Field and Laboratory Investigation on Superpave 9.5 mm (SP-9.5) Mixtures in Florida

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ABSTRACT

A full-scale experiment was conducted at the Florida Department of Transportation (FDOT)'s Accelerated Pavement Testing (APT) facility to evaluate the performance of Superpave 12.5 mm and 9.5 mm asphalt mixtures. APT test section lanes were constructed using two nominal maximum aggregate size asphalt mixtures (SP-12.5 and SP-9.5). Those mixtures share aggregate (limestone with 20% RAP) and asphalt binder (PG 76-22 PMA) with the only difference being the nominal maximum aggregate size. The rutting performance evaluation using the Heavy Vehicle Simulator (HVS) indicated the SP-12.5 mixtures perform slightly better than the SP-9.5 mixtures, but the difference was practically insignificant. Other field tests, Circular Track Meter (CTM) and Dynamic Friction Tester (DFT) showed that the SP 9.5 mixtures have a smoother macro texture but generates greater long-term tire-pavement friction. In addition, supplementary laboratory tests (IDEAL-CT and Cantabro Loss) showed SP-9.5 mixtures have better-cracking resistance and durability than the SP-12.5 mixtures, while the Asphalt Pavement Analyzer (APA) and Hamburg Wheel Track Test (HWTT) presented comparable rutting performances. Overall, the rutting performance of SP-9.5 and SP-12.5 mixtures are essentially identical. However, the SP-9.5 mixtures are anticipated to have greater cracking resistance and durability than the SP-12.5 mixtures. The test result justifies the recent adoption of the SP-9.5 mixtures for traffic level E roadways in Florida.

Keywords: Superpave 9.5 mm Mixture, Accelerated Pavement Testing, Nominal Maximum Aggregate Size, Pavement Performance, Asphalt Concrete Pavement, SP-9.5

INTRODUCTION

Background

The nominal maximum aggregate size (NMAS) is one of the most influential aggregate characteristics of hot mix asphalt (HMA) mixtures. Using improperly small NMAS may result in excessive voids in mineral aggregate (VMA). Accordingly, corresponding high binder content and lack of aggregate interlocking may result in instability issues and premature rutting on the HMA surfaces. On the contrary, the use of excessive NMAS possibly causes workability and durability issues due to the insufficient VMA associated with excessive NMAS. (1, 2). Selecting a suitable NMAS is crucial in designing the HMA mixture. Hence, many highway agencies consider various factors, including traffic volume, aggregate source, and climate conditions, to select the proper NMAS.

In Florida, the warm climate combined with heavy truck traffic led to using SP-12.5 mixtures (12.5 mm in NMAS) for most interstate highways for better rutting resistance. The Florida Department of Transportation (FDOT) Standard Specifications restrict the placement of SP-9.5 mixtures (9.5 mm in NMAS) in surface layers (require at least 1.5 inches thickness) with equal or higher than 10 million equivalent single axle loads (ESALs) (traffic level E) for the same reason (4, 5). Restricting construction practices and pavement design unnecessarily imposes limitations that hinder contractors' access to a wide range of products and design flexibility. Additionally, these restrictions curtail the potential advantages of utilizing smaller NMAS, which can offer benefits such as improved workability, cost-effectiveness, and durability. (1, 6-8).

The Use of SP-9.5 Mixtures

HMA mixtures using small NMAS such as 9.5 and 4.75 mm have several benefits, including increased durability, reduced raveling, reduced segregation, reduced tire-pavement interaction noise, improved riding quality and safety characteristics, improved cracking resistance, extended pavement service life (2, 3, 9-14). The drawback of the small NMAS identified in the previous studies is the low rutting resistance as indicated by laboratory wheel-tracking and creep tests (2, 6, 7, 13, 15-17). According to the previous studies, there was no consensus regarding the performance of the HMA mixtures with 9.5mm NMAS. Bhasin et al. investigated the effect of NMAS on HMA performance. The authors did not support using the 9.5mm south Texas aggregate even when combined with crushed coarse aggregate, as the rutting performance of these mixtures was poor (7). Similar findings were reported by Button et al., where HMA mix with 9.5mm NMAS showed poor rutting resistance in the Hamburg wheel tracking test as compared to those with 12.5mm NMAS (18). On the contrary, Hand et al. concluded that the use of 9.5mm NMAS did not yield a significant reduction in rutting resistance as compared to the 19mm NMAS in asphalt mixtures, as measured by the wheel-tracking test in the laboratory and accelerated pavement testing (APT) at the Indiana Department of Transportation (INDOT)/Purdue University APT facility (19).

