performance of these thin overlays. One of the only APT studies of a 4.75-mm NMAS mixture was conducted at the Turner Fairbank Highway Research Center (Li et al., 2011). The 4.75-mm mixture inlay was approximately 1 inch thick and was evaluated for rutting and fatigue resistance. Full-scale rutting indicated satisfactory performance and it was concluded that 4.75 NMAS overlays have the ability to significantly delay top-down cracking as long as the binder does not age excessively. Lane slices and cores revealed air void contents that ranged from

10.4% to 16.3%, which was significantly higher than the target of 10%. The authors also suggested that performance may have been better had field densities not been so low.

Objective and scope

The primary objective of this study was to determine the optimum thickness of a Superpave designed 4.75 mm NMAS friction course (FC-4.75) through full-scale accelerated pavement testing (APT). Test sections were constructed with an FC-4.75 thickness of 0.5 inches, 0.75 inches, and 1.0 inch. In addition, the FC-4.75 included a PG 67-22 unmodified asphalt binder for one set of test sections while a second set of sections used a polymer modified PG 76-22 asphalt binder. The APT performance of the FC-4.75 overlays were compared to results of APT sections surfaced with a Superpave designed fine-graded 12.5 mm NMAS structural course (SP-12.5) that was found to have good performance in a previous APT study. Laboratory testing supplemented the APT results and provided an indication of fracture resistance. Finally, field measurements from a pavement preservation test section constructed in 2012 validated findings of the APT study.

ACCELERATED PAVEMENT TESTING

Test lane construction

Six full-scale pavement test lanes measuring 12 feet wide each were constructed for the APT study. Two of the lanes served as a control and consisted of two 1.5 inch thick fine-graded SP-12.5 mixtures that were paved over a milled portion of a SP-12.5 mixture from a previous study. The only difference in these lanes were the type of asphalt binder. One lane included a PG 67-22 unmodified asphalt binder in both SP-12.5 lifts while the second lane used a polymer modified PG 76-22 asphalt binder in both lifts. The other four lanes included one 1.5 inch lift of a SP-12.5 with a PG 67-22 unmodified asphalt binder followed by a 1.5 inch lift with a polymer modified PG 76-22 asphalt binder. All four lanes were surfaced with a FC-4.75 mixture with a staggered thickness along the length of the lane of 0.5 inches, 0.75 inches, and 1.0 inch. The FC-4.75 overlay included a PG 67-22 unmodified asphalt binder in two of the lanes while the other two included a polymer modified PG 76-22 asphalt binder. The FC-4.75 had a target asphalt content of 6.5% and target air voids of 5.9%. Both mixture types were Traffic Level C (3 to 10 million Equivalent Single Axle Loads) and used 75 gyrations. The supporting layers of all of the test lanes included a 10.5 inch limerock base and a 12 inch stabilized subgrade consisting of a mixture of limerock and native soil. The pavement structure represented a typical Florida roadway and was constructed according to standard FDOT specifications. Table 1 shows the design and as-built gradations, asphalt content, and air voids of each mixture. Figure 1 illustrates the pavement structures. The FC-4.75 mixture design was based on a FDOT developmental specification, which was developed considering criteria proposed by the National Center for Asphalt Technology (West et al., 2011). Granite aggregate was used in all of the asphalt mixtures. The FC-4.75 mixture used aggregate from a Georgia pit and local sand. The SP-12.5 mixture used granite from the same Georgia pit, but also used granite from a Nova Scotia source.

Table 1. Job Mix Formula and As-Built Properties**.**

Sieve Size	FC-4.75			SP-12.5		
	Job Mix Formula	As-Built with PG 67-22	As-Built with PG 76-22	Job Mix Formula	As-Built with PG 67-22	As-Built with PG 76-22
3/4 in	100	100.0	100.0	100	100.0	100.0
1/2 in	100	100.0	100.0	100	97.3	98.4
3/8 in	100	100.0	100.0	87	86.3	87.5
#4	99	98.7	98.7	62	57.8	61.9
#8	77	79.1	78.2	41	39.2	42.4
#16	56	55.7	55.0	29	28.7	31.1
#30	39	40.3	40.0	22	22.1	24.0
#50	26	26.7	26.0	12	13.2	13.8
#100	15	15.1	15.5	4	4.9	5.2
#200	9	8.9	9.5	2	2.8	2.9
% AC	6.5	6.0	6.0	5.1	4.9	4.9
% Air Voids at N_{des}	5.9	6.3	4.6	4.0	3.3	3.9
% Density from Cores	NA	NA	NA	93.0	93.2	93.6

