Florida Department of TRANSPORTATION

Asphalt Pavement Interlayer Bonding Study

DOT Office

State Materials Office

Authors

Ohhoon Kwon

James Greene

Gregory Sholar

Date of Publication

Apr. 2022

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EXECUTIVE SUMMARY

A total of four full-scale test sections using trackless tack with various residual rates, including 0.02, 0.04, 0.06 gal/yd^2, and also a no tack condition, were constructed in the FDOT's accelerated pavement testing (APT) facility to investigate the appropriate tack application rate. Interlayer bond strengths were determined through the Florida shear strength test using core specimens obtained from the test sections. APT was performed to evaluate fatigue performance, and finally, the majority of the top layer was milled to identify the scabbing resistance of the tacked sections (0.02, 0.04, and 0.06 gal/yd2 sections). The test results imply that tacked sections, regardless of tack application rate, have comparable cracking performances and scabbing resistances, whereas the unbonded section exhibited premature slippage cracks. Conversely, the calculated composite modulus using the FWD deflection showed the interlayer binding strength had a negligible impact on the pavement structural capacity toward the static-vertical FWD load. In conclusion, a minimum residual rate of 0.03 gal./ yd^2 or emulsion rate of 0.06 gal./ yd^2 was suggested for the trackless tack for the newly paved asphalt surface. Furthermore, the tack coat application rate was rigorously controlled and measured during this study. It is recommended that construction inspection prioritize measurement of tack coat application rate to ensure appropriate coverage.

1 INTRODUCTION

1.1 Background

It has been widely agreed that a poor bonding or debonding of hot mix asphalt (HMA) interlayer causes premature distresses, including rutting, cracking, potholes, and slippage. Accordingly, pavement deficiencies due to inadequate interlayer bonding require substantial maintenance work and, eventually, shorten the pavement service life. *(1, 2, 3).* A study conducted by the Minnesota Department of Transportation (MnDOT) reported that approximately 30% to 50% of the flexible pavements in Minnesota might exhibit up to 25% reduction in service life due to debonding of HMA layers *(4).* Also, the Wisconsin Department of Transportation (WisDOT), based on 3,402 cores specimens obtained across the state, postulated that approximately 10% of HMA roadways in Wisconsin might suffer from a debonded interlayer. (*5).*

Multiple studies have identified that poor tack coat applications, including improper dilution of tack material, lack of application uniformity and quantity, and deterioration of the tacked surface due to the construction traffic driving over the tacked surface prior to paving, mainly cause the debonded interlayer (*4, 5, 6, 7)*. Hence, many highway agencies require a minimum amount of tack coat with a uniform application for sufficient interlayer bonding strength and durability. However, a minimum tack coat rate does not necessarily meet the optimum application rate requirements of the various tack-coat materials available to an agency *(8, 9, 10, 11)*. In addition, as newer and more advanced tack coat materials are introduced, there will be a greater need for optimizing specifications to meet the optimum application rates for a wide range of tack coat materials.

In 2004, a trackless tack material, NTSS-1HM, was first placed in Florida. According to the manufacturer, the trackless tack is designed to cure extremely fast and change into a drivable coat within 30 minutes after application *(8).* The high residual viscosity of the trackless track prevents pick-up and transfer to vehicle tires and provides significantly improved interlayer bonding strength compared to conventional tack coat materials. In addition, the trackless tack helps to achieve a higher density with less compaction effort and may provide up to 50% greater fatigue performance for a dense-graded HMA overlay *(8, 9)*. For these reasons, in 2015, the trackless tack became the mandatory tack coat material in Florida.

Despite the substantial performance improvements of the trackless tack material, there is a fundamental question regarding the optimum application rate. Unlike the minimum application rate of 0.05 gal./yd^2 used in Florida, some recent studies identified that the trackless tack requires a higher rate to maximize its bonding strength. *(9, 12)*. Such a discrepancy led FDOT engineers to investigate the appropriate tack coat rate of the trackless tack material to maximize its performance, constructability, and economics. Consequently, a full-scale experiment was conducted through the FDOT's accelerated pavement testing (APT) program.

