Applied Research and Innovation Branch

Evaluation of Tack Coat Bond Strength Tests

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16. Abstract

Poor bonding between asphalt pavement overlays and the substrate pavement layer can greatly influence the long term performance of hot mix asphalt (HMA) in the form of premature cracking and fatigue. The primary method to achieve bonding between layers is by using an asphalt emulsion tack coat. Additionally, field staff is charged with determining whether an existing pavement, especially a milled surface, is clean enough prior to tack coat placement, to ensure an adequate bond. Because CDOT is prescriptive in its tack coat application specifications, responsibility for any pavement failures related to poor bonding lies with CDOT. However, if a performance related test to measure tack coat bond strength could be specified, failures related to poor bonding should be reduced. This study evaluated four bond strength tests for SMA and HMA overlays on HMA and Portland cement concrete pavements. Results of this study indicate that bond strength of HMA overlays can be measured using pavement cores, that a significant difference in test precision was observed when CRS-2P was used a tack coat and that one of the test pavements demonstrated significantly poorer than recommended bond strength for the tack coat utilized. Recommendations are provided for developing a performance related specification based on future performance observed on the four pavements.

Implementation of this research can be done as follows: 1) specify a minimum tack coat application rate of 0.05 gal/sq-yd of 50:50 diluted CSS-1h or CRS-2P for construction of dense graded HMA over other dense graded HMA.

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Cores from pavements were needed to obtain the data needed to complete this research. This task could not have been accomplished without considerable help from CDOT in Regions 2, 3, and 4. For this cooperation, the author would like to thank Craig Weiden, CDOT Region 2 Materials Engineer for identifying appropriate locations to core I-25 and helping to acquire the cores. Jeremy Lucero, Coulter Golden, Randy Neece and Clint Moyer of CDOT Region 3 provided all the assistance needed for locating and acquiring the cores at the site on SH13 north of Rifle, CO. Gary DeWitt, Region 4 Materials Engineer helped locate coring locations on SH119 near Boulder, the I-25 Frontage Road near Wellington, I-25 at SH392 and I-76 near Brush. And, finally, all cores were obtained utilizing CDOT equipment and could not have been accomplished without coordination provided by David Weld, the traffic control personnel and the amazing crew of the Region 4 core drill rig.

To accomplish the variable tack coat rate on I-25 at SH392 and on I-76 the research team is indebted to the contractors for allowing this to be done on their projects where the contract did not require it. Therefore, thanks are due to Rob Wise and John Cheever of Aggregate Industries and John Pinello and Derek Daniels of Simon Contracting for their help in accomplishing this goal.

The scientific curiosity and engineering interest provided by all individuals involved with this project is gratefully acknowledged for without their cooperation studies like this are considerably more difficult or impossible to achieve.

EXECUTIVE SUMMARY

Poor bonding between asphalt pavement overlays and the substrate pavement can greatly influence the long term performance of hot mix asphalt (HMA) in the form of premature cracking and fatigue. Bonding is achieved by using an asphalt emulsion tack coat. The adhesive bond depends on the type and surface texture of the substrate, cleanliness of the substrate and the type and quantity of the tack coat. Current specifications are prescriptive. Therefore, if the materials and workmanship prescribed are provided by the contractor any failure with respect to bonding lies with CDOT. However, if a performance based test to measure tack coat bond strength could be specified, failures related to poor bonding should be reduced and an opportunity by the contractor to utilize more innovative techniques would become possible.

This study evaluated four bond strength tests for SMA and HMA overlays on both HMA and Portland concrete substrates. Two of the tests proved to be imprecise and, consequently, of limited value in measuring bond strength on pavement cores.

Results of this study indicate that bond strength of HMA overlays can be measured using pavement cores, that a significant difference in test precision was observed when CRS-2P was used as a tack coat, and that the bond strength for the SMA was significantly lower than the bond strength for the HMA overlays for the same tack coat application rates. In fact, the bond strength for the SMA was below the published recommended minimum values.

Further, it appears the minimum bond strength is achievable for 0.05 gal/sq-yd diluted asphalt emulsions for dense graded HMA overlays. This means the bond strength tests are not needed if the tack coat application rate is measured and verified during construction of these types of overlays. However, it is not known what tack coat application rate provides adequate bond strength for SMA construction since a recommendation for SMA bond strength is still to be determined.

Contents

INTRODUCTION

Literature Review

Asphalt pavements are often layered structures. These layers might consist of asphalt concrete base courses with asphalt concrete binder and asphalt concrete surface courses, or levelling courses with surface courses, or simply surface courses on top of old asphalt or concrete pavements. Pavement structures are designed to act as solid beams without slippage between the layers. When slippage occurs and the bond is broken between the layers, performance suffers (Van Dam, et al, 1987, Lenz, et al 2008). One study showed that reducing the interface bond by only 10 percent caused fatigue life to decrease by 50 percent (West, et al, 2005).

When the bond between pavement layers is insufficient, the pavement does not act as a solid structure, but instead, as multiple structures sliding past each other as they bend (Canestrari, F., et al, 2005). This reduces the stiffness of the structure according to layered elastic analysis (Willis, J. and Timm, D. 2007). In fact, the upper layers can even delaminate causing slippage failures in areas of the pavement where turning, deceleration or acceleration occur (Romanoschi, S. and Metcalf, J. 2001). Debonding research at NCAT found that bond strength increases with depth in the pavement. This suggests that pavements are more susceptible to debonding near the pavement surface (Willis, J. and Timm, D., 2007).

Tack coats are the most common tool for bonding pavement layers and studies have shown that at least five factors affect the bond provided by the tack coat according to Tashman, L., et al (2008). These are:

- Binder type
- Spray rate
- Curing time
- Surface condition
- Pavement temperature

While asphalt cements, cutbacks and emulsions are all used as tack coats around the world, emulsions are almost exclusively used in the U. S. with only one state reporting use of cutbacks and three states reporting use of cements (Mohammed, L., and Button, J., 2005).

Testing to evaluate tack coat bond strength has been done on laboratory prepared samples and on pavement cores. Tests have included both shear and tension configurations. Tests have measured various effects including with and without tack coat, with dirt contamination, various temperatures, and various normal loads. Nearly every study concluded that a tack coat increases the bond strength and that lower temperature and higher normal loads contribute to higher bond, as well (Uzan, J., 1978, Sangiorgi, C., et al, 2002, Hachiya, Y. and K. Sato, 1997).

The apparatus used to test bond strength varies significantly between researchers as documented by NCHRP 9-40 (Mohammed, L. and Button, J., 2005). These include the Virginia Shear Fatigue Test, a pull-off test from Switzerland, a wedge splitting test, traction test and impulse hammer test. Twenty different apparatus were discovered in the NCHRP 9-40 study.

Objective

The objective of this research was to identify the bond strength necessary between an asphalt overlay and the underlying substrate to prevent debonding of the two layers.

INITIAL APPROACH

To accomplish the objective, the initial approach was to identify poorly bonded and well bonded pavements, obtain core samples of these pavements, and measure the bond strength at each location. The idea of this approach was that poorly bonded cores would provide bond strengths that could be used to develop the lower limit of a bond strength specification.

The second part of this approach was to determine which bond strength test to use.

Since resources precluded evaluating all twenty bond strength tests identified in the literature, four of the tests that appeared to offer the most promise based on laboratory and field correlations, simplicity and cost were chosen for this research. These four consisted of three shear tests and one direct tension test. The three shear tests have been reported in the literature as follows:

- Mohammad, L. and J. Button. *NCHRP Project 9-40: Optimization of Tack Coat for HMA Placement*, Draft Phase 1 Report, Transportation Research Board, Washington, D.C., 2005.
- West, R.C., J. Zhang, and J. Moore. *Evaluation of Bond Strength between Pavement Layers*. NCAT Report 05-08, National Center for Asphalt Technology, Auburn University, 2005.
- Hakimzahdeh, S., Buttlar, W. G., Santarromana, R., *Evaluation of Bonding Between HMA Layers Produced with Different Tack Coat Application Rates Using Shear-Type and Tension-Type Tests,* Journal of the Transportation Research Board (2012).

The fourth test, a direct tension test, while not reported in the literature, was attractive because it offered field portability and a different state of stress for evaluating bond strength. And, while direct tension may not be the state of stress that affects debonding in real pavements, the test may still be desirable if good precision could be demonstrated. The test also uses 2 inch diameter cores which are faster to extract. And, if six inch cores are taken back to the laboratory for testing, three tests can be obtained for each six inch core. This test is portable allowing it to be used in the field, if desired; a distinct advantage when rapid conformance to specifications is desired. However, although it was planned to use this apparatus in the field, after practicing with the equipment in test trials in the laboratory, it was decided a controlled laboratory environment would be desirable at this stage.

Sites 1 and 2

Two pavements were identified where poorly bonded and well bonded overlays were present on the same project.

These sites are on SH13 north of Rifle, CO and I-25 south of Fountain, CO. Six-inch diameter cores were obtained from both sites. Cores were taken in areas of the pavement that appeared to demonstrate both good performance and potentially poor performance resulting from delamination of the upper asphalt layer. All cores were taken from the wheel paths in close proximity to each other.

<u>Direct Tension Testing</u>
The cores were taken to the CSU laboratories in preparation for delamination testing. This preparation consisted of cutting three 2-inch diameter cores from within the six-inch cores as shown in Figure 1. Grips are cemented to the top of the core as shown in the lower left of Figure 1.

Figure 1. Direct Tension Cores

The six-inch core is positioned below the testing apparatus as shown in Figures 2 and 3. The grip is attached to the testing apparatus and the device begins to pull the grip away from the core. A successful test was when the core separated at the tack coat interface as shown in Figure 4. However, over 30 percent of the samples failed at the grip as seen in Figure 5.