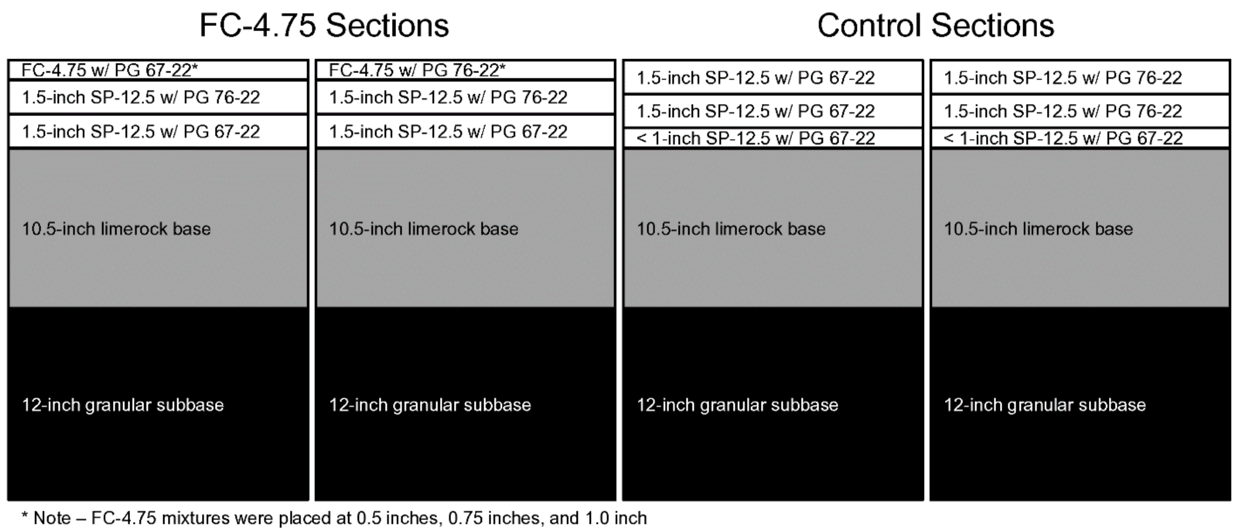

Figure 1. Pavement structures evaluated.

Accelerated loading

FDOT uses APT to allow for a faster and more practical assessment of pavements under closely simulated in-service conditions. In Florida's APT program, the accelerated loading is performed using a Heavy Vehicle Simulator (HVS). Accelerated loading is performed uni-directionally and the pavement temperature is maintained at 120 ^{O}F. To normalize the effect of construction and differential pavement aging prior to testing, at least three tests are performed for each pavement section using a randomized test sequence. Rut depth measurements are conducted periodically using a laser profiling system mounted on the either side of the HVS carriage. Each test section is trafficked until a rut depth of 0.5 inches is accumulated or 100,000 passes is achieved and rutting has stabilized. In this study, accelerated loading was performed using a wide-base Super Single tire (Goodyear G286 A SS, 425/65R22.5) loaded to 9 kips and inflated to 100 psi. Test sections were trafficked with a wheel wander of 4 inch. The Super Single tire was selected because it accelerates pavement damage. A previous HVS study found that the Super Single tire generated a 0.5 inch rut depth approximately 10 times faster than a standard dual tire when loading dense graded surfaces (Greene et al., 2010) Figure 2 shows FDOT's HVS with insulated panels installed to maintain the test temperature. More detailed information of FDOT's APT facility is described elsewhere (Byron et al., 2004).

Figure 2. FDOT’s Heavy Vehicle Simulator.

Figure 3 and Figure 4 show the average rut progression of each test section. In general, thicker FC-4.75 overlays performed better than thinner overlays. All FC-4.75 overlay sections, regardless of thickness or asphalt binder type, had similar or better rut resistance than the SP-12.5 control without polymer modified binder. This indicates that all overlay options would provide adequate rutting resistance on low volume roadways. On roadways with higher volumes of truck traffic where a polymer modified binder is required, the 0.75 and 1.0 inch FC-4.75 overlay had similar or better rut resistance than the SP-12.5 control with PG 76-22 asphalt binder. Cores and lane slices taken from each test section indicated that rutting was confined to the upper FC-4.75 or SP-12.5 layer and did not extend to the granular layers.