Wisconsin Department of Transportation (WisDOT) Standard Specifications limit the NMAS of HMA mixtures to only 12.5 mm in the surface layer. Christensen et al. evaluated the performance of 9.5mm HMA mixtures to allow the use of these mixtures in WisDOT surface layers. Their study, using predictive models, showed a negligible relationship between NMAS and modulus or layer coefficient, indicating no significant decreases in the structural capacity of the HMA mixture with 9.5mm NMAS as compared to 12.5mm mixtures. Based on theoretical stress analyses, 9.5 mm, and 12.5 mm mixtures showed comparable thermal cracking resistance. The AASHTO MEPDG analysis indicated a minor relationship between rutting performance and NMAS. The 9.5mm mixtures showed slightly reduced rutting resistance as compared to the larger NMAS mixtures. Based upon the results of this study, the WisDOT revised its standard specifications in which 9.5mm mixtures are currently permitted in surface layers (20).

Alabama Department of Transportation (ALDOT) specifies using 9.5mm mixtures by limiting the VMA corresponding to the traffic level. The VMA for the roadways with lower than or equal to 1 million ESALs (traffic level A/B) should be at most 16.5 percent and a maximum of 18 percent for traffic levels beyond that (21). This shows that ALDOT allows using 9.5mm mixtures under some limitations. Another neighbor state that permits the use of 9.5mm mixtures is Georgia. The Georgia Department of

Transportation (GDOT) currently allows 9.5mm mixtures in the open-graded surface mixture (OGFC), Superpave mixtures, and stone matrix asphalt mixture (SMA) in the *Standard Specifications for the Construction of Transportation Systems* (22). Moreover, the GDOT's Office of Materials and Testing revised the *Criteria for Use of asphaltic Concrete Layer and Mix Types* to accommodate Superpave 9.5 mixtures in GDOT-selected routes with medium to heavy traffic levels (23).

Based upon the review of the state of the practice, there is strong evidence to allow the use of 9.5mm mixtures in surface layers. These mixtures should exhibit better or equivalent performance as that of 12.5mm mixtures, except for rutting resistance. Furthermore, Hu and Zhou conducted laboratory experiments on several SP-12.5 and SP-9.5 mixtures under FDOT specification. They concluded that only limestone SP-9.5 PG67-22 has worse rutting performance than the SP-12.5 mixtures, while other SP-9.5 mixtures, such as granite SP-9.5 PG76-22 and limestone PG 76-22 mixtures, had better or equivalent performance than the SP-12.5 mixtures in terms of rutting, cracking, and durability (7). Prior to this research, the Florida Department of Transportation did not allow the placement of 9.5mm mixtures for traffic levels exceeding 10 million ESALs.

Nevertheless, according to the previously mentioned studies from the literature, the effect of NMAS on rutting resistance needs to be verified, especially in field performance. Therefore, compared to laboratory measurements, full-scale field tests and accelerated pavement testing (APT) are the best methods to assess the rutting performance of 9.5mm mixtures.

Research Objective

The main goal of this study is to:

1. Examine the rutting and cracking performance of 9.5mm NMAS asphalt mixtures (SP-9.5) and compare them to the commonly employed 12.5mm (SP-12.5) asphalt mixtures in Florida.
2. Evaluate the durability and surface characteristics of 9.5mm NMAS asphalt mixtures (SP-9.5) and 12.5mm (SP-12.5) asphalt mixtures.
3. Provide a well-founded rationale for the existing specifications, thereby offering a clear justification for their use.

EXPERIMENTAL DESIGN

In this experiment, the material properties and performance of SP-9.5 and SP-12.5 mixtures were compared. Mix designs for both mixtures were conducted and ensured to meet the FDOT standards. Two test track lanes were constructed and applied field testing including HVS rutting and surface characteristic tests. Supplementary lab testing was also performed to evaluate the rutting, cracking, and durability of both mixtures.

Asphalt Mixture Mix Design

Tables 1 and 2 summarized the aggregate gradation and mix components for both SP-12.5 and SP-9.5 mixtures. Both mixtures had the same asphalt binder (PG 76-22 PMA), RAP content (20%), and virgin aggregate type and source (two sizes of limestone coarse aggregate, screenings, and sand). The SP-9.5 mixtures had 0.2% higher binder content than the SP-12.5 mixtures due to the higher VMA. The gradation plots of both mixtures are shown in Figure 1.

