Florida Department of TRANSPORTATION

Impact of the Interlayer Scabbing on Pavement Performance

DOT Office

State Materials Office

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1 INTRODUCTION

1.1 Background

Milling is a process that removes a portion of the existing pavement layer to provide the desired surface elevation and texture for asphalt or concrete overlays. In general, the milling is categorized into full and partial depth depending on the amount of material removed which is often dictated by the existing pavement condition. Full-depth milling refers to the removal of the entire asphalt layer down to the base and applies to the severely deteriorated pavement structure. On the contrary, partial depth milling removes only an upper portion of the asphalt layer that is distressed, and the remaining asphalt layer continues serving as a structural layer after rehabilitation. Determining the milling depth is a primary concern of partial depth rehabilitation since the milling depth affects the quality, productivity, and project cost *(1)*. Therefore, various factors, including traffic level, distress type and severity, and overlay thickness, are comprehensively considered when determining the milling depth.

When the milling depth is variable or slightly thinner than the existing asphalt lift thickness, a 'scab' may be formed. A scab refers to a thin layer of an existing layer that was not completely removed in the milling process. The scab often results in variations in surface texture and elevation. In addition, the bond between the scab and the remaining existing asphalt may be weakened during the milling and paving process. Multiple studies agree that the scabbing may cause premature pavement distresses, including cracking and delamination, and eventually shorten pavement surface life *(1, 2, 3)*. Hence, multiple highway agencies, including TNDOT, ODOT, NJDOT, VDOT, and the U.S. Army Corps of Engineers, recently developed or updated their milling guidelines to prevent scabbing *(4, 5, 6, 7)*. Those guidelines suggest milling deeper than the interlayer as the most effective method to prevent scabbing. In addition, adjusting the teeth alignment of the milling drum and slowing down the milling speed are also suggested *(5, 6, 7)*.

However, many highway agencies, including FDOT, still do not provide guidelines to eliminate or minimize the likelihood of scabbing. One possible reason could be that the additional milling operations for the scab removal may impact the HMA thickness and result in increased cost in order to add a thicker HMA lift to maintain the structural capacity *(6)*. In addition, the negative impacts of scabbing on pavement performance are difficult to verify due to challenges in monitoring and quantifying the performance of pavements with interlayer scabbing. Therefore, the researchers in the FDOT's Accelerated Pavement Testing (APT) facility investigated construction factors that could generate scabbing. Also, the impact of scabbing on pavement performance was studied using laboratory tests of field cores and accelerated pavement testing of the full-scale pavement test section.

1.2 Research Objective and Scope

Two primary objectives were considered in this study. One is to identify factors affecting the occurrence of scabbing, and the other is to verify the impact of scabbing on pavement performance. Two experimental parameters, including interlayer bonding condition of existing asphalt and milling thickness, were studied for the first objective. For the second objective, core specimens were obtained after the HMA overlay on sections where scabbing was present and not present to compare their interlayer bonding strengths. In addition, APT was utilized to assess the rutting and cracking performance of the test sections.

2 EXPERIMENTAL DESIGN

2.1 Factors Affecting the Occurrence of Scabbing

According to previous studies, insufficient interlayer bonding strength and improper milling thickness are the main factors that create scabbing on the milled surface *(4, 5, 6, 7)*. The following parameters were considered to investigate the impact of those factors.

- Interlayer Bonding Condition: A portion of the test track was primarily used as an access route for construction equipment during the previous test track construction. The applied tack coat was severely deteriorated in this area as a result of the construction traffic, and a weak interlayer bonding was expected. This area of insufficient tack was included in this study to compare the occurrence of scabbing in these areas to the areas with a well-bonded interlayer. After milling, the milled surface was inspected to identify the occurrence of scabbing.

- Milling thickness: Milling depth was carefully controlled by the contractor and monitored by FDOT. The milling depth was varied to produce 0.50- and 0.25-inch-thick scab layers. Those thicknesses represent the nominal maximum aggregate size (NMAS) of the existing mix and half of that, respectively. Similarly, the milled surface was visually inspected to see if milling thickness affected the occurrence and extent of scabbing.