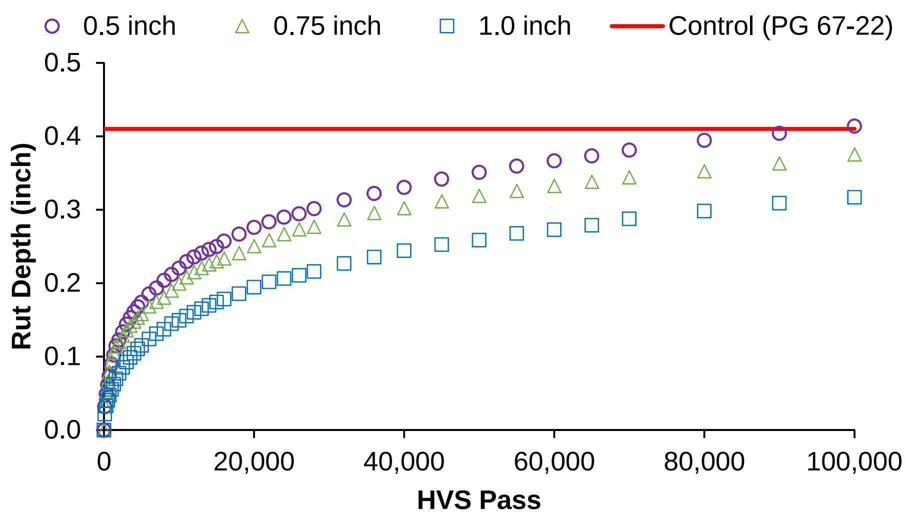

Figure 3. Rut depth measurements for FC-4.75 overlays and SP-12.5 control with PG 67-22 asphalt binder.

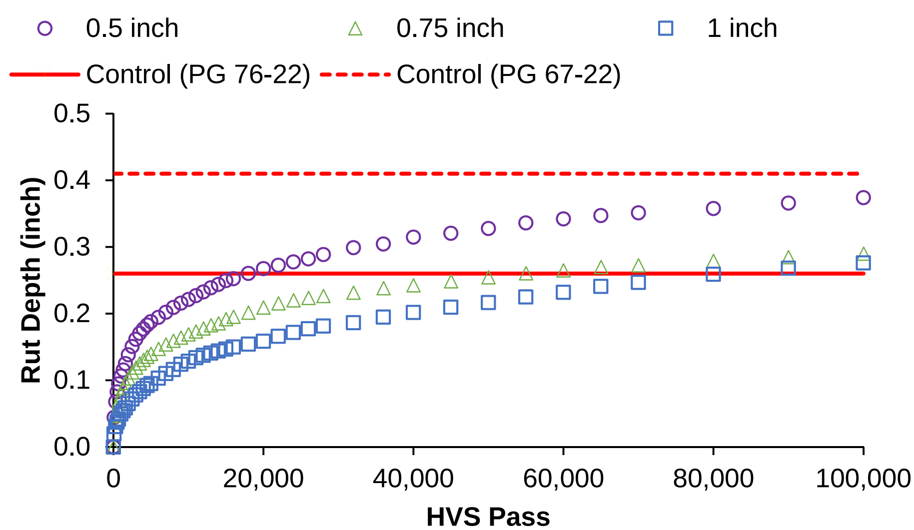

Figure 4. Rut depth measurements for FC-4.75 overlays and SP-12.5 control with PG 76-22 asphalt binder.

As mentioned previously, it is an FDOT APT standard to heat the pavement to 120 ^{O}F when evaluating rut resistance. This elevated temperature simulates summer asphalt conditions and accelerates rutting. It is uncommon for cracks to form during HVS testing under these conditions. However, hairline longitudinal cracks were observed on several 0.5 inch and 0.75 inch FC-4.75 test sections with PG 67-22 asphalt binder. The cracks formed approximately 6 to 8 inches from the tire edge as shown in Figure 5. In response to the observations, surface strain gauges were installed at various offsets from the tire edge on a 0.5 inch and 1 inch thick FC-4.75 section with PG 67-22 asphalt binder. Figure 6 shows that the maximum tensile strain occurred at a similar location from the tire edge as the observed cracks. Cores revealed that the cracks were extremely shallow and consisted of minor surface distortions.