Figure 2. Direct Tension Apparatus

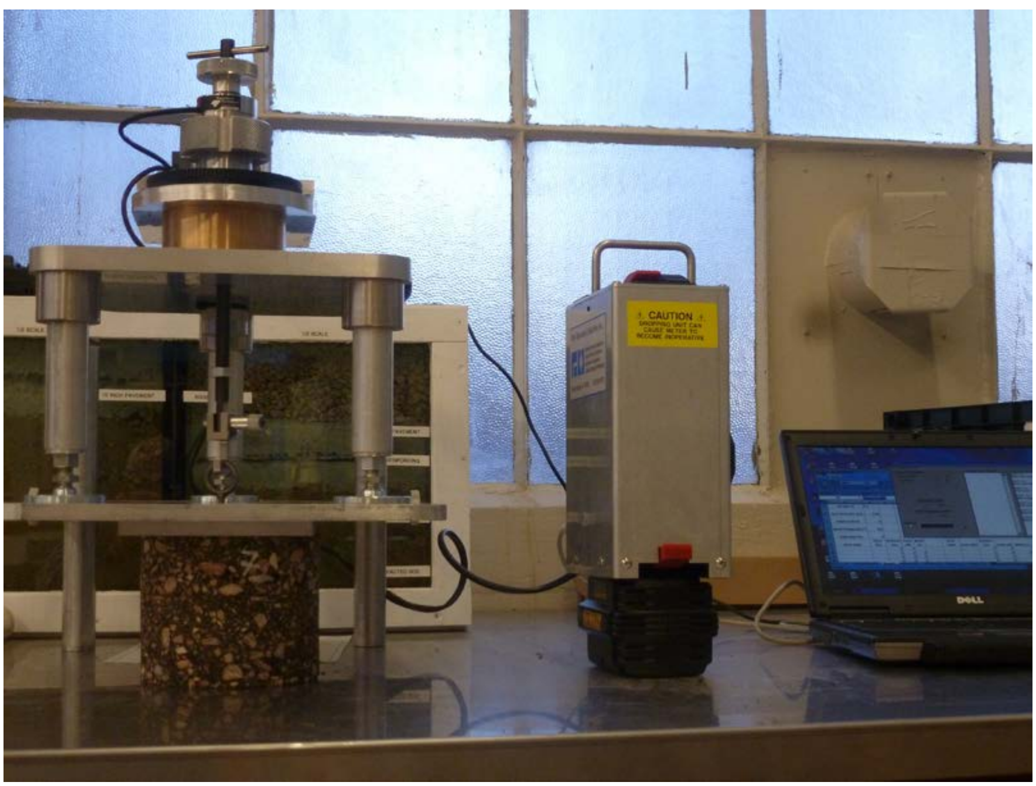


Figure 3. Direct Tension Core in Position for Testing

Figure 4. Direct Tension Core Failure at Interface

Figure 5. Direct Tension Core Failure at Grip

Results

The work energy in Joules required to separate the overlay from the substrate is recorded and appears in Figures 6a and 6b for SH13 and 7a and 7b for I-25. Figure a is for cores that separated at the tack coat between the overlay and the substrate pavement. Figure b includes all cores, including those that failed at the grips. Tensile failure at the grips was always a very low value, hence the decrease in average work energy required to cause failure for both SH13 and I-25 cores.

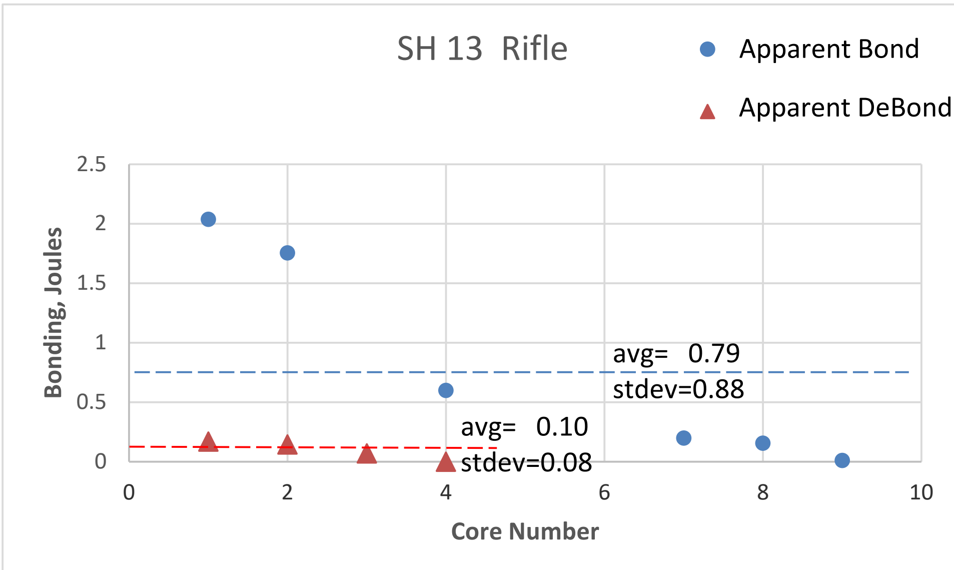


Figure 6a. Tensile Work to Separate Cores (no grip failures)-SH13

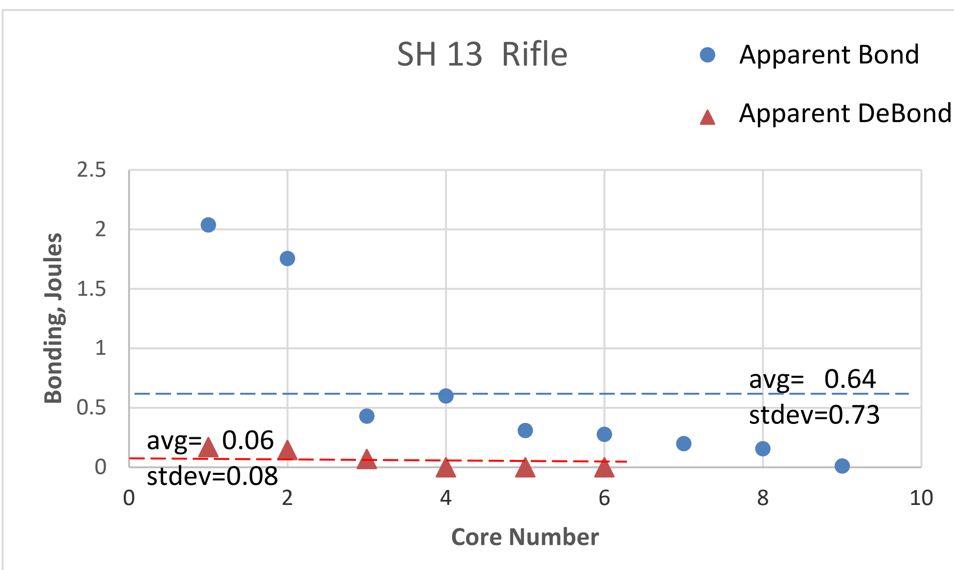


Figure 6b. Tensile Work to Separate Cores (with grip failures)-SH13

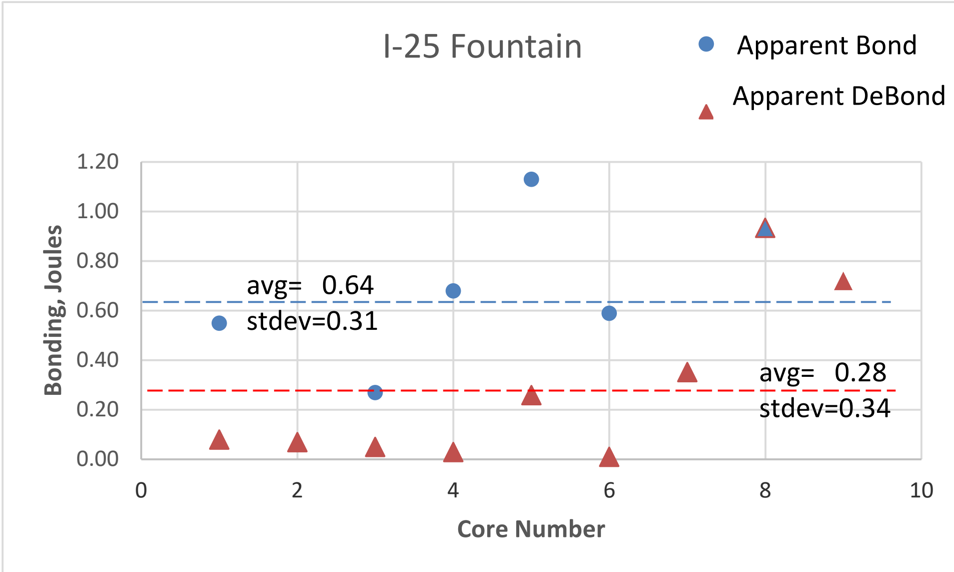


Figure 7a. Tensile Work to Separate Cores (no grip failures)-I25

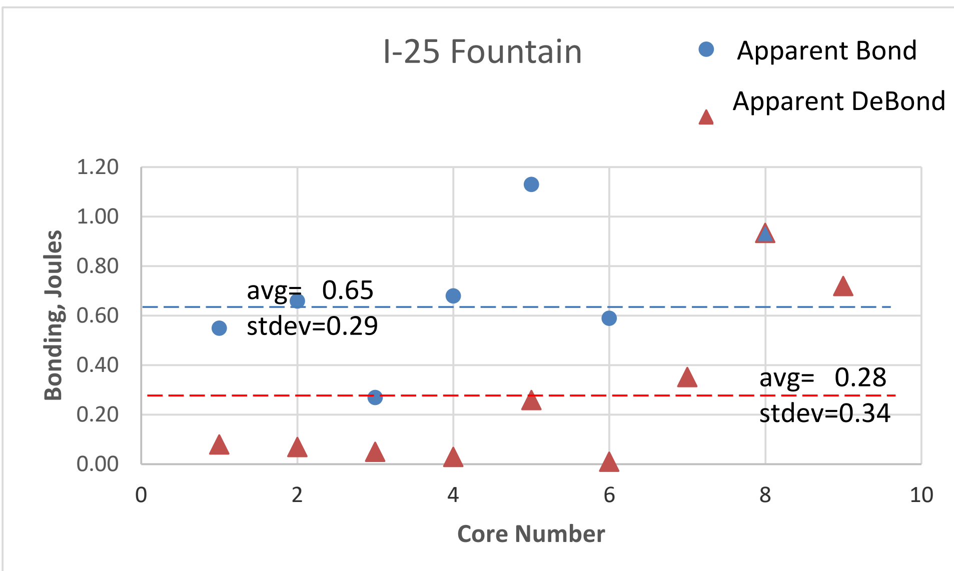


Figure 7b. Tensile Work to Separate Cores (with grip failures)-SH13

Results shown above indicate that the cores from areas of the pavements where no delamination or lack of bonding is apparent appear to have higher bond strength than cores from areas of the pavement where debonding was evident. However, the variation in the test results is unacceptably high with standard deviations nearly equal to or greater than the average bond strength for three of the four groups of tests. This means the test cannot distinguish between well-bonded and poorly-bonded samples.