2.2 Impact of Scabbing on Pavement Performance

The impact of scabbing on pavement performance was investigated by laboratory tests comparing the bond strength of core specimens obtained from areas with and without scabbing and through APT.

- Interlayer bonding strength: Multiple previous studies identified that the lack of interlayer bonding strength between asphalt layers causes premature pavement distresses, including cracking, rutting, and slippage *(1, 2, 3).* A total of 36 core specimens were obtained from the areas with different levels of interlayer scabbing, including no-scabbing, moderate scabbing, and severe scabbing. The Florida shear test (FM 5-599) was performed on the core specimens to identify and compare the interlayer bonding strength. Figure 1 shows the testing apparatus developed in the FDOT state materials office.

Figure 1. Florida Shear Strength Testing Apparatus

- Accelerated Pavement Testing: Accelerated loading was performed using FDOT's heavy vehicle simulator (HVS Mk VI) to evaluate the rutting and cracking performance of the testing areas. Two test locations were selected and included a section with moderate scabbing and another section with no scabbing. All localized areas of severe scabbing were dedicated to preparing core specimens for the interlayer bonding strength test. After overlay, the chosen locations were trafficked using unidirectional passes of an aircraft tire with 4-inches of wheel wander at ambient temperature. Average ambient temperatures during the APT testing were 78.5°F and 78.0°F for the moderate scabbing and no scabbing sections, respectively. A total of 300,000 passes, including consecutive 100,000 HVS passes of 20-kip, 24-kip, and 28-kip wheel loads were applied to each location. According to the Generalized Fourth Power Law, the HVS wheel loads were equivalent to 14.7 million ESALs. The rut depth was measured intermittently during testing using an onboard laser profiler. Cracking performance was assessed through a visual inspection. In addition, six cores for each testing location were prepared to identify the bonding strength loss caused by the HVS loading. Figure 2 shows the HVS Mk VI utilized for the APT.

Figure 2. FDOT's HVS Mk VI

3 TEST SECTION CONSTRUCTION

3.1 Milling of the Existing Asphalt

Prior to milling the existing asphalt test track, 15 cores spaced 20 ft. were retrieved along the centerline of the test track lane to determine the thickness of individual asphalt lifts and the desired milling depths. The milling depths were calculated based on the lift thicknesses and marked on the pavement surface to direct the contractor. During the milling operation, the depth of milling was continuously adjusted for the design scab thickness of 0.25 and 0.5-inch.

3.2 Tack Coat Application

A trackless tack coat, Ultra Tack® (NTSS-1HM), was applied on the milled surface. Both application and residual rate of the tack coat were calculated to check the quantity and uniformity of the tack coat application. Four absorption pads were placed at the randomly selected locations to sample the tack coat material. Table 1 summarizes the calculations of both residual and application rates. Test results presented in Table 1 confirmed that the quantity and uniformity of the applied tack coat satisfy the FDOT's standard specification .

Table 1. Tack Coat Application Data

Pad ID	Weight of Pad (g)	Weight of Pad & Tack Coat (g)	Weight of Tack Coat (g)	Residual Rate (gal/yd²)	Application Rate (gal/yd²)
1	32.5	44.7	12.2	0.029	0.071
2	32.8	44.8	12.0	0.029	0.071
3	32.2	44.4	12.2	0.029	0.071
4	31.9	45.4	13.5	0.032	0.079
Avg.	32.4	44.8	12.5	0.030	0.073
FDOT Requirement for a Milled Surface of the Dense Graded Mix					0.070

3.3 Overlay and Compaction

A 1.5-inch-thick asphalt layer was placed on the milled surface using a 12.5 nominal maximum aggregate size Superpave mixture (SP-12.5) with granite aggregate and PG 76-22 Elvaloy modified asphalt binder. The mixture contained 20% recycled asphalt pavement (RAP). After the overly was placed, it was compacted using a steel drum roller (SAKAI SW850-II). The overlay temperature was recorded behind the paver every 20 ft. using a handheld thermal camera. All temperature readings were within a range of 280 to 300°F. After compaction, the overlay density and uniformity were checked using the PaveScan rolling density meter (RDM). Figure 3 shows (a) the relationship between core densities and PaveScan dielectrics and (b) estimated overlay densities along the right and left wheel path of the test track lane. As presented, all calculated densities of the test track lane ranged from 93% to 94% of maximum theoretical density (Gmm). The density variations observed at the section start/end were due to the vibration of the PaveScan instrument when it was moving over the drop/raise of the surface elevation.