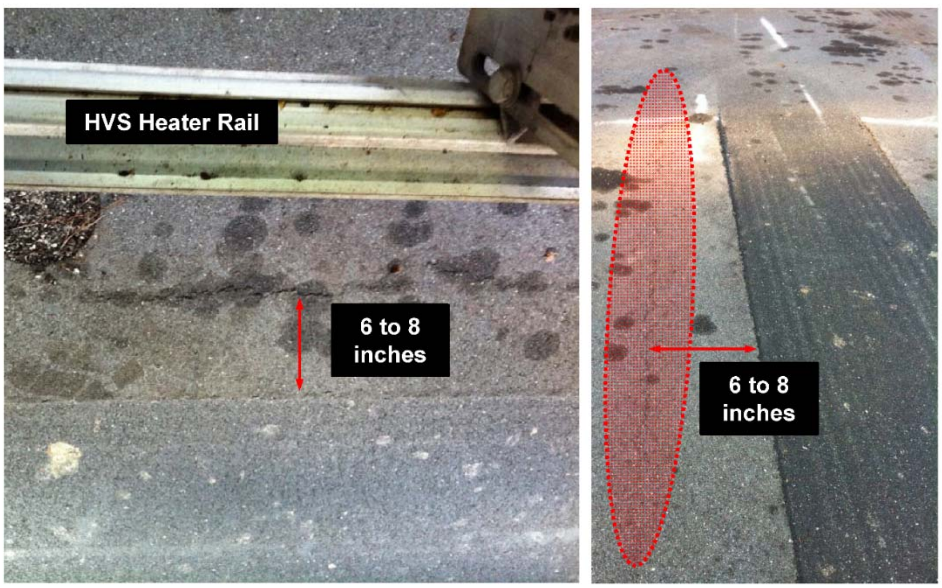

Figure 5. Hairline longitudinal crack on 0.75 inch FC-4.75 overlay with PG 67-22 asphalt binder.

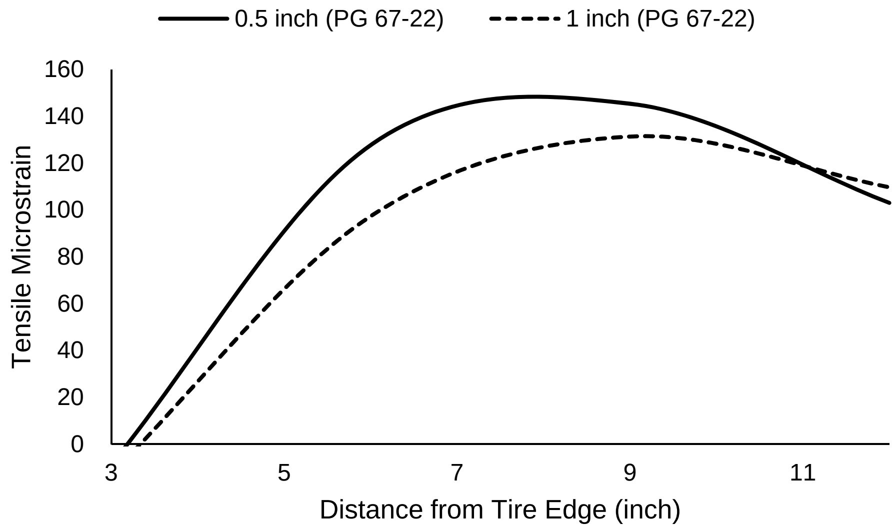

Figure 6. Surface strain measurements on FC-4.75 overlays.

Laboratory Data

Asphalt material was sampled from delivery trucks during construction of the HVS test lanes for laboratory performance testing. Samples were reheated and prepared to determine dynamic modulus and fracture properties. Figure 7 shows the dynamic modulus master curves of the FC-4.75 and SP-12.5 mixtures. Dynamic modulus data at lower frequencies is often associated with rutting performance while low temperature cracking performance is related to dynamic modulus data collected at higher frequencies. In general, binder grade does not appear to have an effect on the dynamic modulus of either mixture. The SP-12.5 mixtures have a slightly greater dynamic modulus at higher frequencies which suggests better low temperature crack resistance. The additional asphalt content and smaller maximum aggregate size of the FC-4.75 may have resulted in the slightly lower dynamic modulus.