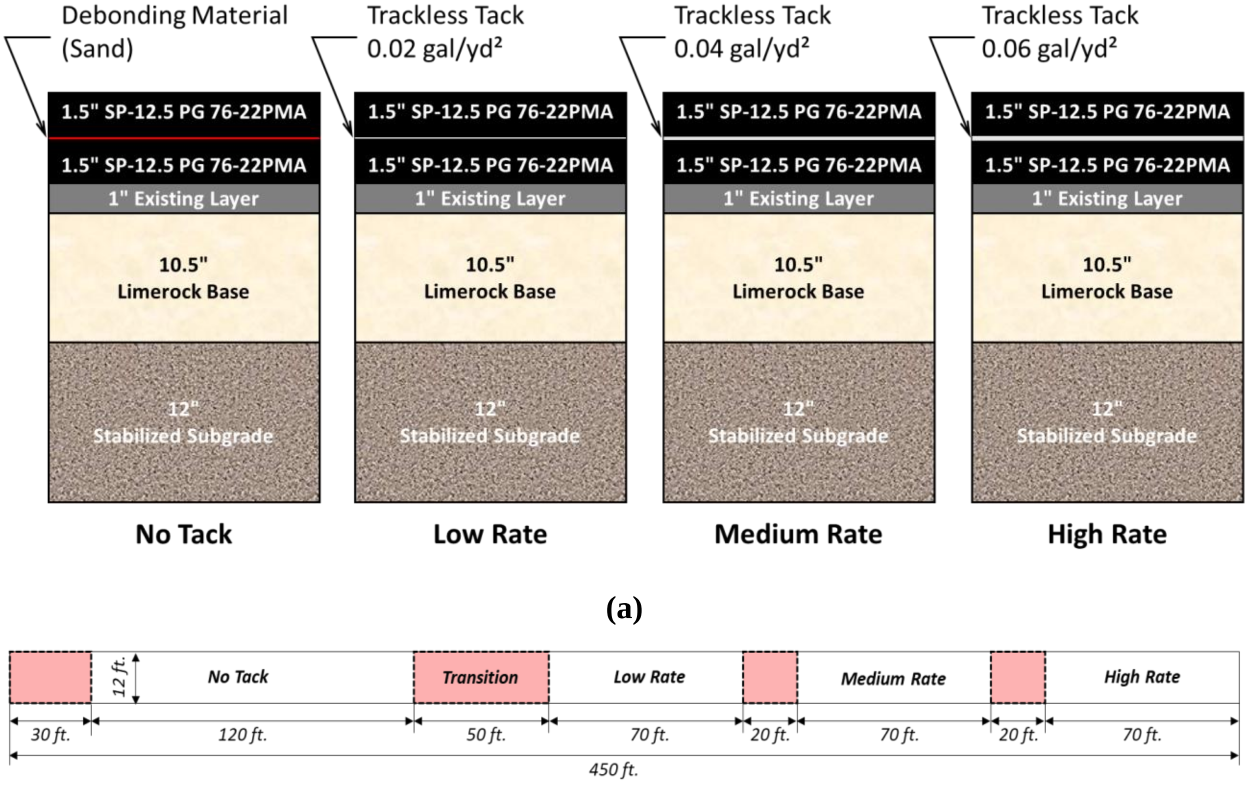
1.2 Research objective and scope

The primary objective of this study is to determine the appropriate application rate of the trackless tack for interlayer bonding between newly paved hot mix asphalt (HMA) layers. Four full-scale test sections using the trackless tack with different residual rates, including no tack, 0.02, 0.04, and 0.06 gal/sy^{2,} were constructed at FDOT's APT facility. Interlayer bonding strengths were determined through core specimens obtained from the test sections. FWD and APT were utilized to identify the structural capacity and fatigue performance of the test sections, respectively. Lastly, the upper layer was partially milled to study the impact of the interlayer bond on new overlays when an inadequate milling depth fails to remove the entire layer. Scabbing is often used to refer to the sections of thin HMA material remaining if the milling depth is not sufficient to remove the entire layer.