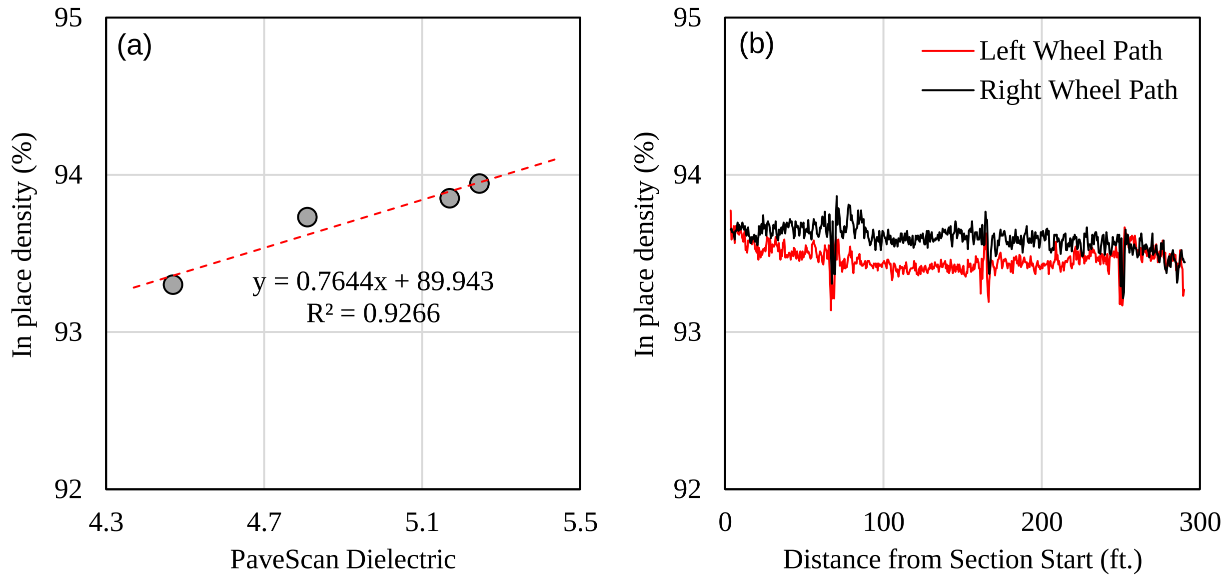
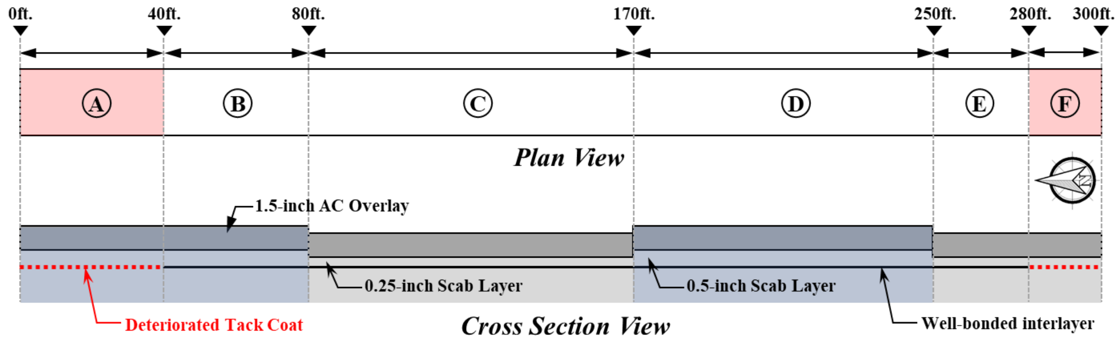


Figure 3. (a) Relationship between core densities and PaveScan dielectrics and (b) Estimated overlay densities

3.4 Test Section Layout

A 300 ft. long test track lane was divided into four section groups: *1.* weak interlayer bonding with 0.5-inch scab thickness, *2.* well-bonded interlayer with 0.5-inch scab thickness, *3.* well-bonded interlayer with 0.25-inch scab thickness, and *4.* weak interlayer bonding with 0.25-inch scab thickness. As explained earlier, the tack coat between the scab and underlying layer for the first and last groups severely deteriorated since those areas were utilized as delivery truck paths during the previous construction. Figure 4 shows the section layout and description of the four section groups.