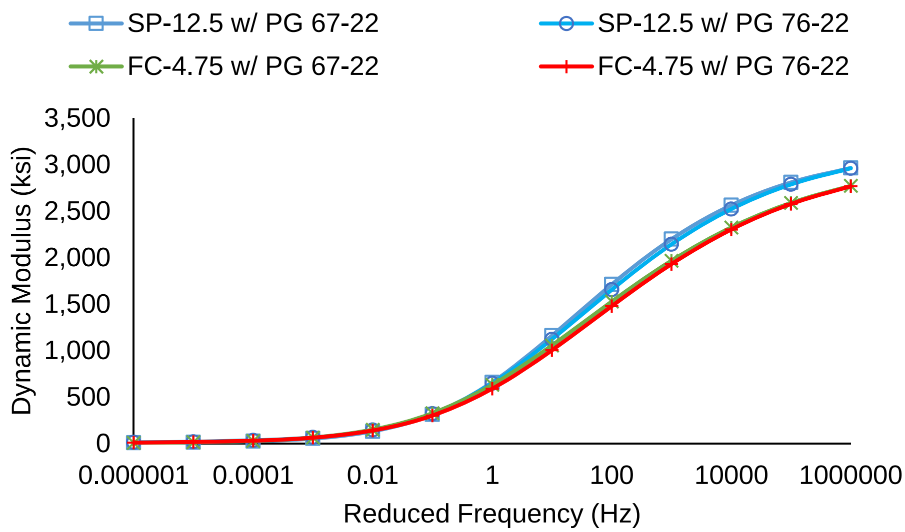

Figure 7. Dynamic modulus of FC-4.75 mixtures and reference SP-12.5 mixtures.

The Energy Ratio (ER) concept and the Laboratory Overlay Tester (OT) were used to assess mixture fracture properties. The Energy Ratio model links asphalt mixture damage to dissipated creep strain energy ($DCSE_f$), which is a function of the maximum tensile strength, resilient modulus of the mixture, and creep compliance (Zhang et al., 2001). According to this model, two crack initiation thresholds exist. Mixtures can fail under repeated loads with low magnitudes when the accumulated damage induced exceeds the dissipated creep strain energy (DCSE) threshold. Damage below this threshold is healable, while damage above this threshold will initiate a macro-crack or will propagate a macro-crack if one already exists. The second threshold occurs when the fracture energy (FE) is exceeded due to a single critical axle load. The ER is defined as the ratio of the dissipated creep strain energy at failure ($DCSE_f$) and the minimum dissipated creep strain energy required to produce a 2 inch crack ($DCSE_{min}$). To determine the properties required to assess ER, indirect tensile (IDT) tests were performed at 50 ^{O}F. This test temperature has been shown to correlate well with field cracking performance of Florida pavements. Mixtures with good cracking performance have been found to have an ER that exceeds 1.0 (Roque et al., 2004).

The Laboratory OT was developed to assess mixture crack resistance due to the opening and closing of joints and cracks. Tests were conducted at 77 ^{O}F with a 0.025 inch displacement.

Testing was conducted until a 93% reduction of the maximum load was recorded. Florida has not yet developed OT performance criteria, but Texas has proposed that mixtures should have greater than 300 cycles for adequate reflective cracking resistance and rich-bottom mixtures should have greater than 750 cycles for satisfactory reflective cracking performance (Zhou et al., 2004).

Table 2 shows the results of the ER and OT tests. Overall, all of the mixtures had satisfactory cracking resistance properties. However, it is interesting to note that the FC-4.75 mixture with polymer modified PG 76-22 asphalt binder has ER and OT results greater than double the other mixtures. This suggests that this mixture may also be a good candidate as an interlayer to resist reflection cracks. It should be noted that reclaimed asphalt pavement (RAP) was not included in either of the mixtures. RAP has been shown to reduce mixture fracture resistance depending on the age and quality of the RAP. Figure 8 shows that ER and OT results have a positive correlation and rank the mixture performance similarly.

Table 2. Energy Ratio and Overlay Tester Results.

Mixture	Energy Ratio Properties			Overlay Tester Cycles to Failure
	Fracture Energy (kJ/m^3)	DCSE$_f$ (kJ/m^3)	Energy Ratio	
SP-12.5 with PG 67-22	2.3	2.1	2.8	362
SP-12.5 with PG 76-22	2.8	2.6	4.2	469
FC-4.75 with PG 67-22	3.2	2.9	4.7	701
FC-4.75 with PG 76-22	4.4	4.1	10.9	922

