Evaluating the Performance of Tack Coat Materials in Saskatchewan Climate by Means of a Field Study and Laboratory Study – Part 1 Field Study

Laura Stasiuk, M.Sc. Candidate
Research Assistant
University of Saskatchewan

Haithem Soliman, Ph.D.
Assistant Professor
University of Saskatchewan

Ania Anthony, M.Sc., P.Eng.
Director, Materials and Surfacing
Saskatchewan Ministry of Highways and Infrastructure

Chris Dechkoff, P.Eng.
Technical Manager
ACP Applied Products

Jen Penner, M.Sc. Candidate, EIT
Asset Integrity Engineer
Pounder Emulsions (Husky Energy)

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ABSTRACT

Tack coat materials are used to provide sufficient bond between an existing asphalt concrete layer and a new asphalt concrete overlay and/or in-between two lifts of newly placed asphalt concrete. Most of the time, agencies and contractors rely solely on emulsified bituminous products for use as tack coats. Recent developments in tack coat materials are focusing on fast curing and non-tracking emulsions. The objective of this project is to evaluate the performance of several tack coat materials in Saskatchewan climate through a field study and a laboratory-testing program. Ten test sections were constructed in August 2017 on a two-way, two-lane rural highway (Highway 12) near Blaine Lake, Saskatchewan. Construction and installation of the tack coat materials was completed over two days to eliminate any variability due to weather conditions. A post-construction inspection was conducted in September 2017 to document any surface distresses related to the construction process. A distress survey will be conducted following the spring season of each year for 5 years. Core samples were collected in September 2017 to evaluate the initial bond strength of the tack coat materials. Core samples will be collected following the spring season of each year to evaluate the degradation of bond strength over time. Findings from this project will be used to update the approved tack coat materials list and provide recommendations and guidelines for construction best practices. This paper introduces the experiment, discusses the products used, and provides a summary of observations from the field component of the project.

1. BACKGROUND

Current industry standards widely overlook the importance of a tack coat in the performance of pavement structures. Tack coats are bituminous materials used to provide bonding between asphalt layers. Typically, the industry has been relying on emulsified asphalt products for this purpose. An ideal tack coat material would have short break and set times to limit the inconvenience to the contractor and to the public which arise from long curing times. Short break and set times ensure achieving proper bond between asphalt concrete layers without slowing down the construction process. In addition, short break and set times reduce pickup and tracking of emulsion residue on construction equipment and on traveling vehicles which occasionally end up traveling on a tacked road surface.

A tack coat material "breaks" when its colour changes from brown to black as shown in Figure 1. Break times vary significantly, depending on the properties of the material itself, whether and how it is diluted with water, as well as with weather conditions. A tack coat sets when the emulsion residue is no longer picked up from the road surface. This can be determined by blotting the surface with a tissue on the emulsion, and by observing product transfer to vehicle tires. Minimal transfer of residue indicates that any water previously present in the material has evaporated and the asphalt bitumen is forming a homogeneous layer on the road surface.

Figure 1. Broken and Unbroken Tack Coat Material

Achieving sufficient proper bond strength between asphalt concrete layers is critical to ensure that the bonded layers will act and resist stresses as one homogeneous system. If the bond is inadequate, asphalt concrete layers will act separately as multiple layers which will increase the stress levels within these layers and lead to cracking and premature failure. Figure 2 shows the difference in asphalt concrete layers behaviour with good and poor bond. In Figure 2b a poor bond between new and old asphalt concrete layers makes the two layers act independently as two thin layers, which leads to exceeding the tensile strength of asphalt concrete and cracking of the new asphalt layer.