Section Group	Section ID	Experimental Parameters	
		Interlayer Bonding Condition	Scab Layer Thickness (in.)
1	A	Deteriorated Tack Coat	0.5
2	B and D	Well Bonded	0.5
3	C and E	Well Bonded	0.25
4	F	Deteriorated Tack Coat	0.25

Figure 4. A schematic of section layout and description of section groups

4 TEST RESULT AND ANALYSIS

4.1 Visual Inspection

Localized areas of scabbing with different severity levels were successfully generated through the milling of the test track lane. For the visual inspection, the severity levels of the scabbing were categorized into the following conditions.

- No scabbing: This condition refers to a typical texture of the milled surface without any signs of scabbing.

- Moderate Scabbing: Relatively small and scattered scabs were observed in this area. In most cases, this severity level of scabbing was observed in the sections with a 0.25-inch thick scab layer.

- Severe Scabbing: Scabs were larger than moderate scabbing. The texture and elevation of the scabs were clearly distinctive from the nearby areas without the scabs. The debonded or partially bonded interlayer may cause severe scabbing.

Figure 5 compares the surface textures of the three conditions, including (a) no-scabbing, (b) moderate scabbing, and (c) severe scabbing.

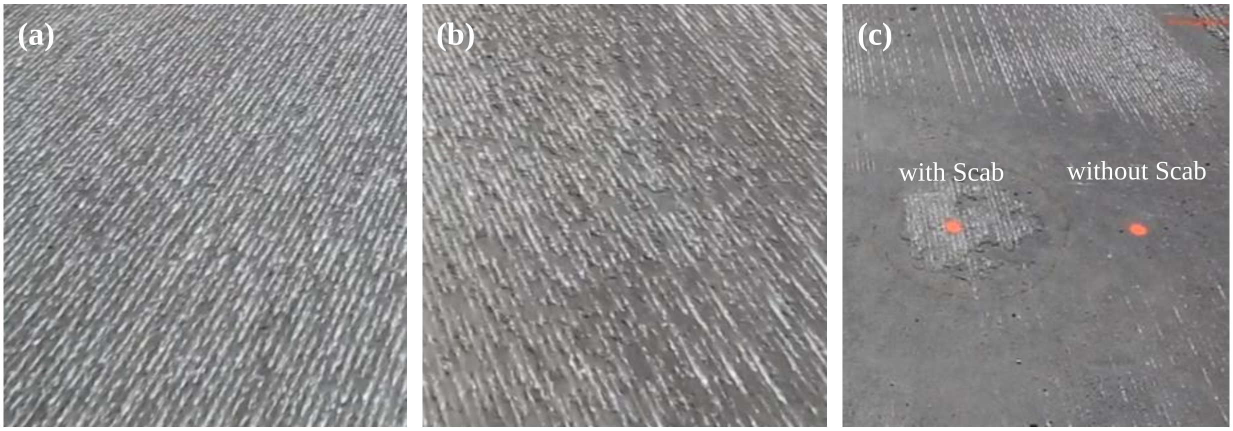


Figure 5. (a) No scabbing, (b) Moderate scabbing, and (c) Severe scabbing with and without scab layer

Moderate and severe scabbing were frequently observed in sections A and F since the tack coat of those sections was severely deteriorated. Conversely, most of the milled surfaces in Sections B and D showed typical milling texture with minimal scabbing. Those sections had a well-bonded interlayer and the scab layer thicker than 0.5 inches. Lastly, Sections C and E showed moderate and severe scabbing. Severe scabbing was observed near the longitudinal edge of the test track lane, where the weakened interlayer bonding is expected due to the infiltrated moisture. In other areas of these sections, some localized areas of moderate scabbing were observed, possibly due to the deeper milling resulting in the scab layer being thinner than the NMAS. Figure 6 shows images of the milled surface of (a) Section A, (b) Sections B and C, (c) Section D, and (d) Section E. Interestingly, in Figure 4(b), moderate and severe scabbing was generated right after lowering the height of the milling drum by 0.25 inches at the beginning of Section C. This clearly shows that the thickness of the scab layer affects the occurrence of the scabbing.