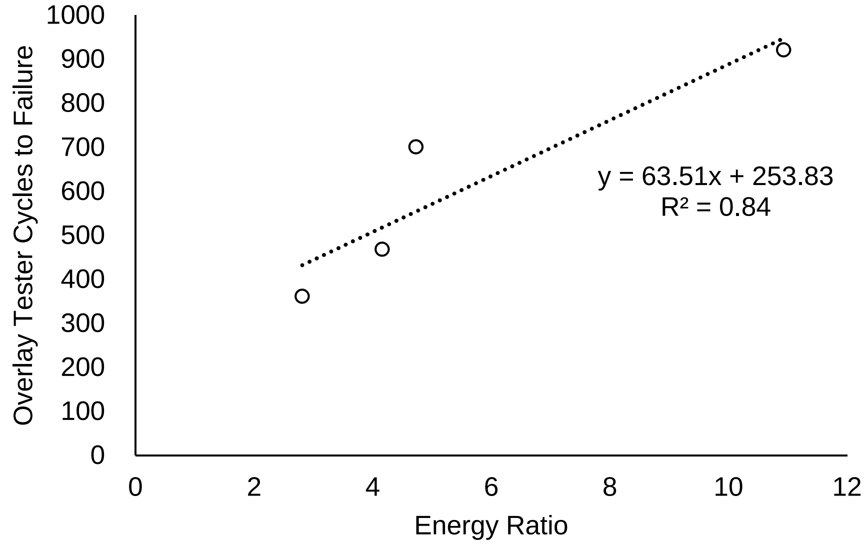

Figure 8. Energy Ratio and Overlay Tester relationship.

Friction and Surface Texture Measurements of the APT Test Sections

Friction measurements of the FC-4.75 overlay were made using the Dynamic Friction Tester (DFT). In addition, the Circular Track Meter (CTM) was used to determine the mean profile depth (MPD). Ten friction and texture measurements were randomly made outside of the loaded wheel path area on two of the lanes with both binder types. Six friction and texture measurements were made within the wheel paths to determine the potential impact of traffic. DFT measurements made at 40 mph (DFT40) were converted to Friction Number values at 40 mph using a ribbed tire (FN40R) based on a relationship developed in a previous FDOT study that included SP-9.5 and SP-12.5 surfaces (Choubane et al., 2012). No difference was found between asphalt binders used in the FC-4.75. Table 3 shows the average friction and texture measurements. There was approximately 39% difference in friction due to loaded wheel traffic. However, friction within the wheel path was still satisfactory according to an FDOT minimum required FN40R of 35. The high friction measurements may be due to the aged asphalt surface. Both set of measurements were made after completion of the APT study, which was more than two years after construction of the test sections.

MPD values measured outside of the wheel path shown in Table 3 were generally less than those of typical FDOT SP-9.5 and SP-12.5 mixtures. MPD values measured within the wheel path where typical of FDOT SP-9.5 mixtures, suggesting the texture increased as traffic was applied. Figure 9 shows the MPD distribution of newly placed FDOT friction courses measured over an eight year period using a 64 kHz laser mounted on a vehicle travelling at highway speeds. An FDOT study found the MPD determined with the CTM and the 64 kHz laser were similar (Choubane et al., 2012).

Table 3. FC-4.75 friction and texture measurements.

Location	**DFT40 x 100**	**FN40R**	**MPD (inch)**
Outside wheel path	0.65	62	0.009
Within wheel path	0.44	43	0.016

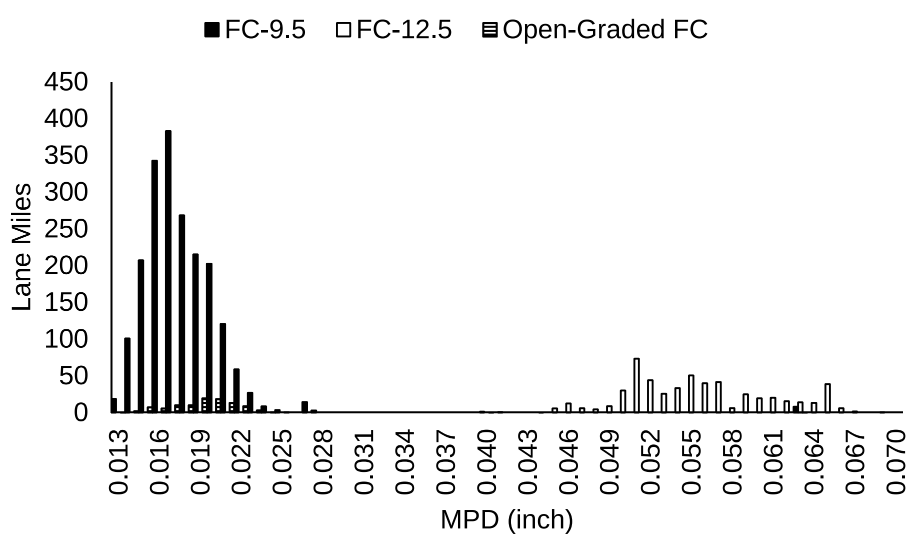

Figure 9. MPD distribution of FDOT friction courses.