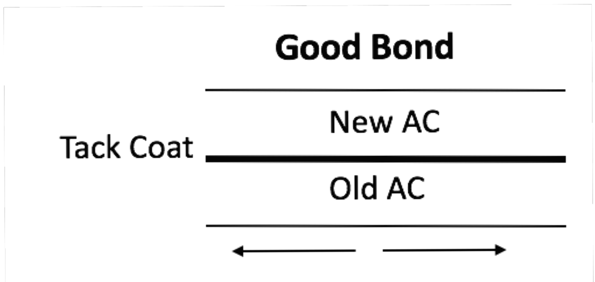

Figure 2a. Old and New AC Layers Act as One Thick Layer

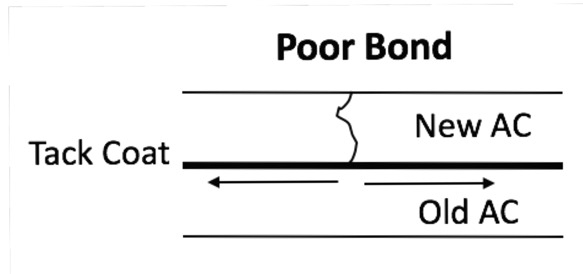

Figure 2b. Old and New AC Layers Act as Two Separate Layers

Figure 2. Behaviour of Asphalt Concrete Layers with Good and Poor Bond

There has not been a lot of study focus on the effectiveness of tack coat materials in Canadian climate. Past industry studies reviewed the bond strength and application procedures of tack coat materials, however, these studies did not take into account the extreme weather conditions experienced in Saskatchewan.

A recent comprehensive study was performed by the Transportation Research Board (TRB) and is summarized in a technical publication titled NCHRP 712: Optimization of Tack Coat for HMA Placement [1]. This study explores multiple aspects of tack coat procedures including application rates, effects of poor construction practices, development of an in situ tack coat quality test, and the development of a lab test (AASHTO TP 114). A worldwide survey was also conducted as part of the study to gain knowledge about the methods agencies in North America and around the world use for construction practices, and quality assurance [1].

According to the worldwide survey conducted as part of the NCHRP712 project, 26% of the surveyed agencies allow construction trucks to drive on unbroken emulsion. Furthermore 70% of the surveyed agencies allow construction trucks on broken emulsion before it has set. Out of the 53 surveyed agencies, 74% of the agencies allow paving to begin immediately after the tack coat material breaks, whereas 26% do not allow paving until the tack coat emulsion sets. 92% of the surveyed agencies stated that they do not test to measure the bond strength at the interface between AC layers. Based on the above statistics, there is clearly a need for fast breaking and setting tack coat materials and better construction practices and monitoring [1]..

The NCHRP712 report identified twenty testing methods used by agencies for tack coat bonds including both laboratory and in-situ tests. Most of these tests measure shear stress or tensile strength. Some of these tests include the Leutner Shear Test, Florida Direct Shear Test, and the Switzerland Pull Off Test [1]. A study has been performed in 2017 at Oregon State University to develop the Oregon Field Torque Tester (OFTT) [2]. This in-situ bond strength tester offers a cheaper and less destructive method of testing for interlayer shear strength. The OFTT requires smaller core samples than previously mentioned methods. Cores diameters are 2.5 inches and not taken at full depth. The OFFT devices measures peak torque in the field. Peak torque was correlated with lab interlayer shear strength results obtained from following the AASHTO TP

114 procedure. Field results from the OFTT were highly correlated with the shear strength results of core samples in the lab [2].

Several studies reviewed the best practice of tack coat application. Destrée and De Visscher (2017) concluded from a field study that there was no significant difference between the bond strength of cores that had been exposed to varying levels of pressure washing on milled surface prior to tack coat application [3]. A study from the Louisiana Transportation Research Center in 2010 found that roughness of the underlying layer had an effect on bond strength; a milled HMA yielded the highest bond strength followed by an existing unmilled layer and then a new HMA lift [4].