This raised two questions:

1) is the test too variable to be of use, or
2) is the test actually measuring variable tensile forces to separate the samples reflecting variability in tack coat application rates?

The answer to the first question is probably that the test is too variable to be of use. This conclusion came as the result of so many test specimens failing at the grips. When failures occur at the grips, the test is not measuring the adhesion of the tack coat, but instead the adhesion of the sample to the grip. And, in the case of the grip failures in this study, the failure loads were very low. When this happens frequently, the value of the test must be questioned.

The answer to the second question lead the research team to recommend a change in the scope of the research. Because the tack coat rates on the pavements was unknown, and could have been variable along the alignment, even precise bond tests would measure differences in bond strength, assuming tack coat rate affects bond strength. These differences in bond strength could then be considered variances in the bond tests. Also, debonding might be due to other factors not related to tack coat.

Therefore, rather than trying to locate test pavements that display bonded and unbonded behavior and then evaluating the bond strength in the laboratory, the approach was changed to varying the tack coat rates on several pavements and then evaluating the bond strength. This way, the tack coat application rates and the tack coat type could be measured as effects on bond strength.

REVISED APPROACH

The objective of the revised approach was to use the three shear strength tests described previously to evaluate the bond strength as a function of tack coat application rate and tack coat type. Therefore, three tack coat rates, including no tack coat on some sites, were evaluated by the three tests. Three core samples were tested for each tack coat rate to obtain sufficient data for analysis. And, two of the three tests were conducted by the laboratories that developed the test to avoid as much operator error as possible. The third test was conducted by Mead Westvaco (MWV). All of these tests were done blind, that is, the laboratories conducting the tests did not know the tack coat application rates represented by each core. And, core labels were scrambled so laboratories could not speculate as to the tack coat application rates. In addition, none of the laboratories knew other laboratories were conducting the tests.

Four test sites were identified where varying quantities of tack coat could be applied prior to HMA overlay construction. These sites included two HMA overlays over smooth asphalt surfaces, an SMA over a Portland cement concrete pavement and an SMA over an HMA pavement. These sites are as follows:

- Site 3 – I-25 Frontage Road
- Site 4 – SH119
- Site 5 – I-25 at SH392
- Site 6 – I-76 near Brush, CO

Cores were taken approximately 12 months after construction of the overlays in the wheelpaths.

Below are descriptions of each test site.

Site 3 – I-25 Frontage Road

Site 3 was constructed on July 2, 2014 on the east frontage road of I-25 immediately north of mile marker 284. Four rates of tack coat were applied the surface of the existing asphalt pavement prior to placing the overlay as shown in Figure 8. CDOT Region 4 constructed the overlay by placing 1.5 inches of SX hot mix asphalt over the existing asphalt pavement. The tack coat applied was a CSS-1h emulsion with 65% residue by weight diluted 50:50 prior to spraying.

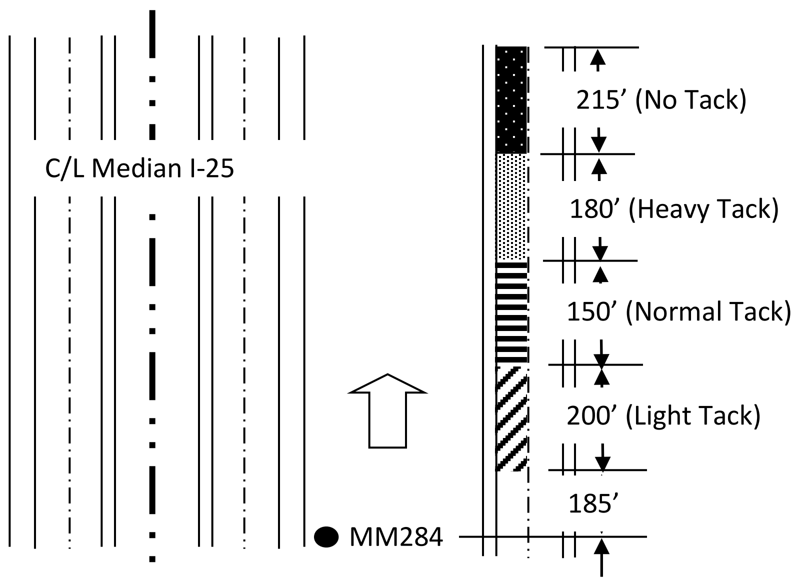


Figure 8. Bond Strength Test Sections on East Frontage Road of I-25

The 'Normal' tack coat rate was based on 250 gallons of tack coat emulsion placed in 2500 feet of roadway 15 feet wide. This equates to 0.06 gallons per square yard. The 'light' tack coat rate was achieved by doubling the speed of the tack coat distributor and the 'heavy' tack coat rate was achieved by slowing the speed by half. At these speeds the light rate and heavy rates, respectively would be 0.03 and 0.12 gallons per square yard.

Three 6 inch cores from each test segment were sent to each of the three organizations conducting the bond strength tests for a total of 36 six-inch cores.

Test Results

Results of all bond strength tests from Site 3 are shown in Figures 9, 10 and 11 below. The objective this research was to find a test that could discriminate between the various tack coat application rates. Therefore, although the dependent variable (y-axis) is unique to each test the tests can still be evaluated for how well each is able to determine the tack coat application rate. That is, if the tests cannot tell the difference between low tack coat rates and high rates, the value of the test must be questioned. Although cores were carefully wrapped and shipped in wooden crates, some cores were damaged and could not be tested. That is why, in some cases, fewer than three data points are shown for some tack coat application rates. For example, in Figure 11 only two data points appear for the 0.06 gallon per square yard rate for the MWV tests.