PAVEMENT PRESERVATION TEST SECTION

A pavement preservation test section consisting of ten treatments was constructed in 2012 on both directions of US-98 in Gulf County. At the time of construction, it was standard for the asphalt binder to include 5% ground tire rubber in Superpave designed friction courses and 12% ground tire rubber in the open-graded friction course. Unlike standard FDOT pavement rehabilitation methods, several sections were not milled prior to overlay to assess the effectiveness of the treatment in delaying reflection cracks. Each test section is approximately 1500 feet long and has been monitored annually since construction. Pavement smoothness and rut depth were determined using a high speed inertial profiler. Friction measurements were collected with a locked-wheel friction tester. A 64 kHz laser mounted on the locked-wheel friction tester was used to assess the surface texture in the wheel path. Cracking was assessed through a visual survey. The average annual daily traffic for this site is approximately 7000 vehicles per day with 5.5% trucks.

Table 4 describes the test sections and the most recent crack survey observations. Two sections were not treated in order to serve as controls. The predominant crack types for both travel directions are shown in the table. While the FC-4.75 overlay has improved the extent of cracking compared to the control, fine cracks are propagating throughout the wheel paths at a greater rate than for most other treatments. However, the 1 inch FC-9.5 overlay appears to be more crack resistant than the thinner FC-4.75 overlays. Milling also appears to delay the presence of reflection cracking.

Table 4. Pavement preservation test sections.

<table>
<tr><th rowspan="2">Test Section</th><th rowspan="2">Treatment</th><th colspan="2">Predominant Crack Percentage at Year 4</th></tr>
<tr><th>Wheel Path</th><th>Outside Wheel Path</th></tr>
<tr><td>1, 9</td><td>Control (no resurfacing)</td><td>30% Class III</td><td>20% Class III</td></tr>
<tr><td>2</td><td>Microsurfacing</td><td>30% Class I</td><td>5% Class I</td></tr>
<tr><td>3</td><td>0.5 inch FC-4.75 overlay</td><td>25% Class I</td><td>5% Class I</td></tr>
<tr><td>4</td><td>0.75 inch FC-4.75 overlay</td><td>35% Class I</td><td>5% Class I</td></tr>
<tr><td>5</td><td>1 inch FC-9.5 overlay</td><td>10% Class I</td><td>3% Class I</td></tr>
<tr><td>6</td><td>1 inch mill and 1 inch FC-9.5 overlay</td><td>10% Class I</td><td>7% Class I</td></tr>
<tr><td>7</td><td>1.5 inch mill and 1.5 inch FC-12.5 overlay</td><td>10% Class I</td><td>3% Class I</td></tr>
<tr><td>8</td><td>0.75 inch open-graded friction course with heavy polymer tack coat (bonded friction course)</td><td>10% Class I</td><td>2% Class I</td></tr>
<tr><td>10</td><td>1.5 inch hot-in-place recycling (HIPR)</td><td>15% Class I, Rippling</td><td>5% Class I</td></tr>
<tr><td colspan="4">Class I – Cracks less than or equal to 1/8 inch
Class II – Cracks greater than 1/8 inch and less than 1/4 inch
Class II – Cracks greater than 1/4 inch</td></tr>
</table>

Figure 10 and Figure 11 show the pavement rut depth and smoothness of each section. Treatment types and both control section measurements were averaged. Overall, the sections with an FC-4.75 are performing well. Both sections have rut depths less than 0.15 inch and are among the smoothest sections with a mean IRI of approximately 50 inches/mile. Upon construction, all of the treatment sections had friction values (FN40R) that ranged from 50 to 60 and all except the bonded friction course had a drop in friction by approximately 15% after the first year. The bonded friction course values dropped by approximately 8%. The average MPD for the FC-4.75 overlay sections is 0.017 inches, which is in the typical range of standard dense-graded friction courses shown previously in Figure 9. All of the sections continue to have acceptable friction properties after four years of service.