Table 1: Design Aggregate Gradation of SP-12.5 and SP-9.5 Asphalt Mixtures

Aggregate Gradation (Sieve Size)	Percent Passing		SP-12.5 Control Points		SP-9.5 Control Points	
	SP-12.5	SP-9.5	Min.	Max.	Min.	Max.
¾" 19.0mm	100	100	100	---	---	---
½" 12.5mm	98	100	90	100	100	---
3/8" 9.5mm	89	98	---	90	90	100
No. 4 4.75mm	64	73	---	---	---	90
No. 8 2.36mm	49	51	28	58	32	76
No. 16 1.18mm	40	40	---	---	---	---
No. 30 600μm	34	32	---	---	---	---
No. 50 300μm	20	20	---	---	---	---
No.100 150μm	9	10	---	---	---	---
No. 200 75μm	5.1	5.1	2	10	2	10

Table 2. Components of Asphalt Mixtures

Mix Type	SP-12.5	SP-9.5
NMAS	12.5 mm	9.5 mm
RAP Content (%)	20	20
Total Binder Content (%)	5.0	5.2
$\%G_{mm}$ @ N_{100}	96.0	96.0

Figure 1: Aggregate Gradations of Asphalt Mixtures

Field Testing

Construction of APT Test Track Lanes

Two 12-ft wide by 120-ft-long test track lanes were milled and resurfaced at the FDOT's APT facility. Each test track lane consisted of three loading areas, as shown in Figure 2. Both test track lanes have identical pavement structures but different surface layers, including a 1.5-inch SP-9.5 mixture and SP-12.5 mixtures, as presented in Figure 3. The same tack coat rate (0.079 gal/yd^2) and target compaction level of 93% density were applied for both test track lanes. Cores were taken from both test track lanes after the construction to check the density. The SP-9.5 section had 93.6% density while the SP-12.5 section had 93.0% density.