As a result, the visual inspection indicates that both interlayer bonding conditions and scab thickness highly affect the occurrence of scabbing. As discussed earlier, the ideal prevention of the scabbing could be milling deeper than the interlayer. However, in many cases of partial depth repair, milling depth is limited to reserve the structural capacity of the existing pavement. In such cases, it is recommended to maintain the scab layer thicker the same as the NMAS of the asphalt mix.

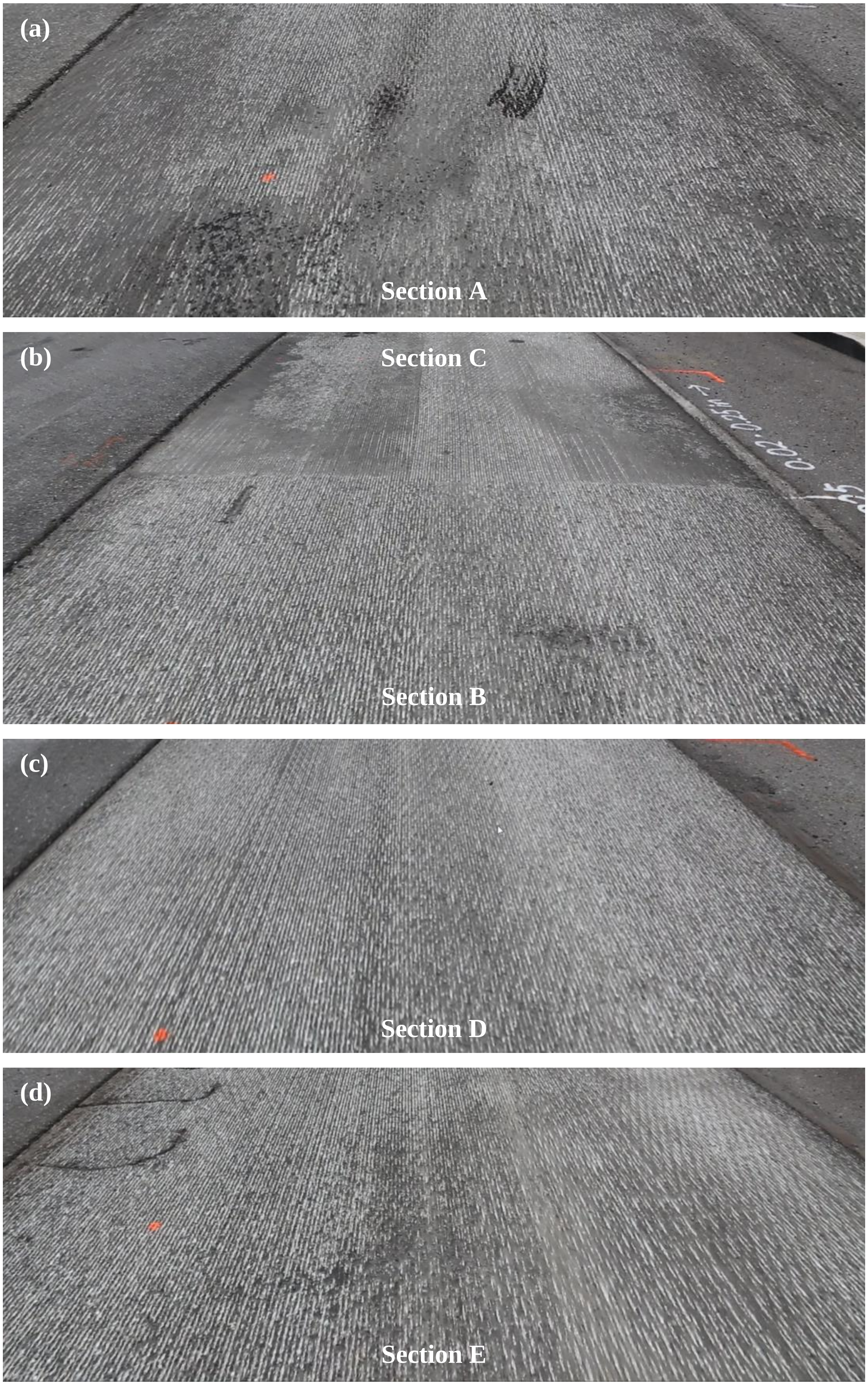


Figure 6. The milled surface of the test sections

4.2 Interlayer Bonding Strength

Multiple previous studies identified that the lack of bond strength between asphalt layers is critical in premature pavement distresses, including cracking, rutting, and slippage of the wearing course. Those studies also agreed that the interlayer texture significantly affects the bonding strength *(1, 2, 3)*. The Florida shear strength test was performed to identify the interlayer bonding strength of the interlayer conditions, including no-scabbing, moderate scabbing, and severe scabbing. Twelve cores were retrieved from each interlayer condition, and a total of 36 core specimens were tested, as presented in Figure 7. Cores from the no-scabbing area showed the greatest interlayer bonding strength with an average value of 279.6 psi, while the specimens from the minor and severe scabbing area showed relatively lower bonding strengths with an