2 TEST SECTION CONSTRUCTION

2.1 Test Section Construction

A 12-foot wide and 450-foot-long test track lane was milled and resurfaced at FDOT's APT facility located at the State Materials Office. Existing HMA was milled to a depth where approximately 1-inch of existing material remained. Tackless tack was applied, followed by a 1.5-inch lift of dense-graded HMA mixture. Next, the trackless tack with a 0.45 dilution rate was sprayed at different settings of the distributor to achieve the target residual rates, including no tack, 0.02, 0.04, and 0.06 gal/sy^2. After 30-minute curing, another 1.5-inch lift of dense-graded mixture was placed on the tacked surface. Figures 1 (a) and (b) show the structural design and layout of the four test sections.



(b)

Figure 1. Test section (a) structural design and (b) layout

2.2 Quantification of the tack coat rate

Two methods were employed to quantify the tack coat rate. The application rate measures the amount of tack coat sprayed from the distributor truck. The volume of tack coat material is divided by the dimension of sprayed area to calculate the application rate. For its simplicity, the application rate is widely utilized at the construction site for quality control (QC).

The other method is the residual rate which measures the amount of tack coat materials remaining on the pavement surface after the tack has broken and the water has evaporated. This method requires installing absorption pads on the pavement surface to capture the applied tack coat. Following ASTM D2995, the residual rate can be calculated using the dimension of the absorption pad and the weight of the tack coat residue on the pad. The residual rate provides an accurate amount of tack coat applied at a specific location. Accordingly, the residual rate was used to quantify the tack coat applied to the test sections.

Prior to spraying the tack coat, a total of 12 absorption pads were placed across the width of each test section to verify the actual residual rate applied. Figure 2 shows the absorption pads placed on the test sections. The tack coat rate was controlled by pre-determined flow rates of the sprayer with a constant truck speed of 7 mph. It is noted that the center nozzle of the sprayer was clogged and resulted in a lean application of the center area. This area was excluded from further sampling and testing.

Figure 2. Preparation for measuring tack coat residual rate

After applying the tack coat, the residual rate of each pad was calculated in accordance with the ASTM D2995 method, and the calculated values were averaged for each section. Corresponding application rates were also estimated using the water-to-bitumen ratio of the tack coat emulsion. Of note, the minimum application rate required for the newly paved surface is 0.05 gal/yd^2 in Florida. Table 1 summarizes the target and measured tack coat rates.

Table 1. Summary of Tack Coat Application Rates

Section ID	Target Residual Rate	Application Setting	Obtained Residual Rate	Corresponding Application Rate
Low Rate	0.02 gal/yd^2	1 GPM* at 7 mph	0.019 gal/yd^2	0.042 gal/yd^2
Medium Rate	0.04 gal/yd^2	35 GPM at 7 mph	0.041 gal/yd^2	0.091 gal/yd^2
High Rate	0.06 gal/yd^2	55 GPM at 7 mph	0.054 gal/yd^2	0.113 gal/yd^2

***** The minimum setting value for the sprayer used to construct the track lane

3 EXPERIMENTAL DESIGN

3.1 Interlayer Bonding Strength

A total of 12 cores (three cores per section) were initially retrieved from all test sections to compare interlayer bonding strength after construction. Additional tests were performed 6 and 12 months after the initial strength tests. The section with no tack was excluded from the 6 and 12 months tests since the initial cores confirmed the un-bonded interlayer condition. Bonding strengths of the core specimens were tested in accordance with FM 5-599 “Florida Method of Test for Determining the Interlayer Bond Strength between Asphalt Pavement Layers.” The results of three replicate tests were averaged to compare. Figure 3 shows the testing apparatus used by the Department for the interlayer bonding strength test.

Figure 3. Testing apparatus used for the interlayer bonding strength test

3.2 Accelerated Pavement Testing

Accelerated loading was performed using FDOT's Heavy Vehicle Simulator (HVS Mk.4), shown in Figure 4. Each loading area was trafficked with unidirectional passes of a super single tire (Goodyear G286 A SS, 425/65R22.5) and 4 inches of wheel wander. A total of 200,000 passes of the 11,500-pound wheel load was applied to evaluate the fatigue performance of each test section. This load is equivalent to 0.6 million equivalent single axle loads (ESALs). HVS loading was performed during the winter season under ambient temperature.