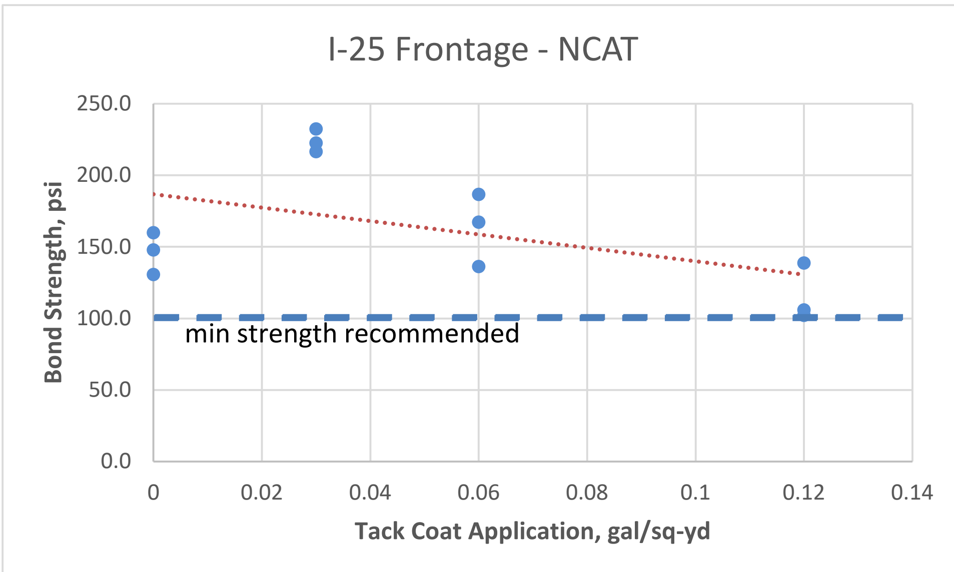


Figure 9. NCAT Bond Strength at I-25 Frontage Road

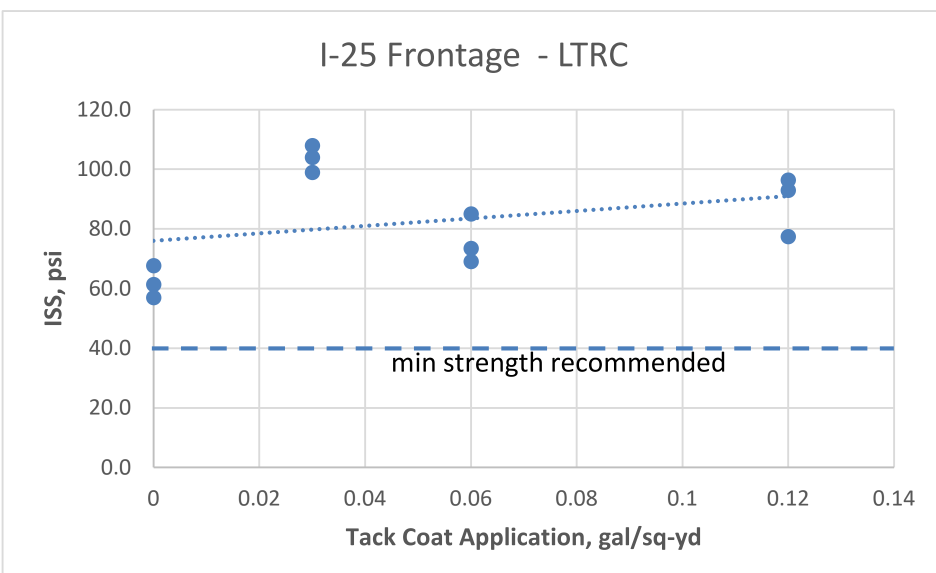


Figure 10. LTRC Bond Strength at I-25 Frontage Road

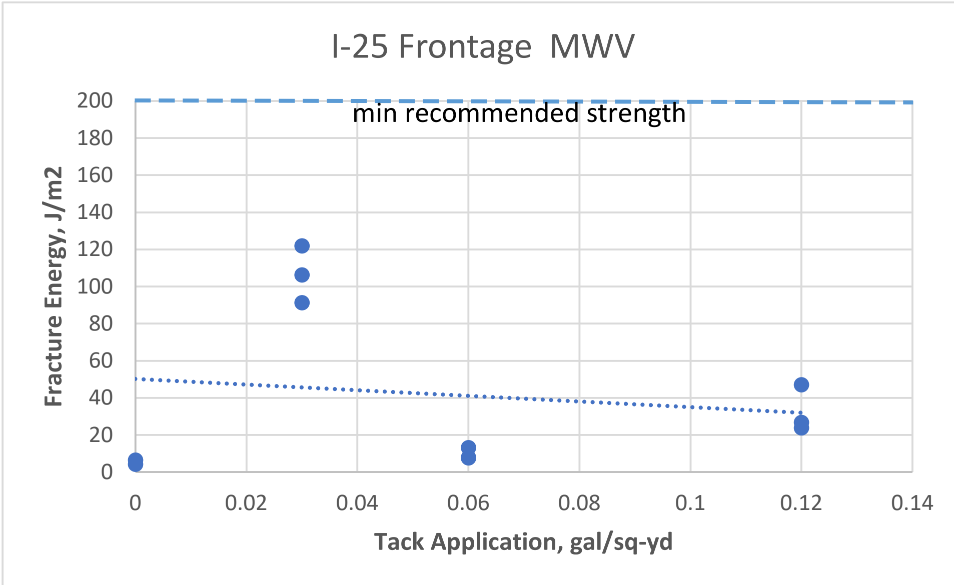


Figure 11. MWV Fracture Energy at I-25 Frontage Road

<u>Site 4 – SH119</u>

The Site 4 project was constructed on July 15, 2014. CDOT Region 4 constructed the overlay by placing 1.5 inches of SX hot mix asphalt over the existing asphalt pavement. The tack coat applied was a CSS-1h emulsion with 65% residue by weight diluted 50:50 prior to spraying. It is located on SH119 in the northeast bound direction north of the intersection of Iris and Foothills Blvd near Boulder, CO. An area map is shown in Figure 12 and specific test segments are shown in Figure 13.

The 'Normal' tack coat rate was based on 250 gallons of tack coat emulsion placed in 3450 feet of roadway 13 feet wide. This equates to approximately 0.05 gallons per square yard. The 'light' tack coat rate was achieved by doubling the speed of the tack coat distributor and the 'heavy' tack coat rate was achieved by slowing the speed by half. At these speeds the light rate and heavy rates, respectively would be 0.025 and 0.10 gallons per square yard.

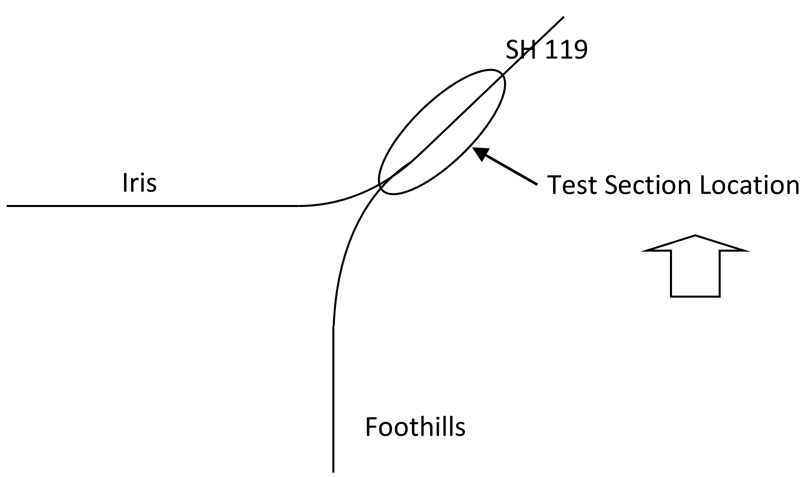


Figure 12. General Location of Test Sections on SH 119

Specific locations of the test sections are as shown on Figure 10.

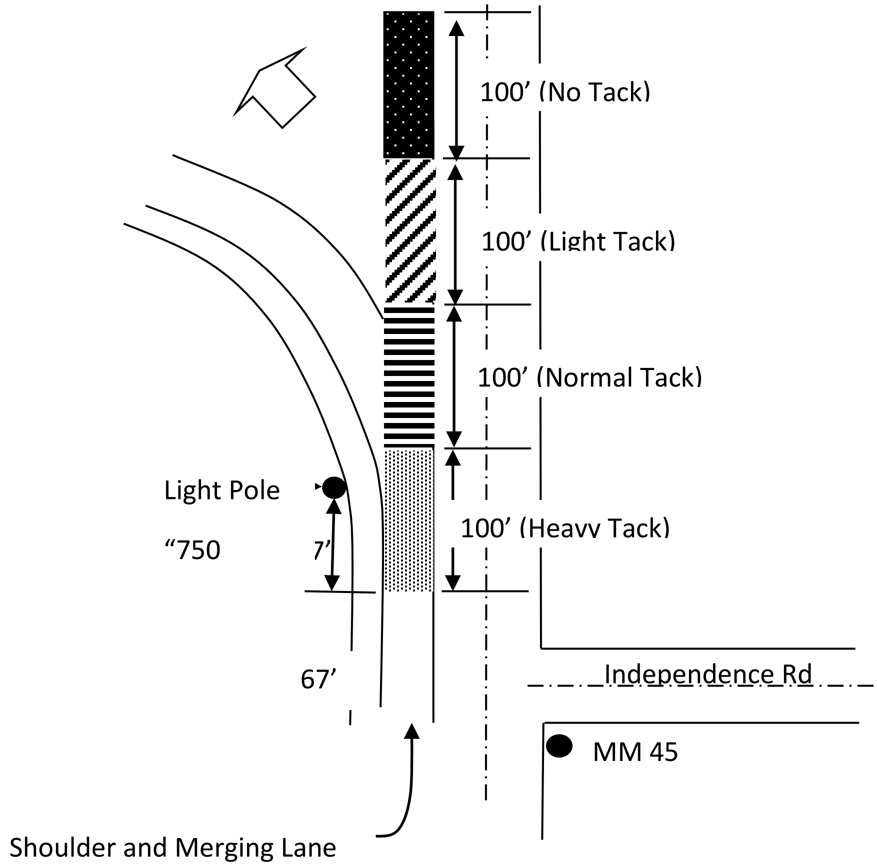


Figure 13. Specific Test Section Locations on SH 119

Test Results

Results of all bond strength tests from Site 4 are shown in Figures 14, 15 and 16 below.