average of 233.6 psi and 236.9 psi, respectively. The higher variation of the interlayer bonding strength with the severe scabbing could be due to the inconsistent interlayer texture. Specifically, the cores from the scab areas showed greater bonding strength than those without scab areas, with an average bonding strength of 259.1 psi and 214.8 psi, respectively. Regardless of the strength level, the inconsistency in bonding strength could negatively affect the pavement performances *(4, 8, 9)*.

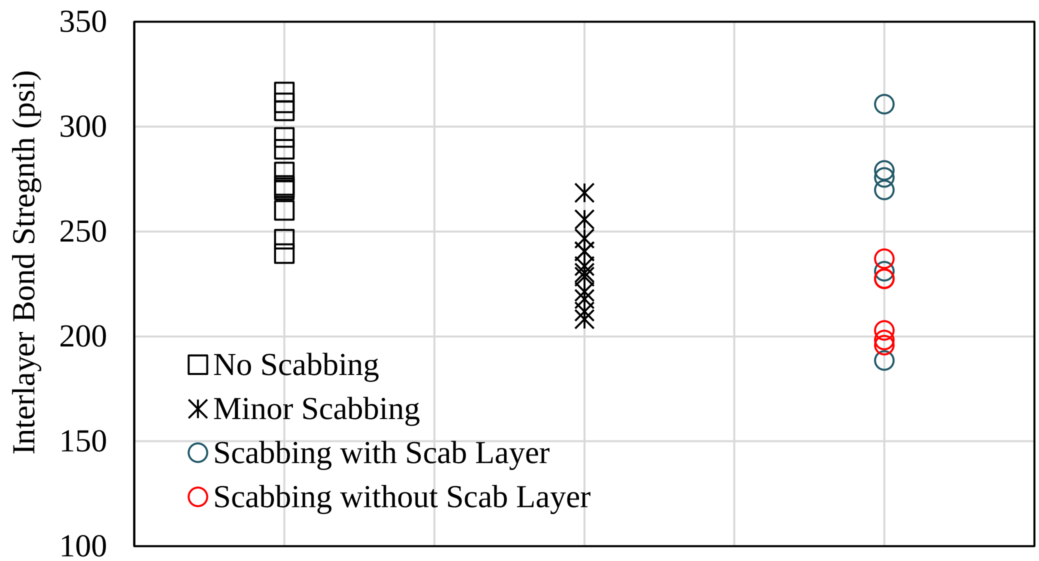


Figure 7. Comparison of interlayer bonding strength

Table 2 compares the average bond strength of the cores from no-scabbing and scabbing areas using Welch's T-test, which is a reliable tool for determining whether two population means are equal or not even when the two data set have unequal variances *(10)*. Test results indicated that the difference in interlayer bonding strength is statistically significant at a 95% confidence level. In addition, the core specimens without scabbing showed significantly greater consistency in interlayer bonding strength. Based on the bond strength test results, it can be postulated that the pavement without interlayer scabbing has the potential to perform better than the pavement with interlayer scabbing. Of note, the average bonding strength of the no-scabbing cores is comparable to the interlayer bonding strength of the other APT studies with the same trackless tack coat applied.