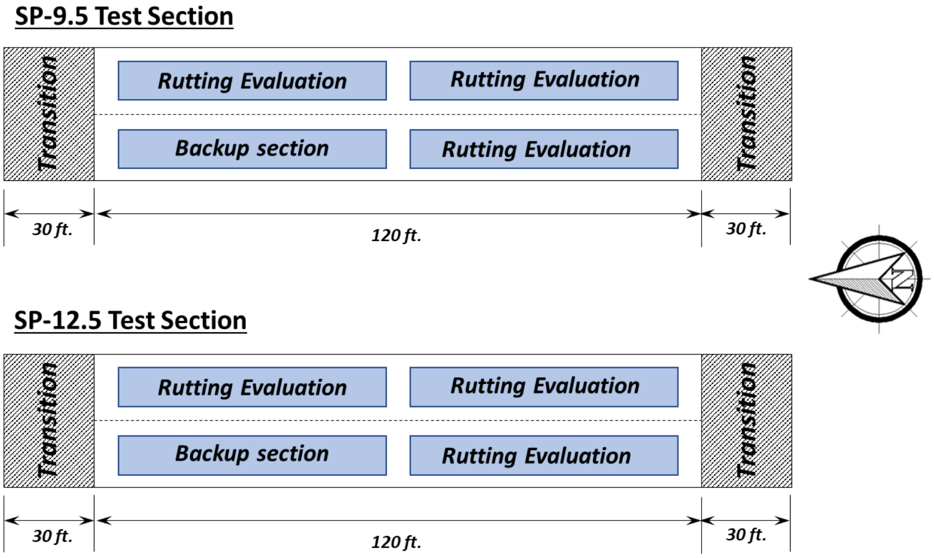


Figure 2. Test Sections Layout

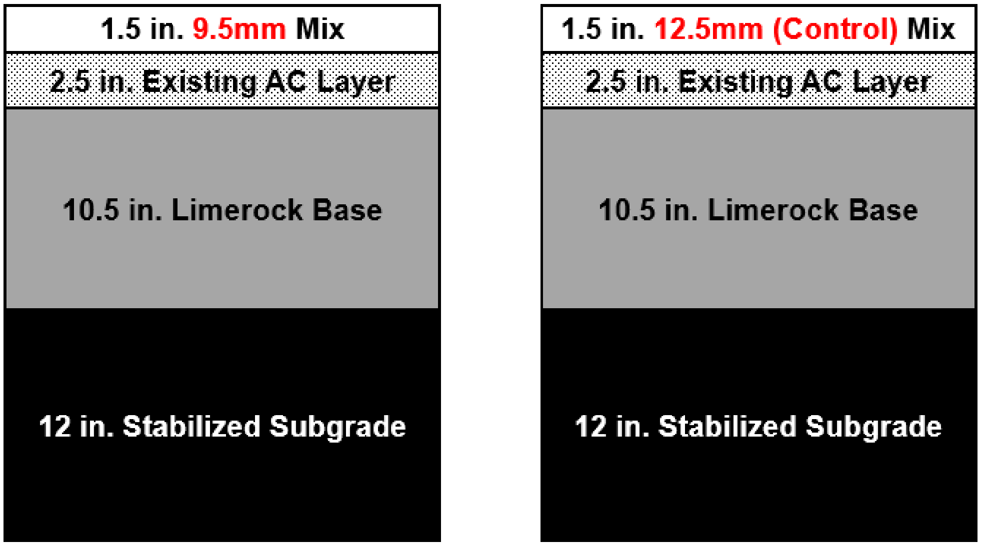


Figure 3. Cross-Section of the Test Sections

Accelerated Pavement Testing (APT)

Accelerated loading was applied using FDOT's Heavy Vehicle Simulator (HVS) Mk.4 to evaluate the rutting performance of the test sections. Each loading area was trafficked with unidirectional passes of a Super single tire (Goodyear G286 A SS, 425/65R22.5) with 4 inches of wheel wander. 100,000 passes of the 9-kip HVS wheel load were applied, with an average of 10,000 passes per day at a speed of 8 mph under a controlled temperature of 50°C at 2 inches below the pavement surface. Rut-depths of three loading areas assigned to each test section were averaged to compare the rutting performance of the test sections. Figure 4 shows FDOT's HVS Mk.4, which was utilized for the evaluation of the rutting performance.

Figure 4. FDOT's HVS Equipment in the APT Facility

Surface Characteristic

The surface characteristics of SP-9.5 and SP-12.5 were evaluated by measuring the surface macrotexture and frictional properties. It was found that pavement surface macrotexture is related to noise level generated from tire/pavement interaction (24). The macrotexture can be quantified by measuring the mean profile depth (MPD). A past study stated higher MPD could produce higher noise levels at low frequencies for dense-grade asphalt pavement (25). A Circular Texture Meter (CTM) in accordance with ASTM E2157 was used to collect the MPD data in this research. Four test locations were selected, including three locations inside the HVS loading area and one outside the HVS loading area. Each test location was tested three times to get an average MPD value.

The frictional properties of SP-9.5 and SP-12.5 mixtures were assessed by the Dynamic Friction Tester (DFT). The DFT measurements were then mathematically converted into the equivalent friction numbers obtained at the standard test speed of 40 mph using the locked-wheel tester with a ribbed tire (FN40R). The same testing locations and protocols from MPD tests were followed. The regression equation relating the locked wheel test results at 40 mph (65 km/h) and the DFT results developed from the past study is presented below (26):

$$FN40R = 0.88 * DFT40 + 4.74 \qquad (1)$$

Laboratory Testing

Laboratory Testing Plan

Loose asphalt mixtures were collected from the delivery trucks (hereafter referred to as plant mixtures) before paving; pavement cores were collected from the APT test sections after construction for further supplementary laboratory testing. The loose mixtures were re-heated to the required compaction temperature (for about 2 hours) before compaction in the Superpave Gyratory Compactor (SGC).

Additional aging was applied to the IDEAL-CT samples to evaluate the long-term aging effect. Aging has long been recognized as a significant driver of distress for asphalt pavements. Aging causes the material to stiffen and embrittle, creating a high potential for cracking and raveling (27). Since Florida is in a hot climate region and the long summertime could cause oxidation to asphalt binder, leading to potential top-down cracking, it is crucial to age the lab asphalt mixtures long-term before evaluating the cracking resistance. For aging the asphalt mixture specimens prior to laboratory testing, the recommendations from NCHRP report 871 were followed (28), where the plant (loose) mixtures were long-term oven aged (LTOA) for five days at 95°C prior to compaction in the Superpave Gyratory Compactor (SGC).

Table 3 details the laboratory tests on the asphalt specimens prepared from the loose mixtures and pavement cores.