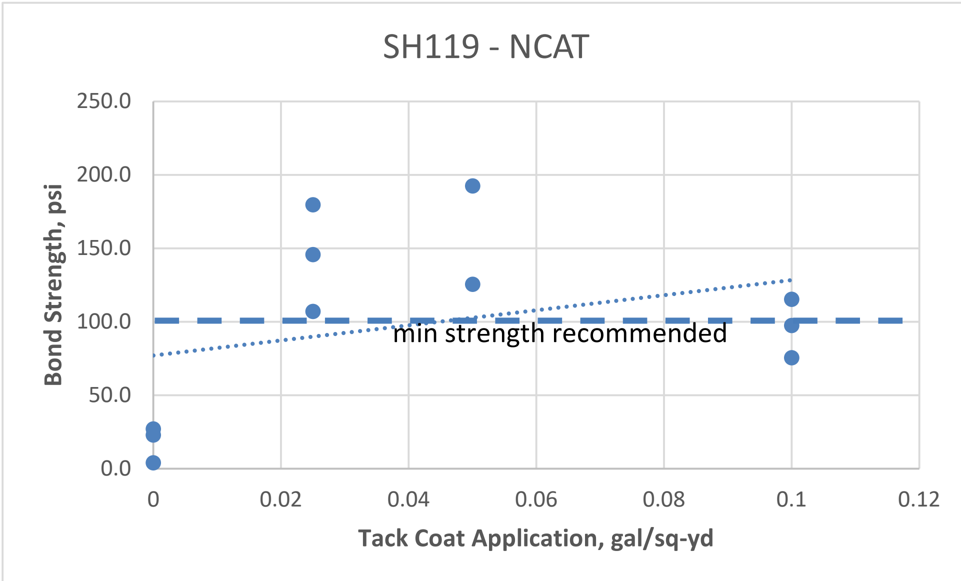


Figure 14. NCAT Bond Strength at SH119

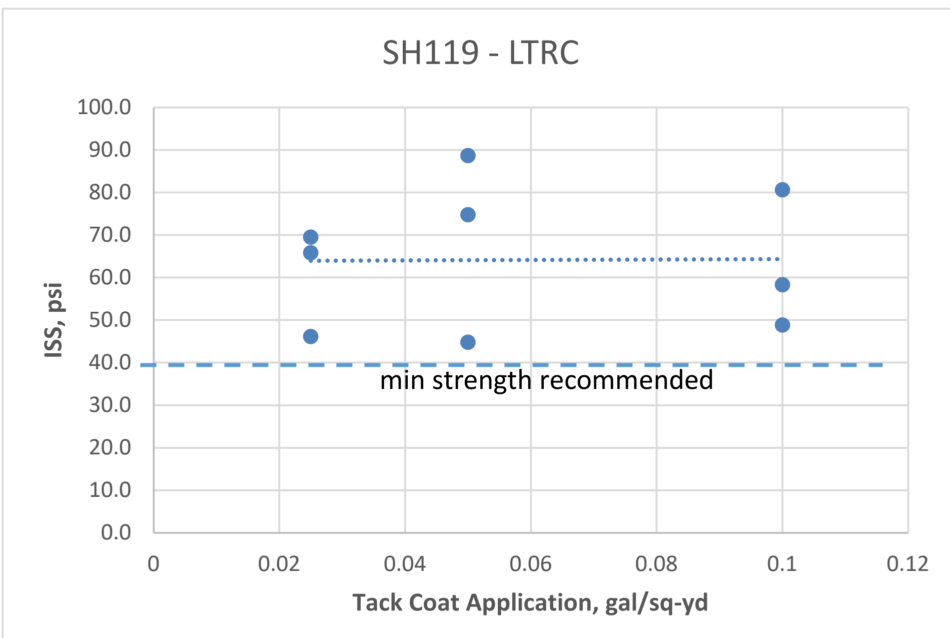


Figure 15. LTRC Bond Strength at SH119

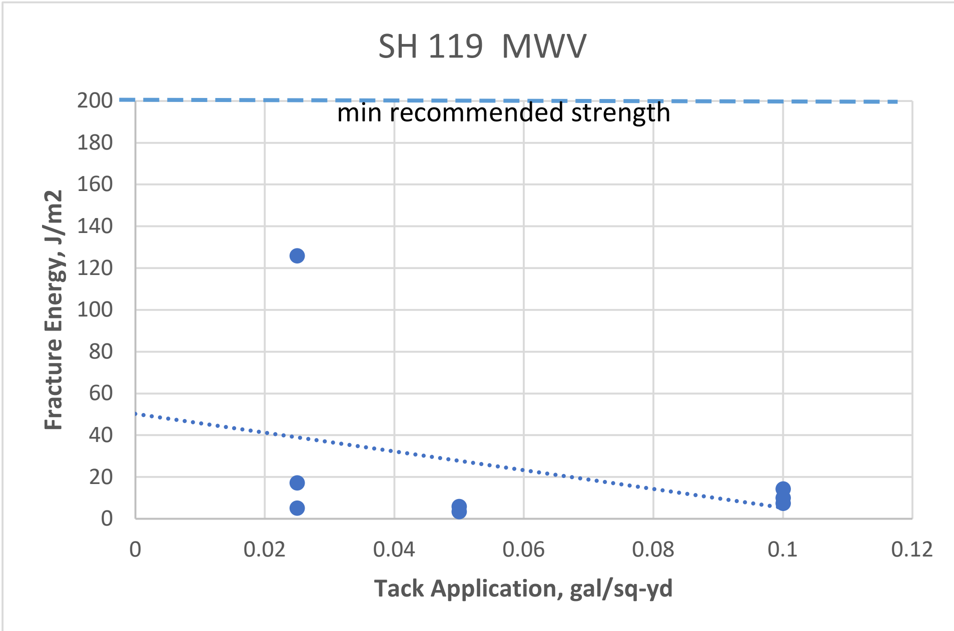


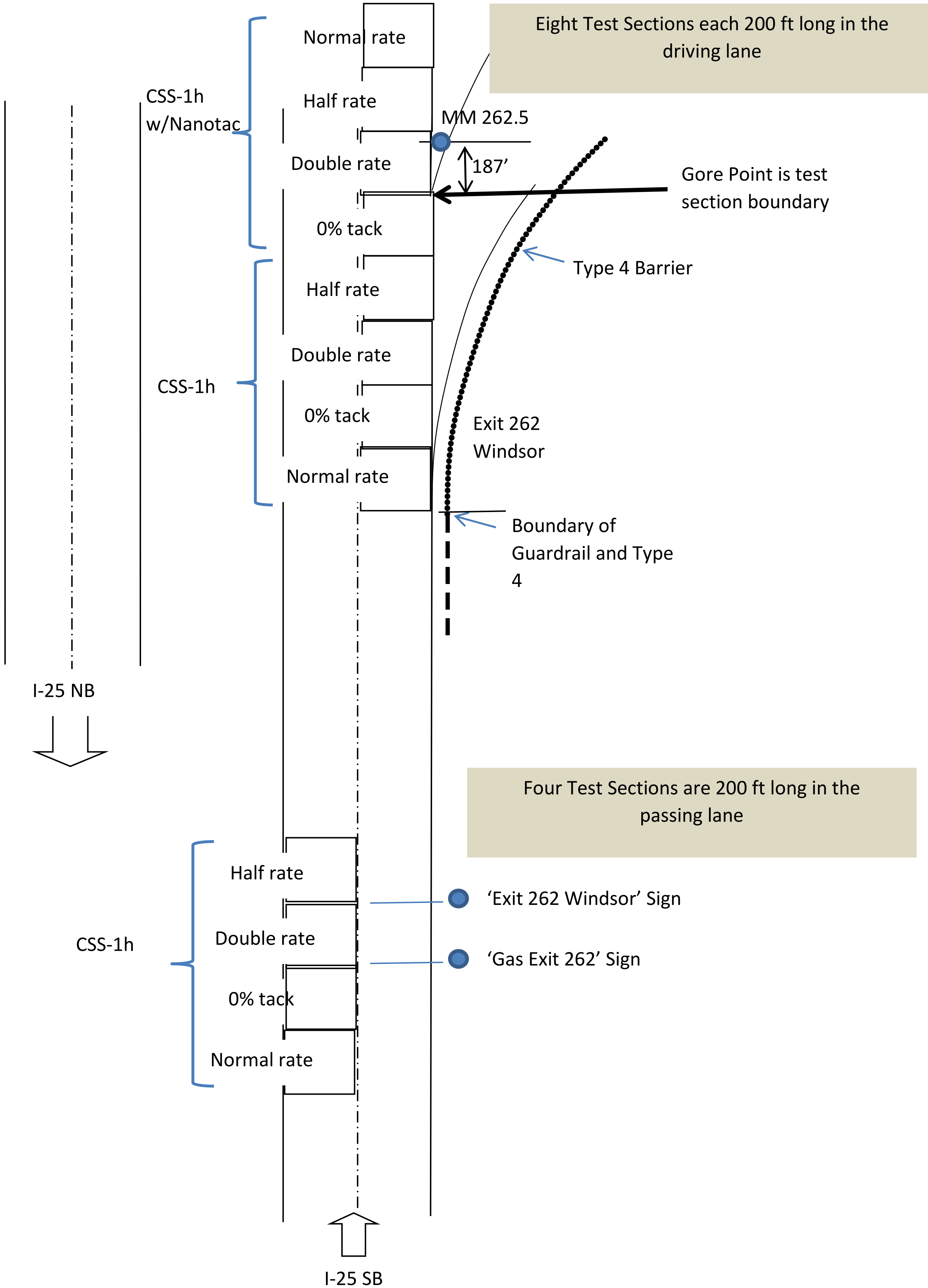
Figure 16. MWV Fracture Energy at SH119

Site 5 - I-25 at SH392

Site 5 was constructed between August and October, 2014. Test sections are located in the southbound driving and passing lanes of I-25 adjacent the SH392 exit. Aggregate Industries, Inc. constructed the overlay which consists of SMA over HMA over concrete in the passing lane and SMA over concrete in the driving lane. The tack coat applied was a CSS-1h emulsion with 65% residue by weight diluted 50:50 prior to spraying. .

The 'Normal' tack coat rate was based on 300 gallons of tack coat emulsion placed in 4150 feet of roadway 13 feet wide. This equates to approximately 0.05 gallons per square yard. The 'light' tack coat rate was achieved by doubling the speed of the tack coat distributor and the 'heavy' tack coat rate was achieved by slowing the speed by half. At these speeds the light rate and heavy rates, respectively would be 0.025 and 0.10 gallons per square yard.

Four segments make up the test section in the passing lane and eight segments make up the test section in the driving lane. The four passing lane test segments are measuring tack coat bonding between dense graded hot mix and the SMA surface course. The eight driving lane test segments are measuring bonding between unmilled Portland cement concrete and the SMA surface course. In addition, four of the test segments in the driving lane were constructed with the proprietary tack coat additive 'Nanotac' to measure the difference in performance compared with conventional CSS-1h. The locations of these test segments are shown below:


Eight Test Sections each 200 ft long in the driving lane
Normal rate
Half rate
CSS-1h w/Nanotac
MM 262.5
Double rate
187'
Gore Point is test section boundary
0% tack
Type 4 Barrier
Half rate
Double rate
CSS-1h
0% tack
Exit 262 Windsor
Normal rate
Boundary of Guardrail and Type 4
I-25 NB
Four Test Sections are 200 ft long in the passing lane
Half rate
'Exit 262 Windsor' Sign
CSS-1h
Double rate
'Gas Exit 262' Sign
0% tack
Normal rate
I-25 SB

Test Results

Results of all bond strength tests from Site 5 are shown in Figures 17 to 22 below. The segments where the Nanotac were applied are represented as "CSS-1h+".