Tack coat application procedures are not well defined or followed by many transportation agencies. Some construction practices, such as allowing delivery trucks to drive on the tack coat before it is set, often do not leave enough tack coat material in the wheel paths to form a strong bond between the asphalt concrete layers. Poor bonding contributes to early deterioration of roads because the stresses and strains in the asphalt concrete exceed the design limits. Most engineers are familiar with the extreme cases of bond failures, as shown in Figure 3. However, the effects of poor bonding can also be subtle and instead of catastrophic failures, may manifest themselves more gradually, in the form of accelerated fatigue cracking (as shown in Figure 4), often in the later stages of the pavement life cycle. Based on current practice, tack coat materials typically cost between 1 and 1.5% of total pavement cost. If the bond is weak, the resulting costs can amount to 30% and all the way up to 100% of total pavement cost [5]. Ensuring that an adequate bond is formed between pavement layers will maximize the agency paving budgets and taxpayer investment into road infrastructure.

Figure 3. Example of Slippage Failures from Poor Bonding Between Asphalt Layers

Figure 4. Example of Fatigue Cracking

Saskatchewan Ministry of Highways and Infrastructure (SMHI) is interested in expanding their repertoire of tack coat asphalt emulsion products. SMHI specifications currently limit tack coat materials to the basic slow setting emulsions, SS-1 and SS-1h. SMHI is interested in testing the bond strength and measuring field parameters of several tack coat materials available in Saskatchewan to evaluate their effectiveness, and the best application practices to follow. To carry out this project, SMHI partnered with the City of Saskatoon, ACP Applied Products, Pounder Emulsions (Husky Oil) Ltd., McAsphalt Industries Ltd., Colasphalt, and the University of Saskatchewan. The performance of several tack coat materials will be evaluated in the Saskatchewan climate through a field study and laboratory testing program. Results from the field study and the laboratory testing will be used to develop performance based specifications for selection of tack coat materials, and to recommend tack coat application best practices. This research aims to optimize road construction and maintenance costs and prevent premature pavement failures.

This paper presents the preliminary results of the field study and the future steps for this project.

2. MATERIALS

Seven tack coat materials provided by industry partners will be evaluated in this study. Three slow setting emulsions were provided: SS-1, SS-1h, and a cationic SS-1h (CSS-1h). An anionic medium setting emulsion, MS-1, was also tested. The slow setting anionic emulsion SS-1 was tested in three sections and SS-1h was tested in two sections. SS-1 will be used as the control material for comparison because it is the typical material used in all Saskatchewan Highways projects. Three fast breaking/quick setting proprietary products were also provided by the industry partners; these products are labelled as A, B, and C throughout the paper.

Two samples of each product were taken from the distributor at the time of application. These samples were sent to two industry partner labs for quality control testing. Tests included:

- ASTM D5: Standard Test Method for Penetration of Bituminous Materials [6]

- ASTM D6997: Standard Test Method for Distillation of Emulsified Asphalt [7]
- ASTM D7175: Standard Test Method for Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer [8]
- ASTM D7404: Standard Test Method for Determination of Emulsified Asphalt Residue by Moisture Analyzer [9]
- ASTM D7496: Standard Test Method for Viscosity of Emulsified Asphalt by Saybolt Furol Viscometer [10]

Both labs provided similar results indicating consistencies in testing. In Table 1 below are the quality control results provided by the manufacturers prior to construction.

Table 1. Measured Properties for Tack Coat Materials from Suppliers Prior to Construction

Product	**SS-1**	**SS-1h**	**CSS-1h**	**MS-1**	**A**	**B**	**C**
Residue by Distillation (% b.w.) - ASTM D6997	60.1	61.3	61	59.5	55.6	61.4	58.9
Oil Portion of Distillate (% b.v.) - ASTM 6997	0.5	0.5	1.0	0.8	0.5	0.5	2
Penetration (dmm) - ASTM D5	130	69	95	151	70	46	135

3. METHODLOGY

This research project is comprised of a field study and a laboratory testing program. The field study will evaluate the constructability and performance of tack coat materials in normal field conditions. Construction and environmental data were recorded at the time of installation of tack coat materials. A post-construction distress survey was completed to document early distresses related to the construction process. Future distress surveys will be conducted following each winter season for four years. In addition to distress surveys, core samples were collected after construction to evaluate the initial bond strength. Additional core samples will be collected following each winter season to evaluate the deterioration on bond due to traffic loading and environmental conditions.