Table 3. Laboratory Tests for Pavement Cores and Plant Mix Specimens

Specimen Type	Performance Evaluation	Test Method/ Measurement	Specimen Aging	Number of Replicates	Relative Specifications
Pavement Cores	In-place density	G_{mb} and G_{mm} [1]	No aging	3	AASHTO – T209
	Rutting resistance	Asphalt Pavement Analyzer (APA)	60 days after construction	2	AASHTO T340
	Durability	Cantabro	No aging	3	AASHTO TP108
Plant Mix Specimens	Volumetric properties	VMA, VFA, and A.V. [2]	No aging	---	AASHTO
	Cracking resistance	IDEAL-CT	No aging and LTOA [3]	3	ASTM D8225
	Rutting resistance and moisture susceptibility	Hamburg Wheel-Track Testing (HWTT)	No aging	2	AASHTO T324
	Rutting resistance	Asphalt Pavement Analyzer (APA)	No aging	2	AASHTO T340

[1] Bulk specific gravity (G_{mb}) and the theoretical maximum specific gravity (G_{mm})
[2] Voids in mineral aggregate (VMA), voids filled with asphalt (VFA), and percent air voids (Va)
[3] Long-term oven aging (LTOA) of loose mix aging for 5 days at 95°C

RESULTS AND ANALYSIS

Field Test Result

Field Rut Depth Measurement (APT)

Field rut depths were measured by the laser profiler installed underside of the HVS wheel carriage at predetermined HVS pass numbers. A total of three tests were performed. Figure 5 illustrates the average rut depth from the HVS tests for both SP-12.5 and SP-9.5 test sections. Results showed the SP-12.5 test section had a 0.6 mm lower average rut depth than the SP-9.5 section after 100,000 passes. Both test results exhibited an average rut depth of less than 4 mm, well below the failure criterion of 12.7 mm. These findings indicate the satisfactory performance of both sections under HVS loadings.

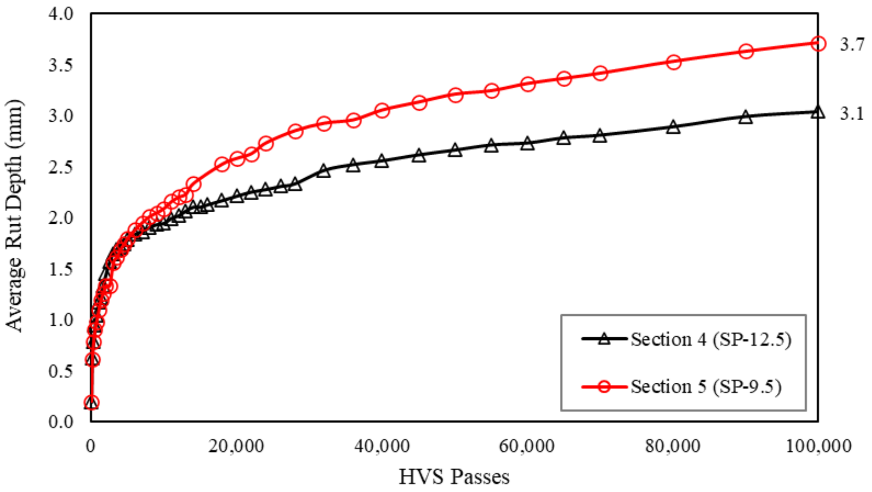


Figure 5. Rut Depth Profiles for SP-12.5 and SP-9.5 Sections

The average transverse rut profiles after 100,000 HVS wheel passes for both test track lanes are shown in Figure 6. A profile showing a higher ratio of shear area to wheel path area indicates rutting is predominantly attributed to shear flow and instability rather than densification as the primary contributing factors. The shear area over densification area ratio for the SP-9.5 section was determined to be 0.25, whereas the SP-12.5 section exhibited a ratio of 0.24. Both sections experienced the same level of shear flow/densification. It is noted that, in general, the loading area with cross slope shows slightly higher rut depth due to the asymmetric cross profile presented in one of the SP-9.5 loading areas.

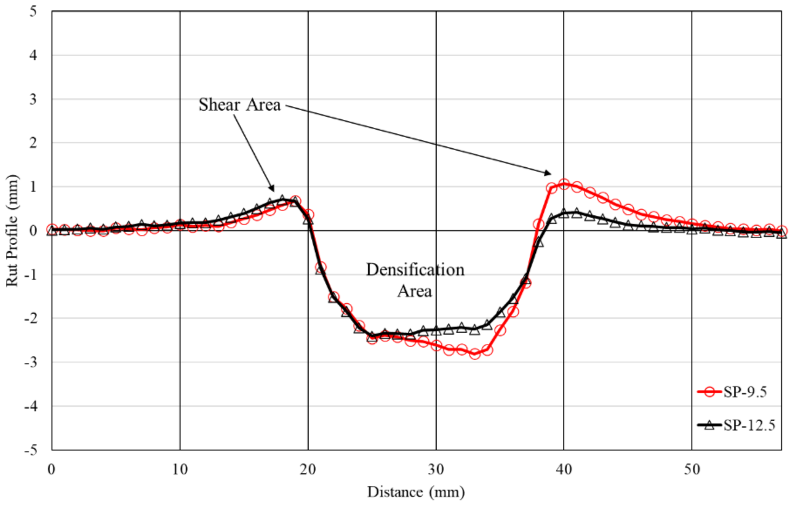


Figure 6. Transverse Rut Profiles at 100,000 HVS Wheel Passes

Safety and Noise Level (Surface Characteristics)