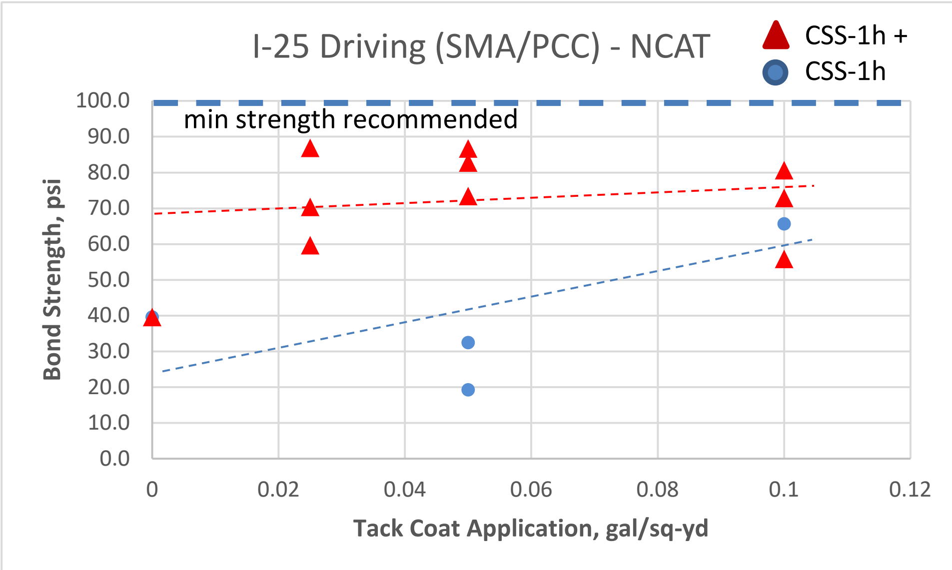


Figure 17. NCAT Bond Strength at I-25 Driving Lane

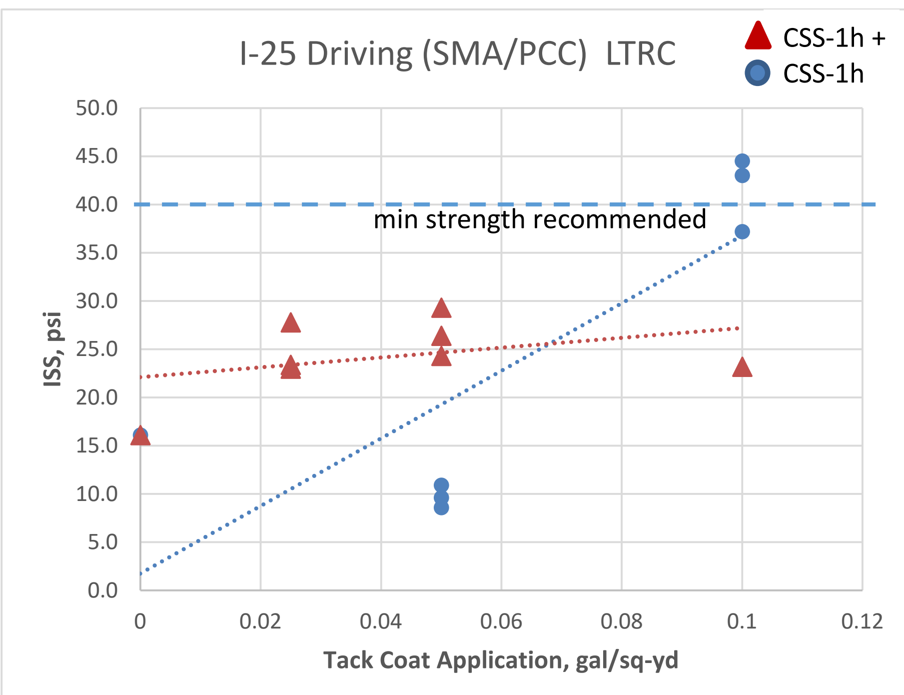


Figure 18. LTRC Bond Strength at I-25 Driving Lane

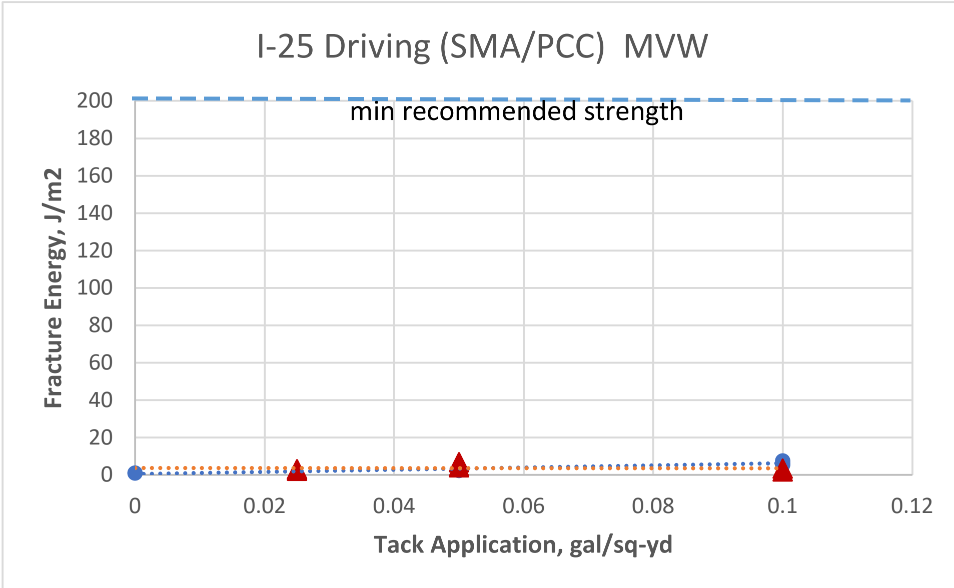


Figure 19. MWV Fracture Energy at I-25 Driving Lane

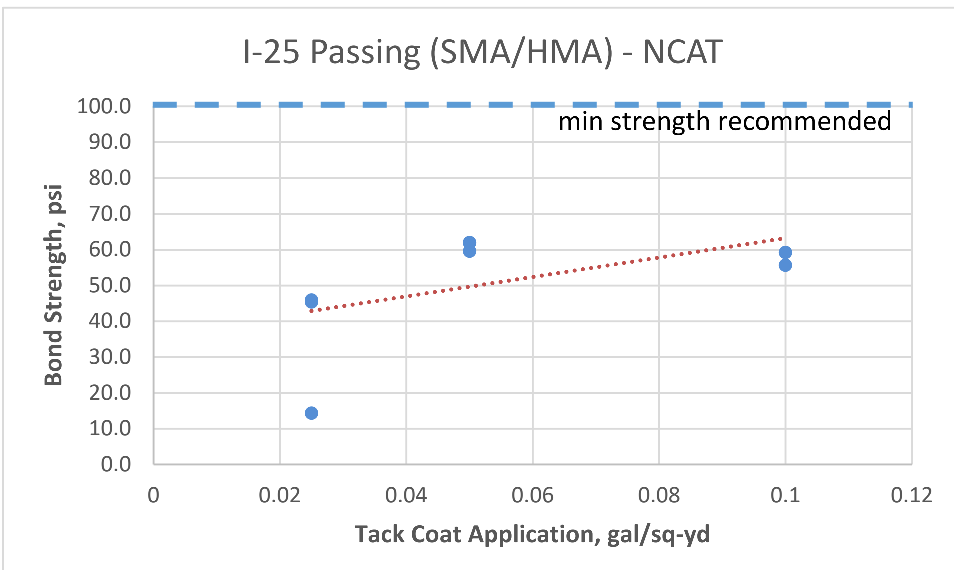


Figure 20. NCAT Bond Strength at I-25 Passing Lane

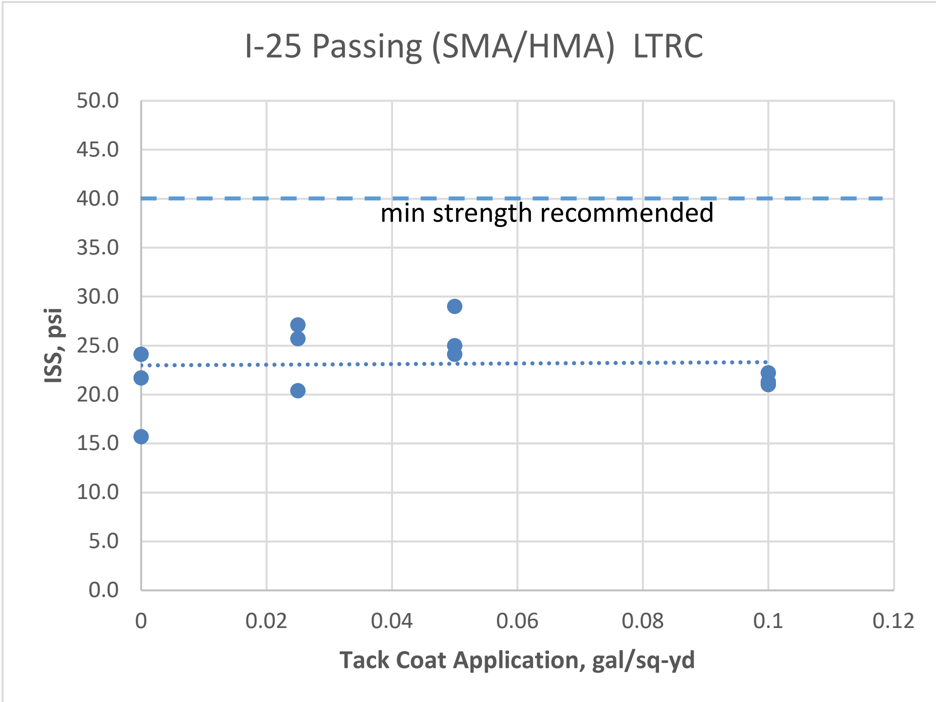


Figure 21. LTRC Bond Strength at I-25 Passing Lane

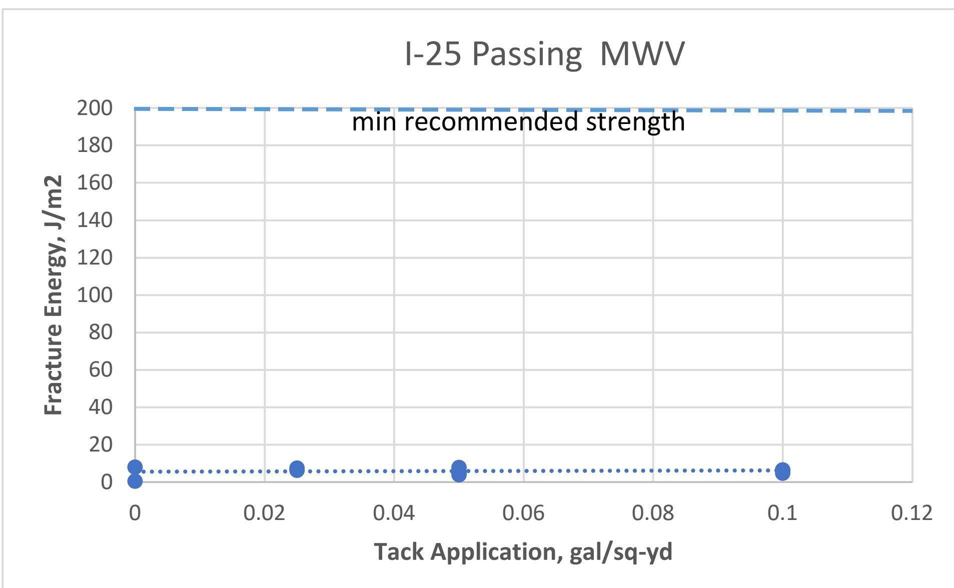


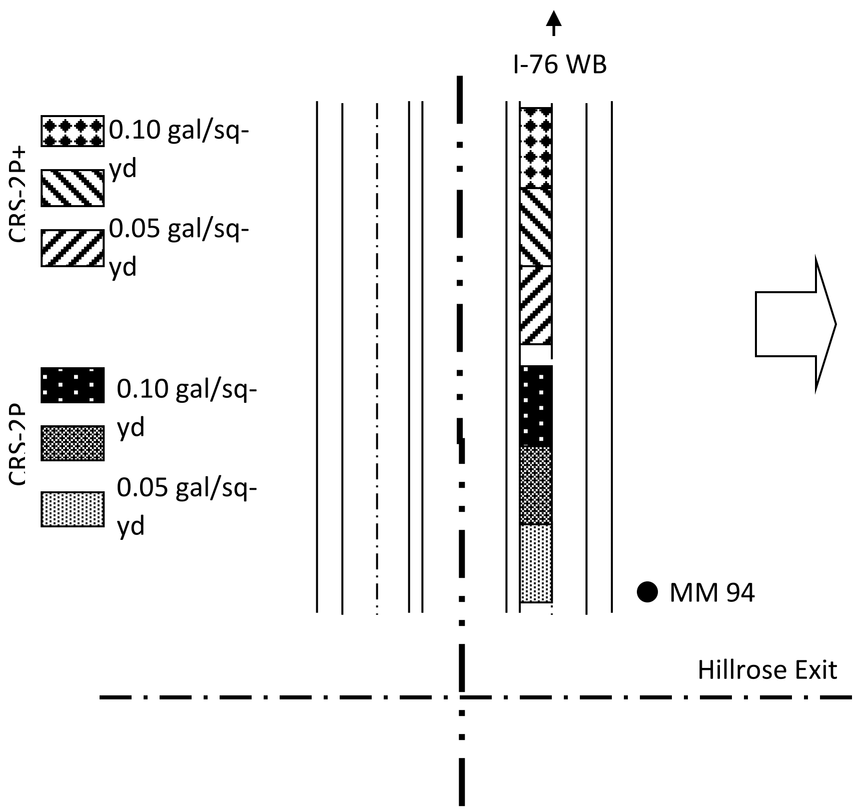
Figure 22. MWV Fracture Energy at I-25 Passing Lane

Site 6 - I-76 at Brush

Site 6 was constructed between August and October 2014. Test sections are located in the westbound passing lane of I-76 just south of the Hillrose exit near Brush, CO. Aggregate Industries, Inc. constructed the overlay which consists of 3 inches of an SX 100 gyration HMA over concrete pavement in the passing lane. The tack coat applied was a CRS-2P emulsion with 65% residue by weight diluted 50:50 prior to spraying. .

The 'Normal' tack coat rate was based on 200 gallons of emulsion placed on 2800 feet of roadway 13 feet wide. This equates to approximately 0.05 gallons per square yard. As was done on previous test sections, the 'light' tack coat rate (0.025 gal/sq-yd) was achieved by doubling the speed of the tack coat distributor and the 'heavy' tack coat rate (0.10 gal/sq-yd) was achieved by slowing the 'normal' speed by half. Each test segment was 500 feet long.

In addition to the CRS-2P sections, three test segments were, again, constructed with the proprietary tack coat additive 'Nanotac' to measure the difference in performance compared with conventional CRS-2P. The locations of these test segments are shown below:



Test Results

Bond strength tests from Site 6 are shown in Figures 23 and 24. Segments where Nanotac was added to the CRS-2P are represented as "CRS-2P+". The MWV testing conducted at Site 5 was more variable than expected and, therefore, was not conducted at Site 6.

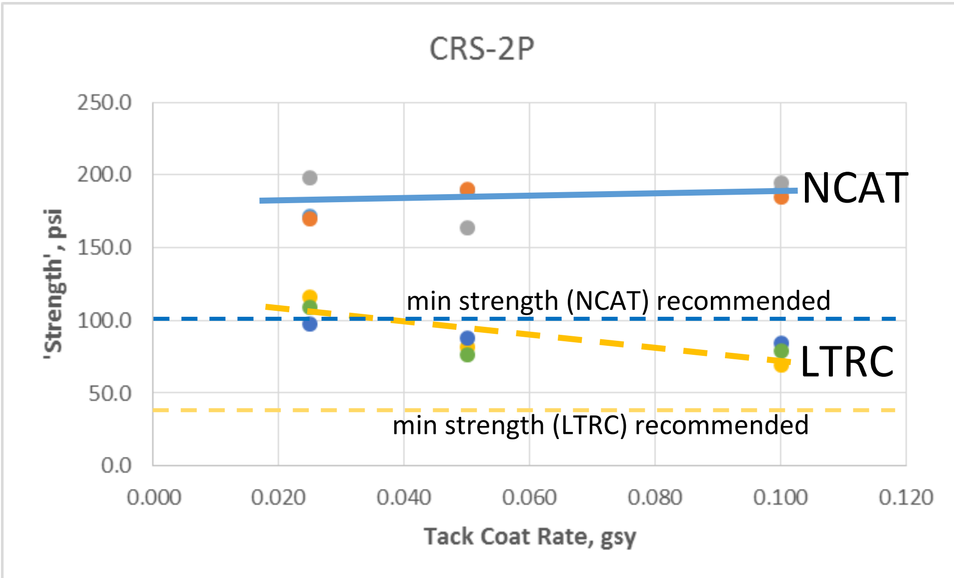


Figure 23. Bond Strength on I-76 with CRS-2P

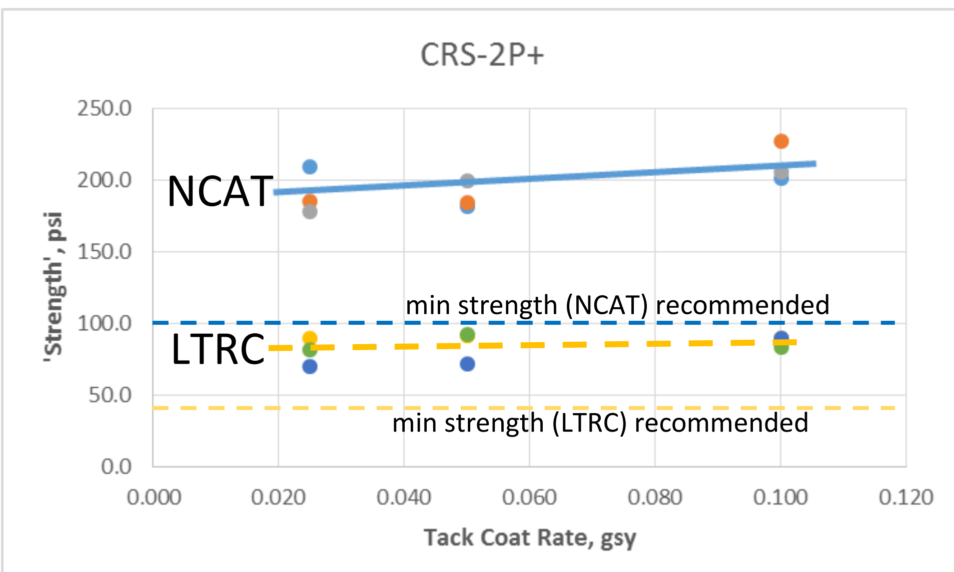


Figure 24. Bond Strength on I-76 with CRS-2P+

ANALYSIS