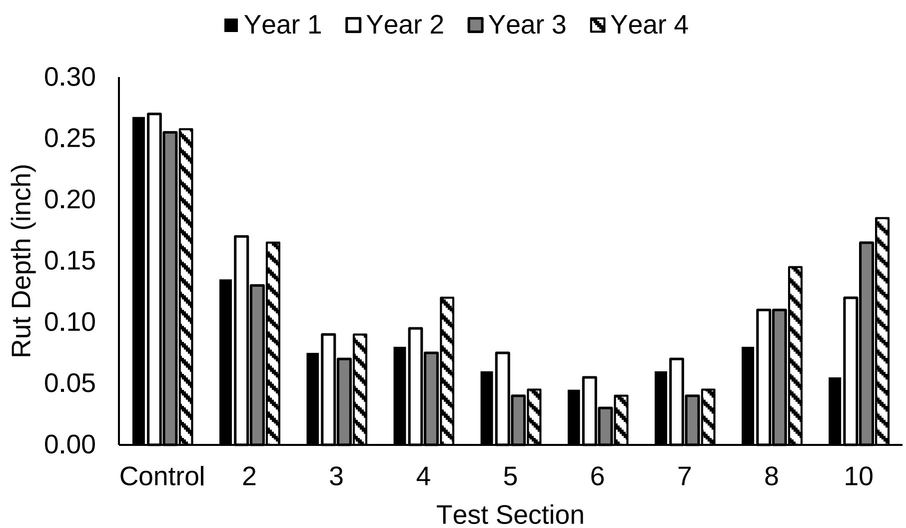

Figure 10. Pavement preservation test section rut depth.

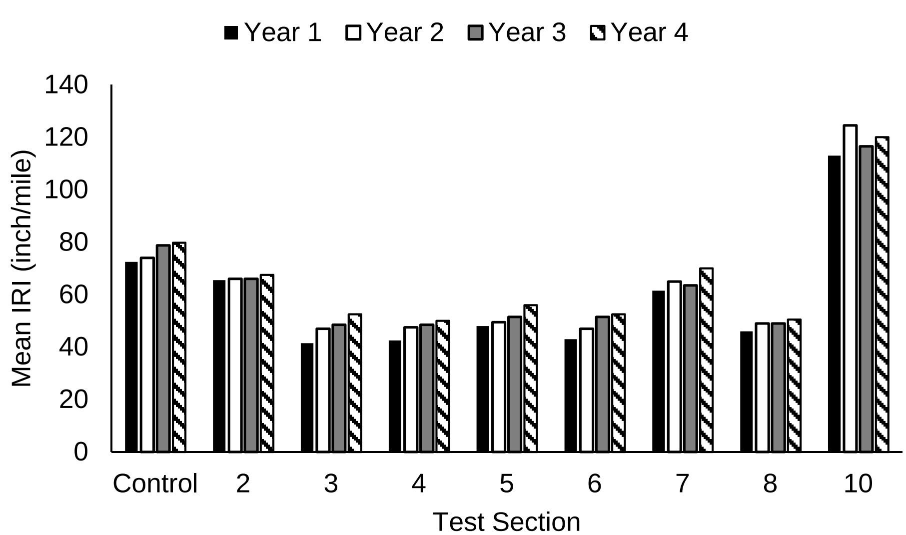

Figure 11. Pavement preservation test section smoothness.

SUMMARY AND CONCLUSIONS

A full-scale APT study, supporting laboratory testing, and field measurements have shown that an FC-4.75 overlay may be effective as a preservation treatment when properly designed and constructed. Laboratory testing showed that the FC-4.75 mixtures had greater cracking resistance than the SP-12.5 mixtures, but visual observations of the pavement preservation test sections showed that reflection cracks propagated through the FC-4.75 overlay at a greater rate than a similarly prepared but thicker FC-9.5 overlay. Milling prior to an overlay also appeared to reduce the appearance of cracks. In addition, minor surface distortions were found on the 0.5 and 0.75 thick FC-4.75 APT test sections with unmodified PG 67-22 asphalt binder. Another potential concern is the hydroplaning potential of a new FC-4.75 mixture due to minimal surface texture. However, measurements of the pavement preservation test sections and the APT test sections showed that FC-4.75 surface texture and friction values were in the typical range of standard FDOT friction courses. Findings and recommendations based on the results of this study can be found below.

- For low volume roadways, all combinations of binder (PG 67-22 and PG 76-22) and thickness (0.5, 0.75, and 1 inch) provided adequate rutting resistance. However, overlays of 0.5 and 0.75 inch with a PG 67-22 binder were found to have minor surface distortions in the APT study which may indicate less resistance to near surface cracking.
- For higher volume roadways, a 0.75 inch or thicker FC-4.75 overlay with PG 76-22 asphalt binder will provide adequate rutting and cracking resistance.
- An FC-4.75 overlay should not be used on roadways with design speeds of 50 mph or greater until more research is conducted to better quantify the hydroplaning potential of newly placed FC-4.75 mixtures.
- Prior to overlay, the existing pavement should be milled to minimize reflection cracking. If milling is not possible or cracks cannot be completely removed, thicker overlays and the use of a polymer modified binder will help delay reflection cracking.
- An SP-4.75 mixture with polymer modified binder showed potential as a crack relief interlayer. More research is needed to optimize the mixture and quantify the potential benefit.

ACKNOWLEDGEMENT

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