The average value of MPD data before and after the HVS loading for both sections is presented in Figure 7. The SP-9.5 section demonstrates an increase in MPD after loading, suggesting a potential increase in noise levels associated with this section. On the other hand, the MPD value from the SP-12.5 section decreases after the HVS loading, indicating a slight reduction in noise levels. Nonetheless, it is essential to note that despite the reduction, the SP-12.5 section still exhibits a higher average MPD value than the SP-9.5 section. This finding is consistent with previous studies that have established a correlation between higher nominal maximum aggregate size (NMAS) and increased MPD values (29).

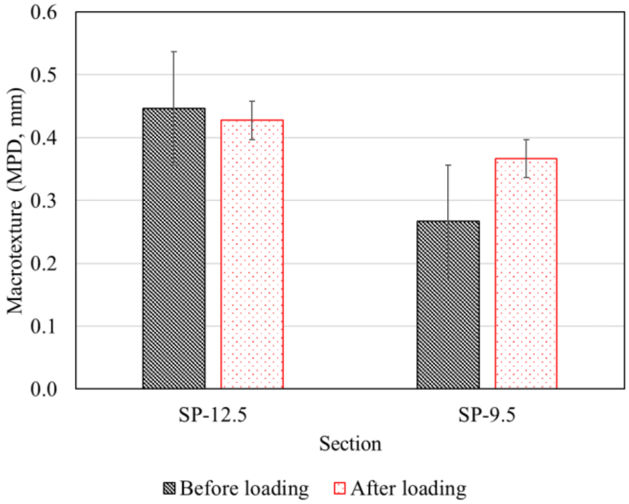
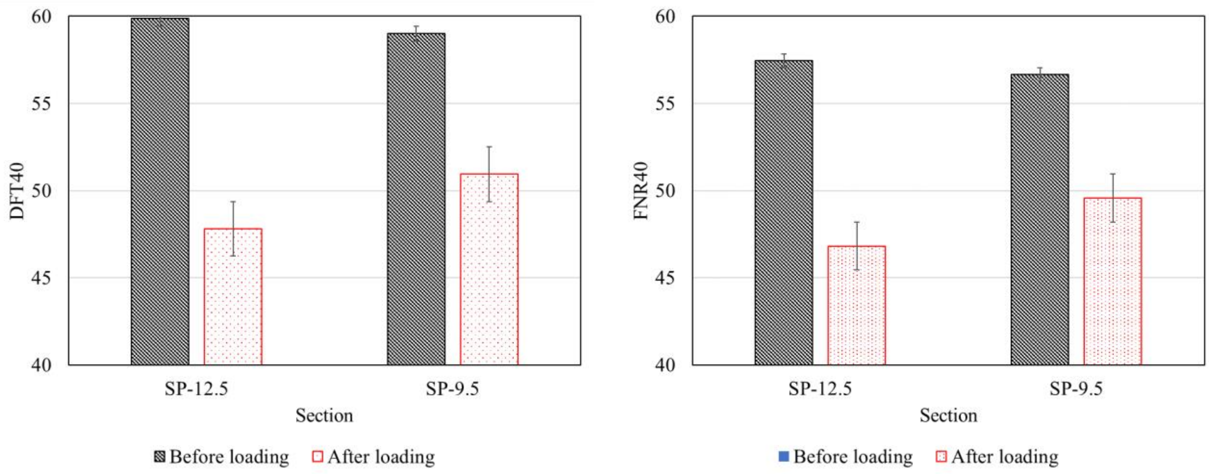


Figure 7. Comparison of MPD Before and After HVS Loading



(a) **(b)**

Figure 8. Comparison of Friction Values Before and After HVS Loading (a) DFT40 (b) FNR40

Figures 8(a) and 8(b) present the frictional properties of the SP-9.5 and SP-12.5 sections before and after the HVS loading tests. Higher DFT40 and FNR40 values mean higher friction values. Both sections demonstrate a decrease in friction performance after the tests. However, it is critical to highlight that the SP-12.5 section experienced a more pronounced drop in friction performance compared to the SP-9.5 section, showing that SP-9.5 might have better frictional properties in the long term.