The variability in the bond strength data for all of the sites except I-76 suggests that little, if any, relationship exists between bond strength and tack coat rate.

The apparently less variable data obtained from I-76 were analyzed using conventional ANOVA techniques in an attempt to determine statistical significance. This was done as a one-way analysis to determine significance of tack coat rate on bond strength. The results of this analysis are shown below.

Table 1 – ANOVA for NCAT Bond Strength and CRS-2P

Groups	*Count*	*Sum*	*Average*	*Variance*
0.025	3	540.1	180.03	253.72
0.05	3	543.6	181.20	232.41
0.1	3	569.8	189.93	22.10

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	175.64	2	87.82	0.52	0.62	5.14
Within Groups	1016.47	6	169.41			
Total	1192.12	8				

Table 2 – ANOVA for LTRC Bond Strength and CRS-2P

Groups	*Count*	*Sum*	*Average*	*Variance*
0.025	3	323	107.67	82.33
0.05	3	246	82.00	36.00
0.1	3	232	77.33	58.33

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1600.67	2	800.33	13.59	0.01	5.14
Within Groups	353.33	6	58.89			
Total	1954.00	8				

Table 3 – ANOVA for NCAT Bond Strength and CRS-2P+

Groups	*Count*	*Sum*	*Average*	*Variance*
0.025	3	572.5	190.83	266.32
0.05	3	564.5	188.17	91.61
0.1	3	633.3	211.10	185.25

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	943.79	2	471.89	2.61	0.15	5.14
Within Groups	1086.37	6	181.06			
Total	2030.16	8				

Table 4 – ANOVA for LTRC Bond Strength and CRS-2P+

Groups	*Count*	*Sum*	*Average*	*Variance*
0.025	3	242	80.67	101.33
0.05	3	255	85.00	127.00
0.1	3	263	87.67	16.33

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	74.89	2	37.44	0.46	0.65	5.14
Within Groups	489.33	6	81.56			
Total	564.22	8				

Results of this analysis indicate that the NCAT bond test cannot discern the difference between any of the tack coat application rates as indicated by P-values well above $\alpha = 0.05$. Also, the LTRC bond test cannot discern differences in tack coat rate for the CRS-2P+. However, LTRC tests can detect a difference in bond strength for the CRS-2P. Further analysis of the LTRC data for the CRS-2P using a Newman-Keuls multiple range test indicates the 0.025 gal/sq-yd shot rate has a higher average bond strength at 107.67 psi compared with 82.00 psi and 77.33 psi at 0.05 and 0.10 gal/sq-yd, respectively.