The laboratory testing program focuses on testing the bond strength of the tack coat materials using the core samples collected from the field test sections. Bond strength tests will be conducted according to AASHTO TP 114: Determining the Interlayer Shear Strength (ISS) of Asphalt Pavement Layers [11]. Part of the post-construction core samples will be conditioned in the lab under accelerated freeze-thaw cycling to simulate field conditions in cold regions. Results of the bond strength tests for lab conditioned and field conditioned core samples will be compared and used to establish guidelines and procedures for accelerated testing of tack coat materials.

A 1.1km two-way, two-lane road segment on Highway 12 near Blain Lake, SK, was designated for the field study. Within this road segment, ten test sections were constructed, five in each lane. The layout of the products and test sections within the road segment is shown in Figure 5.

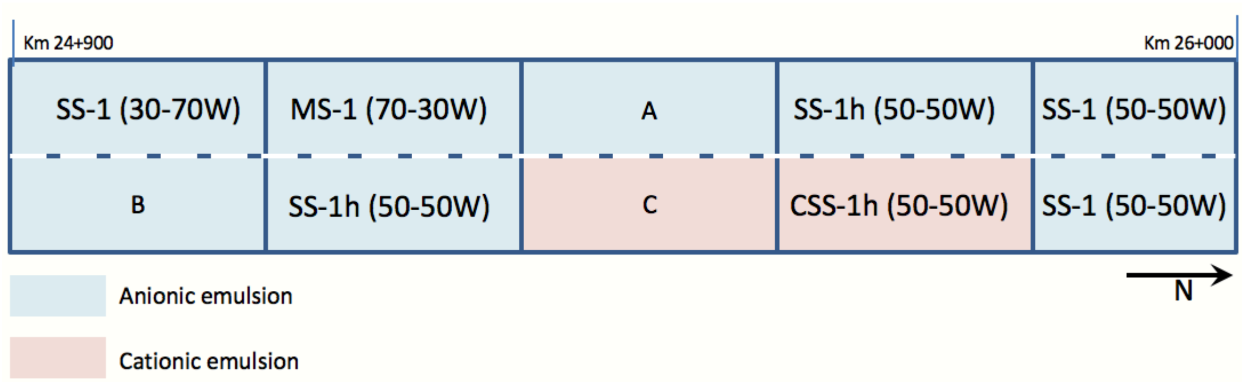

Figure 5. Layout of Test Sections and Tested Materials

Each test section was approximately 225m in length and was further divided into specific areas. These areas are calibration/application rate testing area, pick up and tracking testing area, non-destructive testing (NDT) area, and two coring areas. Figure 6 shows a schematic of the field test section.

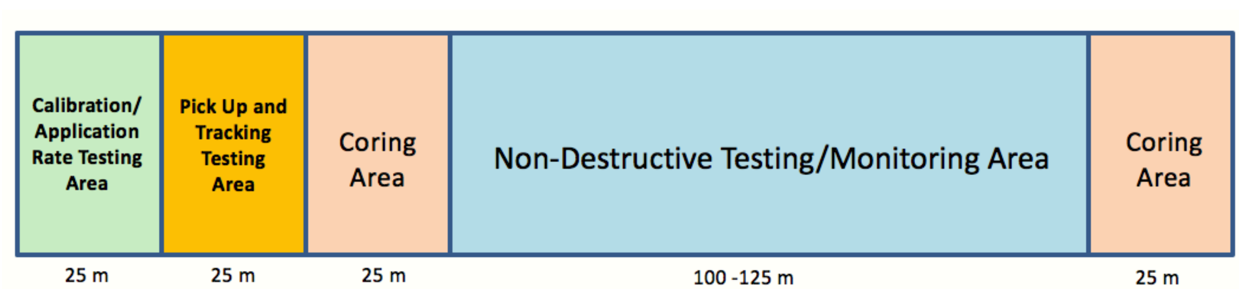

Figure 6. Test Section Schematic

The first area was the calibration/application rate testing area. This 25m area was used to calibrate the distributor by means of a patch test. A patch test was performed to ensure the distributor was applying a consistent desired spray rate [12]. Eleven absorbent patches were placed on the road. The distributor sprayed this first 25m area and stopped. Patches were weighed and actual application rate would be determined. Adjustments were made to the distributor on-board rate control computer if necessary. Figure 7 shows a layout for the patch test.