Laboratory Test Result

Cracking (IDEAL-CT)

The cracking performance of the SP-12.5 and SP-9.5 mixtures was evaluated via the IDEAL-CT test. The performance is presented as the CT_{index}; higher values represent better cracking resistance. The results are shown in Figure 9. Moreover, Table 4 presents the mean, standard deviation, and coefficient of variance (CV) of the test results. The SP-9.5 mixtures were found to have 15% to 26% higher CT_{index} than SP-12.5 mixtures in both non-aged and long-term aged mixtures, meaning that SP-9.5 has better crack resistance than the SP-12.5 mixtures, which could be due to the higher binder content. These findings are similar to past studies in that smaller NMAS mixtures have better crack resistance (3, 8, 12-14)

Table 4. Crack Performance of SP-12.5 and SP-9.5 Mixtures

Mix	Aging	Mean	Standard Deviation	Coefficient of Variance (%)
SP-12.5	Short term	13.6	1.8	13
	Long term	2.3	0.6	26
SP-9.5	Short term	15.7	1.7	11
	Long term	2.9	0.2	7

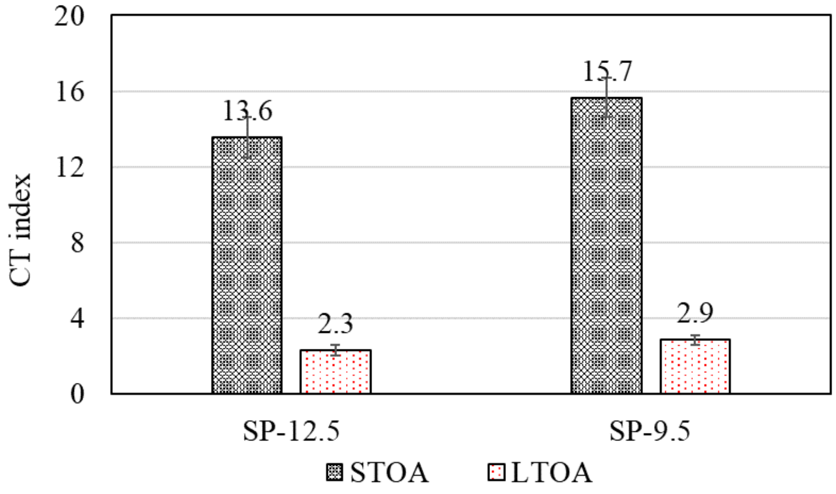


Figure 9. Test Results of IDEAL-CT Test for Control and 9.5mm Mixtures

Rutting (APA and HWTT)

Figure 10 summarizes the results of the rutting tests performed in this study. It was clear that SP-12.5 mixtures had 30%, 43%, and 25% better rutting performance for the HWTT, APA with 4% air voids, and APA field cores than the SP-9.5 mixtures, respectively. Though these percentage differences are large, the practical difference in the actual rut depths are not significant. It should be noted that for the APA with 7% air voids, the SP-9.5 mixtures showed 7% better rutting performance than the SP-12.5 mixtures, which follows the same trend as the previous FDOT research (8). However, in most cases, the SP-12.5 mixtures performed better than SP-9.5 mixtures in rutting tests.

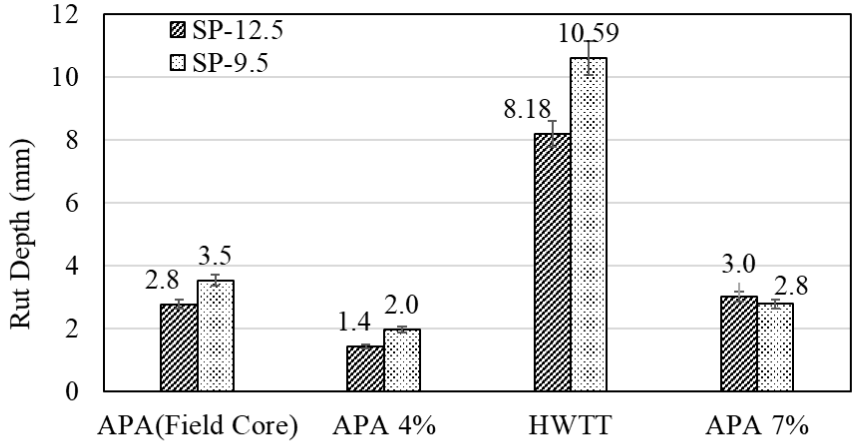


Figure 10. Comparison on Rutting Performance of SP-9.5 and SP-12.5 Mixtures

Raveling (Cantabro Loss)

The test results of the Cantabro loss test for the SP-12.5 and SP-9.5 field cores are illustrated in Figure 11. Higher values mean that the sample lost more weight, which depicts lower durability. The results show that SP-12.5 mixtures have a 2.1% higher average weight loss percentage than the SP-9.5 mixtures, which is 11% differences. This suggested that SP-9.5 mixtures have better durability than SP-12.5 mixtures. These results are reinforced by past research, which has shown that smaller NMAS can increase the durability of the mixture (3, 8, 12-14).