Figure 4. FDOT's HVS Mark 4 utilized in fatigue performance evaluation

3.3 Scabbing resistance

A weak bond or partially debonded interlayer could cause scabbing when the milling depth is insufficient to remove the existing overlay. The scabbing may contribute to poor smoothness and density. Also, it generates premature pavement distresses, including cracking and delamination, and eventually shortens pavement surface life *(14, 15)*. After all performance tests were finished, approximately 80% of the upper layer in depth was milled to identify the scabbing resistance of the test sections with different tack coat residual rates.

4 TEST RESULT AND DISCUSSION

4.1 Interlayer Bonding Strength

Following the Florida Method of Test for Determining the Interlayer Bond Strength between Asphalt Pavement Layers (FM 5-599), core specimens were dried overnight and then placed into a temperature-control chamber at 77°F. The cores were conditioned for at least 3 hours before testing. Then, the shear force was applied at the interlayer of core specimens at a 2 in./min load rate. The testing apparatus automatically displays the peak load value used to calculate the shear strength through Equation 1.

$$IBS = \frac{P_{max}}{\frac{\pi D^2}{4}}$$ **Equation 1**

Where: IBS = interlayer bond strength (psi),

P_{max} = maximum load applied to the specimen (lbs.)

D = diameter of test specimen (in.)

The interlayer bonding test was first performed approximately two months after construction. The second and third sets of tests were performed at subsequent six-month intervals. As presented in Figure 5, all tacked sections showed average shear strength of 270 psi or higher in the first test. A minimum of 300 psi were observed for the second and third tests. West et al. (2005) suggested that an interlayer bonding strength of 100 psi or higher is required to ensure good pavement performance *(3)*. With consideration of the suggested bonding strength requirement, it can be postulated that all tacked sections may exhibit minimal chances of poor performance due to interlayer deficiencies. Figure 6 shows the interlayer condition after the shear strength tests. The interface texture of the low and medium rate section appeared smoother than the high-rate sections, possibly due to the relatively lower bonding strength. Of note, the shear strength test was not conducted on the no-tack section since the top and bottom layers of the core specimens separated during the coring operation.

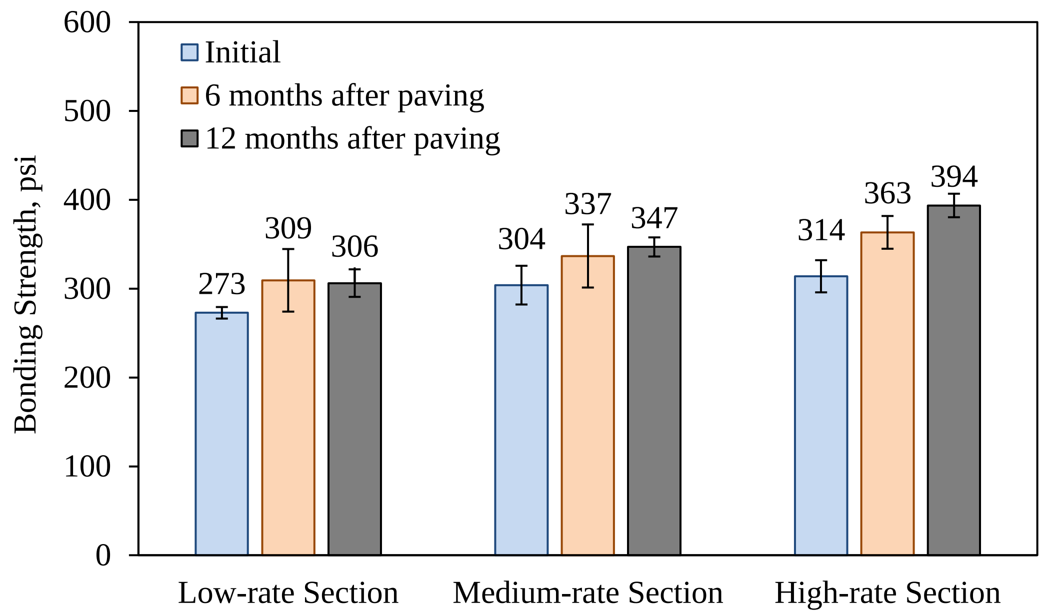


Figure 5. Comparison of interlayer bonding strength for various tack application rates