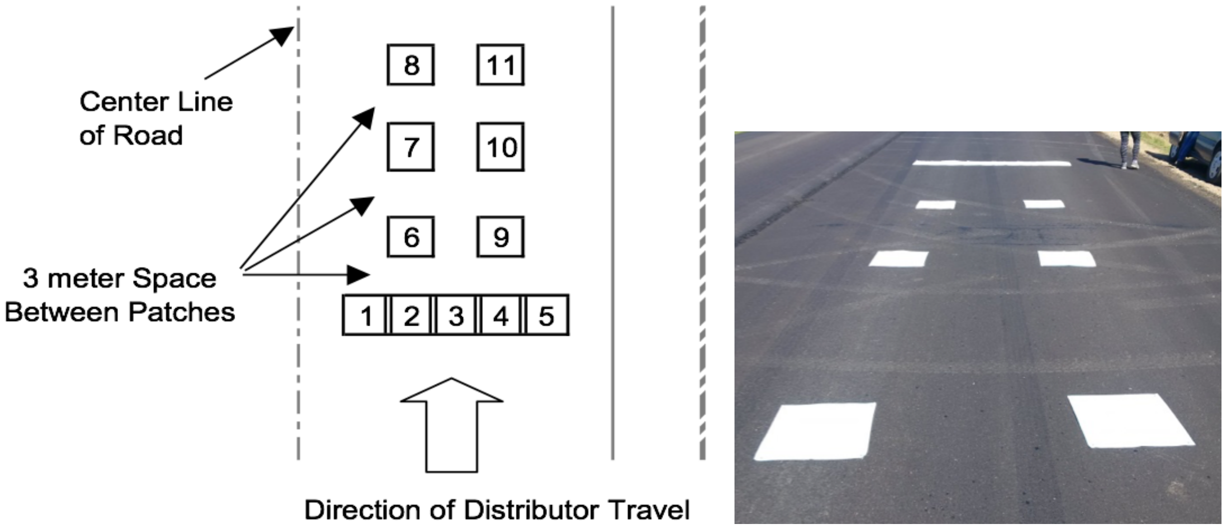

Figure 7. Patch Test Layout [12]

Once the calibration of the distributor was finalized, the remaining 200m was sprayed. This included the pick-up and tracking testing area, non-destructive testing (NDT) area, and the two coring areas.

The second area was the pick-up and tracking test area. This 25m area was used to evaluate the breaking and setting times as well as the material severity to pick-up/tracking by truck tires. Once the product had set, a truck was driven over the section and the material was given a rating of none, low, medium, or high according to its pick-up/tracking by truck tires.

The third area was the non-destructive testing area. This 125m area will be used to perform the distress survey following winter of each year. Falling weight deflectometer (FWD) testing may be performed as well.

The last areas are the two coring areas. Each coring area will have 32 cores extracted from it during 5 coring periods. The first set of eight cores was collected from each zone following the completion of construction. These cores are red in Figure 8 below. Cores were collected from the inner and outer wheel paths (IWP & OWP), and the centre of each lane. Table 2 shows a breakdown of the cores collected post-construction. The remaining 24 cores will be taken from the road following the winters of years 2018, 2019, 2020, and 2021.