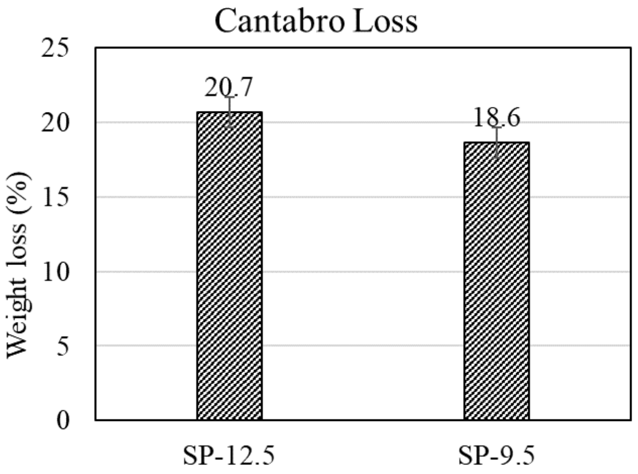


Figure 11. Raveling Performance of SP-12.5 and SP-9.5 Mixtures

CONCLUSIONS

The impact of two different nominal maximum aggregate sizes (NMAS) on pavement performance has been discussed in this study to provide a clear justification for the recently revised Florida specification. Past studies indicated that smaller NMAS could provide several benefits to asphalt mixtures, such as improved durability, ride quality, safety characteristics, cracking resistance and pavement life and reduced permeability, raveling, segregation, and road-tire noise. This study conducted field and laboratory tests to evaluate the performance of the SP-9.5 mixture and compare it to the SP-12.5 mixture based on rutting resistance, noise level, safety, durability, and cracking resistance. Due to the sample size limit, statistical analysis was not performed. Test results are summarized as follows:

- Using accelerated pavement testing the HVS applied 100,000 HVS passes on both sections under identical loading conditions. Test results showed the SP-12.5 section had an average of 3.1 mm rut depth, while the SP-9.5 section had a rut depth of 3.7 mm. The rut depths for both sections did not meet the Department's failure criteria of 12.7 mm (0.5 in), suggesting that both sections provided satisfactory performance under HVS loadings.
- The macrotexture and frictional properties of both mixtures were obtained. It was found SP-9.5 mixtures had less noise level and friction reduction than SP-12.5 mixtures.
- The cracking performance of both mixtures was assessed through the IDEAL-CT test. Test results showed that SP-9.5 mixtures are 15 to 26% better than the SP-12.5 mixtures after short-term and long-term aging; this could be due to the higher binder content and better coating of the aggregate.
- The laboratory rutting tests indicated that the SP-12.5 mixtures outperformed the SP-9.5 mixtures in APA and HWTT tests, except for the 7% air void APA test, in which the rut depths were nearly equal (only 0.2 mm different).
- Cantabro test results showed that the SP-9.5 mm mixtures had 11% lower differences than the SP-12.5 mm mixtures, depicting smaller NMAS have better durability and raveling resistance than the larger NMAS mixtures.

The findings indicated SP-9.5 mixtures outperformed SP-12.5 mixtures regarding cracking resistance, noise level, safety, and durability. While the rutting tests conducted in both field and lab settings indicated slightly inferior rutting resistance for the SP-9.5 mixtures, the rutting differences were minor and utilizing SP-9.5 mixtures would still be advantageous for asphalt concrete pavement in Florida. These findings support the past research suggestions done by Hu and Zhou and the current FDOT specification, which it recommended to remove the restriction and allow the 9.5mm mixtures to be used for traffic levels exceeding 10 million ESALs, provided the layer thickness is 1.5 inches (4-5, 8).

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AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: Frank Ni, Ohhoon Kwon, Gregory Sholar, Charles Holzschuher; data collection: Frank Ni; analysis and interpretation of results: Frank Ni; draft manuscript preparation: Frank Ni, Ohhoon, Gregory Sholar, Charles Holzschuher. All authors reviewed the results and approved the final version of the manuscript.

DISCLAIMER

The research presented in this paper solely reflects the authors' findings and does not represent the views of the Florida Department of Transportation.

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