Table 2. Comparison of the interlayer bonding strength of the core specimens

	Non-scabbing	**Scabbing**
Mean	279.68	235.27
Variance	617.10	882.70
Observations	12	24
Null Hypothesis	$\mu_{no\text{-}scabbing} = \mu_{scabbing}$	
Degree of Freedom	26	
t Stat	4.73	
P(T<=t) two-tail	6.9E-05	
t Critical two-tail	2.06	

4.3 Accelerated Pavement Testing (APT)

Accelerated loading was performed using FDOT's heavy vehicle simulator (HVS Mk. 6) to evaluate the rutting and cracking performance of the testing areas under closely simulated traffic loading. Based on the visual inspection of the milled surface, one testing area for each of the non-scabbing and minor scabbing conditions was selected. Both test areas were in Section C and had comparable structural design and materials. Figures 8 (a) and (b) show the milled surfaces of the selected testing areas. After overlay, those areas were trafficked using unidirectional passes of an aircraft tire with 4-inches of wheel wander. A total of 300,000300,000 passes, includings consecutive 100,000 HVS passes of 20-kip, 24-kip, and 28-kip wheel loads were with up to a 28-kip wheel load was applied to each location

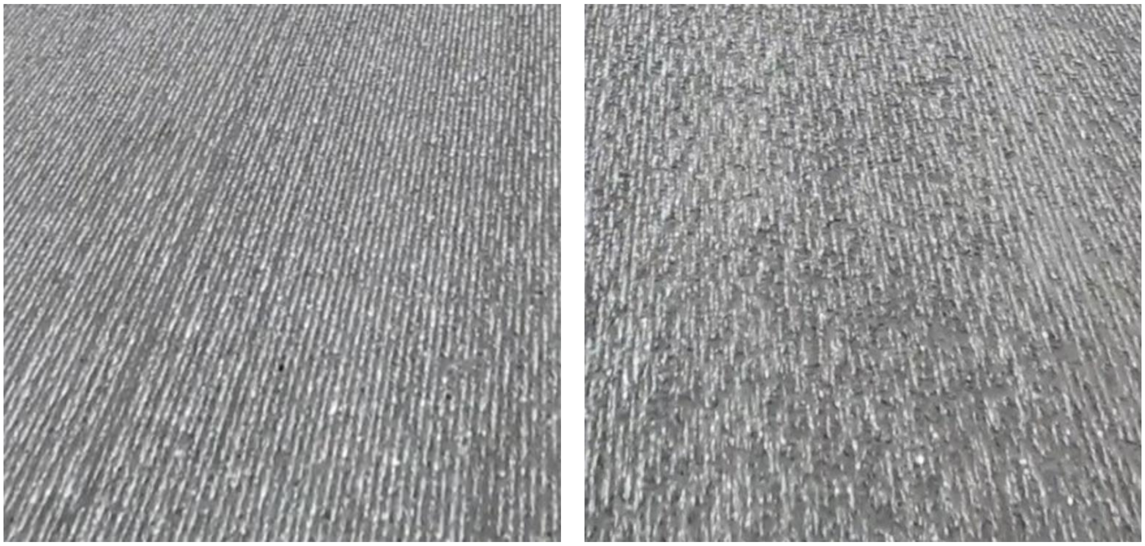


Figure 8. Milled surfaces of the selected testing areas with (a) no-scabbing and (b) moderate scabbing

Rut depths were measured using the laser profiler installed underneath the HVS wheel carriage. As presented in Figure 9, the scabbing section experienced approximately 30% deeper rutting throughout the accelerated loading. Under the heavy traffic load, the lack of interlayer bonding strength of the scabbing section may contribute to the deeper pavement deformation since both loading areas have an identical structural design.