Further analysis was done to determine if the Nanotac additive had any effect on bond strength. Results of this analysis are shown in Table 5 for the NCAT bond strength tests and indicate no significant difference between the CRS-2P and CRS-2P+ at $\alpha = 0.05$.

Table 5 –NCAT Bond Strength for CRS-2P vs CRS-2P+

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1877.33	5	375.47	2.14	0.13	3.11
Within Groups	2102.85	12	175.24			
Total	3980.18	17				

Analysis of the LTRC data had to be separated by tack coat application rate since a significant difference exists between shot rates. Therefore, Tables 6, 7 and 8 show the results of ANOVA conducted at each shot rate.

Table 6 –LTRC Bond Strength for CRS-2P vs CRS-2P+ at 0.025 gal/sq-yd

Groups	*Count*	*Sum*	*Average*	*Variance*
CRS-2P+	3	242	80.67	101.33
CRS-2P	3	323	107.67	82.33

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1093.50	1	1093.50	11.91	0.03	7.71
Within Groups	367.33	4	91.83			
Total	1460.83	5				

Table 7 –LTRC Bond Strength for CRS-2P vs CRS-2P+ at 0.050 gal/sq-yd

Groups	*Count*	*Sum*	*Average*	*Variance*
CRS-2P+	3	255	85.00	127.00
CRS-2P	3	246	82.00	36.00

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	13.50	1	13.5	0.17	0.70	7.71
Within Groups	326.00	4	81.5			
Total	339.50	5				

Table 8 –LTRC Bond Strength for CRS-2P vs CRS-2P+ at 0.100 gal/sq-yd

Groups	*Count*	*Sum*	*Average*	*Variance*
CRS-2P+	3	263	87.67	16.33
CRS-2P	3	232	77.33	58.33

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	160.17	1	160.17	4.29	0.11	7.71
Within Groups	149.33	4	37.33			
Total	309.50	5				

These data indicate the only significant difference occurs at the lowest shot rate of 0.025 gal/sq-yd. as shown in Table 6. This means the average bond strength for the CRS-2P of 107.67 psi is greater than the average strength of the CRS-2P+ of 80.67 psi at $\alpha = 0.05$.

Promising Bond Strength Tests

A trend analysis was used in an attempt to compare all of the bond strength tests for all of the test sites. These trends were analyzed in an attempt to determine which of the test methods may be best suited for measuring tack coat bond strength.

Figure 25 is a matrix containing each of the three bond strength tests and each of the field test sections. The cells in the matrix include a horizontal dashed line signifying the minimum bond strength recommendation determined by the researchers who developed the tests. The solid line is a depiction of the trend in bond strength as a function of tack coat application rate. The distance between the minimum recommended bond strength line and the bond strength of the core samples gives a relative position of the test result and the recommended minimum value. The colored dots indicate the following:

- Green dots in the cells signify strength increasing with tack coat application rate and strength above the minimum recommendation.
- Yellow dots signify strength increasing with tack coat application rate, but below minimum recommended strength.
- White dots signify no change in strength with tack coat application rate and
- Red dots signify decreasing strength with increasing tack coat application rate.

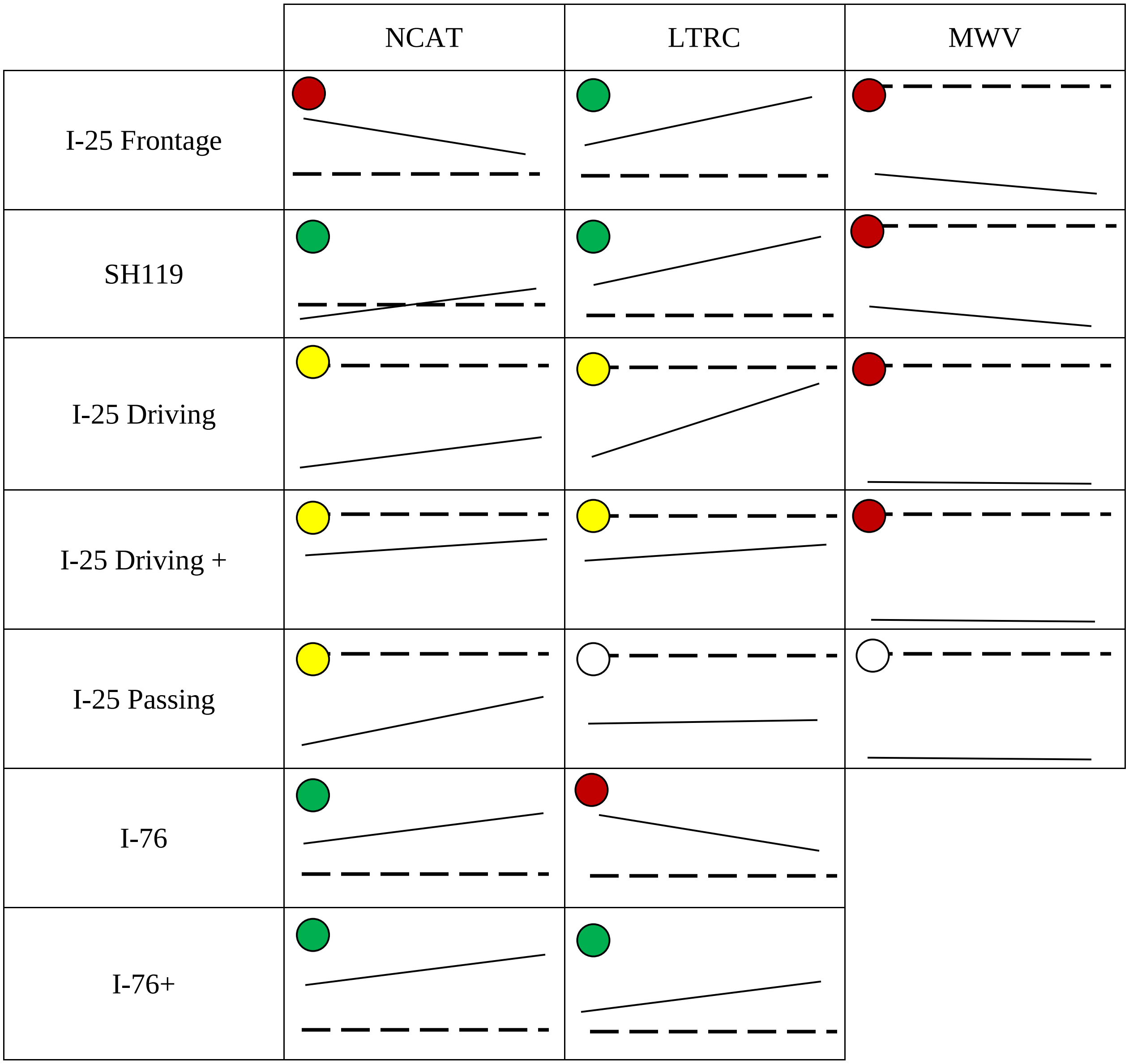


Figure 25 – Bond Strength Test Method Comparison

CONCLUSIONS

Three laboratory bond strength test methods were evaluated in this research to determine which method could best discern differences in tack coat application rate from cores taken from field test sections. Two shear tests and one compact tension test were evaluated. Results of the testing support the following conclusions:

1. The direct shear tests conducted by NCAT and LTRC provided data that was most consistent with expected results, that is, bond strength of the core samples increased with increasing tack coat application rates. However, variability in the data makes this conclusion, although logical and consistent with reported results in the literature, somewhat suspect.

2. The direct shear test data provided by NCAT and LTRC, while somewhat variable for the CSS-1h tack coats contained less variability for the CRS-2P tack coat.

3. Bond strength by the NCAT and LTRC test methods was above the minimum recommended values for all tack coat application rates on all but the I-25 test sections.

4. Bond strength by the NCAT and LTRC test methods was well below the minimum recommended values for all tack coat application rates on the I-25 test sections. This included the sections containing the Nanotac additive.

5. The Nanotac additive appears to have little effect on bond strength when measured by the NCAT test method. However, a negative effect was observed for the LTRC test results at 0.025 gal/sq-yd. No effect was measured at 0.05 or 0.10 gal/sq-yd.

RECOMMENDATIONS

This study provides a unique opportunity to evaluate the adhesive abilities of CSS-1h and CRS-2P tack coats for both HMA and SMA overlays placed over asphalt and Portland cement concrete pavements. Test results indicate bond strength should be inferior on the I-25 test sections compared to the I-25 Frontage, SH119 and I-76 test sections. However, the I-25 test sections were SMA overlays, not dense graded HMA, like the other pavements in the study. This could mean:

1) the tack coat application rate for SMA placed over PCC and HMA should be different than for dense graded HMA overlays, and/or

2) the recommended minimum bond strength for SMA is different than HMA overlays.

Therefore, more work is needed to determine the minimum application rate for tack coat applied under SMA. And, at a minimum, the pavement in the area of the I-25/SH392 test sections should be monitored to determine if there is any evidence of debonding.

IMPLEMENTATION PLAN

Consider implementation of this research as follows:

Specify a minimum tack coat application rate of 0.05 gal/sq-yd of 50:50 diluted CSS-1h or CRS-2P for construction of dense graded HMA over other dense graded HMA. This implementation is justified based on the results of four of the experimental pavements. That is, of all the pavements except the SMA on I-25 at SH392, the 0.05 gal/sq-yd application rate met the minimum bond strength criteria recommended by NCAT and LTRC. The lowest application rate also met the minimum bond strength criteria. However, because the lowest shot rate is more difficult to apply uniformly, the 0.05 gal/sq-yd rate should be specified in order to achieve adequate bond strength by the LTRC and NCAT methods.

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