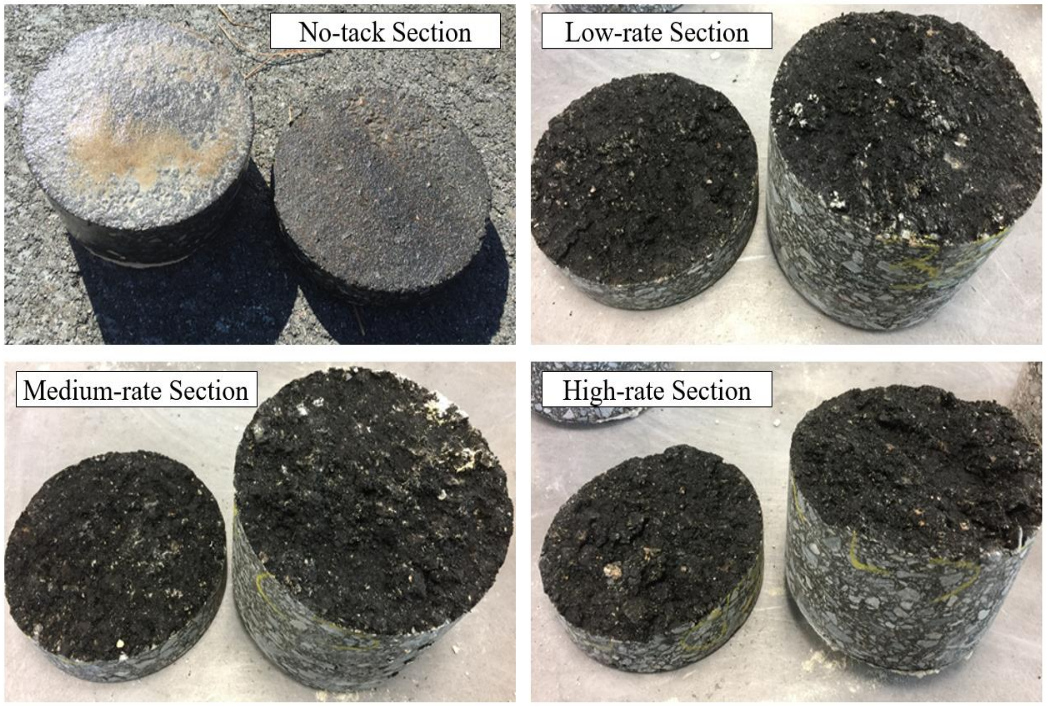


Figure 6. Interface condition after shear strength test for various tack application rates

4.2 APT Cracking Performance

A total of 200,000 HVS passes using a super single tire loaded to 11,500 pounds, equivalent to a half-million ESALs, were applied to a testing area assigned to each test section. An additional 100,000 HVS passes using an aircraft tire loaded to 20,000 pounds were applied to the loading areas in the low and high tack rate sections. The additional HVS passes were equivalent to approximately 2.9 million ESALs. A total of 3.5 million ESALs were applied to each of those loading areas. None of the loaded areas showed signs of fatigue. However, the area in the debonded section exhibited crescent-shaped slippage cracks. Hairline cracks were first observed near the edge of the loading area at 60,000 HVS passes. The cracks then propagated rapidly in a diagonal direction and finally resulted in the shape of slippage cracks. Figure 7 shows the loading area in the debonded section after applying 200,000 HVS passes.

Figure 7. The unbonded section after the application of 0.6 million ESALs

4.3 Scabbing Resistance

After the HVS experiment was completed, the test track was milled. Fifteen cores, spaced at intervals of 20 ft., were retrieved along the centerline of the test track lane. The milling depths were calculated based on the layer thickness of the cores and marked on the pavement surface. During the milling operation, the depth of milling was continuously adjusted to remove approximately 80% of the upper layer. All tacked sections showed typical milling texture with minimal signs of scabbing. Some scabbing was observed in the low tack rate section along the pavement edge, possibly due to the deteriorated interlayer caused by the water filtration. Moderate and severe scabbing was also observed in the transition zones. A weakly or partially bonded interlayer was expected in the transition zones since these areas were utilized as the paths of the construction equipment and trucks. Thus, the tacked surface was severely deteriorated due to the construction traffic driving over the tacked surface prior to paving. Figure 8 shows the milled surface with minor edge scabbing. These observations reinforced the need for adequate interlayer bonding to promote good pavement performance and minimize scabbing potential if milling depths are not adequate to remove an entire layer.