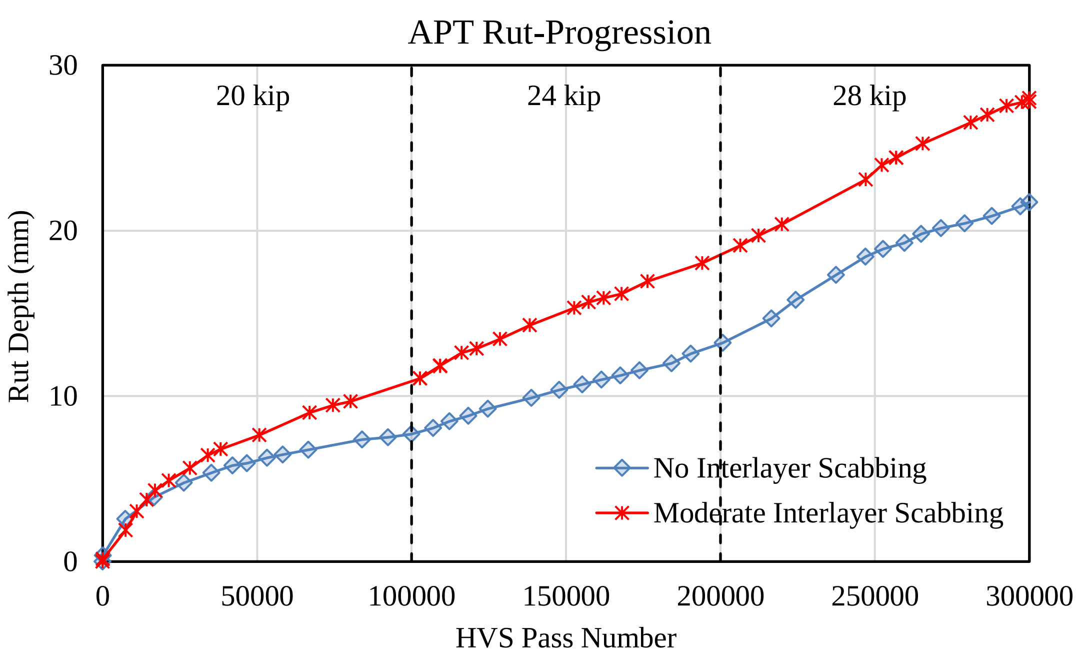


Figure 9. Comparison of rut-depth progression

In addition, the loaded areas were visually inspected to compare their cracking performance. Some longitudinal cracks were observed along the edge of the HVS wheel path of the scabbing section, while no visible cracks were detected on the HVS wheel path without interlayer scabbing. These top-down longitudinal cracks are mainly caused by the excessive lateral strain resulting from the permanent deformation caused by the heavy HVS wheel loads, which is magnified in the scabbed section, whereas the non-scabbed section successfully resisted the permanent deformation and lateral strain and did not crack. Figure 10 shows the longitudinal cracks observed on the loaded area with scabbing.

Figure 10. Longitudinal cracks along the edge of HVS wheel-path on scabbing section

5 SUMMARY AND CONCLUSIONS

The findings of this research are summarized as follows:

- After milling of the test track lanes, the milled surface was visually inspected. The inspection results found that the occurrence of scabbing is highly dependent on the interlayer bonding condition and milling depths. In terms of milling depth, it is recommended to maintain at least the NMAS of the asphalt mix in scab layer thickness to avoid scabbing.

- The bond strength prior to milling is important in resisting scabbing. Once scabs form, the scabs result in a weak or variable bond with the new overlay. On average, the interlayer bonding strength of the cores from the no-scabbing section was approximately 20% higher than those from the scabbing areas. The strength difference was confirmed to be statistically significant at a 95% confidence level using Welch's T-test. Also, the core specimens without scabbing showed significantly better consistency in interlayer bond strength. With consideration of the relationships between pavement performances and interlayer bonding strength, it can be postulated that the pavement without interlayer scabbing performs better than the pavement with interlayer scabbing in terms of rutting, cracking, and slippage distresses.

- Rut depths were measured during the accelerated loading using the laser profiler installed underneath the HVS wheel carriage. The rutting of the scabbing area was approximately 30% greater than the rutting of the no scabbing area throughout the accelerated loading area. In addition, the testing areas were visually inspected to compare cracking performance. Some longitudinal cracks were observed along the edge of the HVS wheel path of the scabbing section, while no visible cracks were detected on the area without scabbing.

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