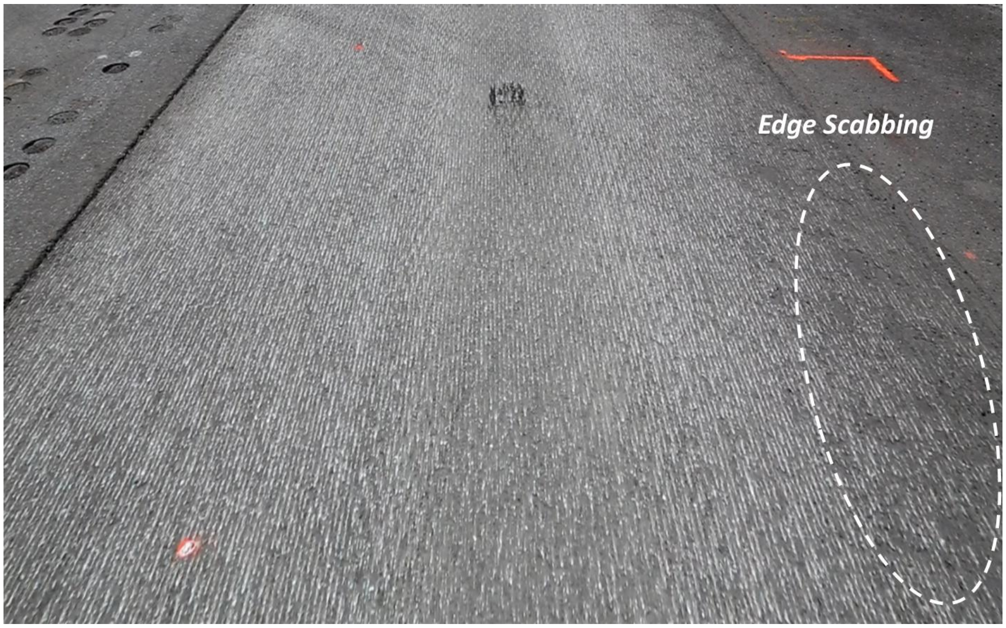


Figure 8. Milled surface with minor edge scabbing

5 SUMMARY AND CONCLUSION

The findings of this study are summarized as follows.

- All tacked test sections exhibited average interlayer bonding strengths of 270 psi or higher. With consideration of the suggested interlayer bonding strength identified in a previous study (100 psi), all tacked sections were expected to exhibit good interlayer performance. Compared to the low tack rate section, double and triple amounts of tack coat rates resulted in approximately 10 % to 20 % increases in interlayer bonding strength.

- Despite the significant amount of accelerated loading, 3.5 million ESALs, no cracks were observed on both low and high tack rate sections, whereas the deboned section showed crescent-shaped slippage cracks with less than 0.5 million ESALs equivalent load applied.

- After the milling operation, all tacked sections showed typical milling texture with minimal signs of scabbing. The high interlayer bonding strength of the test sections offered good scabbing resistance. In contrast, the transition zones showed moderate to severe scabbing.

These areas were used as a path for construction traffic. Accordingly, the applied tack coat was likely not adequate, and a partially or weakly bonded interlayer was anticipated.

A residual rate of 0.03 gal/yd^2 with the trackless tack is an effective and efficient rate that could minimize the chance of interlayer deficiencies, reduce curing time, and lower the construction cost. The suggested residual rate is comparable to the required application rate of 0.06 gal/yd^2 for the newly paved asphalt surface in Florida. In addition, it is recommended that tack rate applications be monitored during construction to ensure adequate application and coverage.

ACKNOWLEDGEMENTS

The work represented herein was the result of a team effort. The authors would like to acknowledge the State Materials Office staff from the Pavement Materials and Bituminous Materials Sections for their assistance with data collection, materials testing, and technical advice.

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