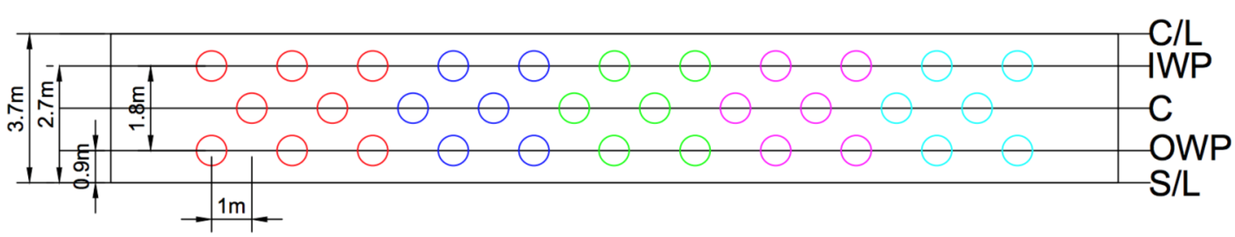

Figure 8. Coring Map

Table 2. Post-Construction Coring Counts

Coring Area 1			Coring Area 2								
IWP	OWP	Centre	IWP	OWP	Centre	Total Zone 1	Total Zone 2	Total IWP	Total OWP	Total Centre	**Total**
3	3	2	3	3	2	8	8	6	6	4	16

4. FIELD STUDY

The construction of the tack coat test section was completed on August 22 and 23, 2017. The location of the test sections is on Saskatchewan Highway 12 just south of Blaine Lake (approximately 80km from Saskatoon). This highway is a two-way, two-lane rural highway. Resurfacing of this highway was underway and a portion of the highway was allocated to the tack coat field study. The resurfacing project involved milling 30mm of the old asphalt surface and laying two lifts of asphalt concrete, each 50 mm in thickness. A 1.1km road segment was designated for the research project, and the test sections were placed once bottom lift asphalt concrete was completed. As a result, this study focuses on evaluating the bond created between the two new layers of asphalt concrete.

Construction took place over two consecutive days to minimize differences in weather conditions. While efforts were made to minimize the difference in weather conditions, there was still some variation in temperature and humidity. Sections constructed in the morning were exposed to colder and more humid conditions than sections constructed later in the afternoon. Temperatures during construction were between 11°C and 24°C. Humidity was between 39% and 85%. While the construction took place, parameters related to materials, weather, and construction process were recorded. The recorded information about the tack coat materials were dilution %, tack coat application temperature (at the sprayer nozzle), break time, set time, and pick-up/tracking rating. The recorded weather information parameters were: air temperature, wind speed, pavement temperature, humidity, and weather condition. The recorded construction information was target application rate, actual application rate from patch test, and average application rate from the distributor data. Table 3 below shows the results of the pick-up/tracking test, and breaking and setting times. Some products did not break and set before paving occurred so a tracking test was not performed. Table 4 contains the recorded field parameters.

Table 3. Pick-Up, Break Times, and Set Times

Product	Pickup Rating	Break Time (min)	Set Time (min)
SS-1 (50-50W) SB	None	79	134
SS-1h (50-50W) SB	N/A	N/A	N/A
A	None	10	120
MS-1 (70-30W)	Medium	20	49
SS-1 (30-70W)	N/A	N/A	N/A
SS-1 (50-50W) NB	N/A	360	N/A
CSS-1h (50-50W)	None	30	68
C	None	5	14
SS-1h (50-50W) NB	N/A	N/A	N/A
B	None	3	10

Note: Products that contain N/A for pickup rating were not subjected to a tracking/pickup test due to the material taking too long to break and set. A tracking test was only performed on set material. Materials with N/A for break and set times were paved without having the tack coat material set.

Table 4. Field Parameters

Product Name:	SS-1 (SB)	SS-1	SS-1 (NB)	SS-1h (SB)	SS-1h (NB)	CSS-1h	MS-1	A	B	C
Dilution (%):	50-50W	30-70W	50-50W	50-50W	50-50W	50-50W	70-30W	0	0	0
App Temp (°C):	26.3	40	31	30.1	42.2	36.3	32.3	32.0	49.7	40.8
Pavement Temp (°C):	20	37	24	31	40	33	42	37	35	41
Target App Rate (L/m^2):	0.5	0.5	0.5	0.5	0.5	0.5	0.41	0.36	0.33	0.33
Actual App from Patch Test (L/m^2):	0.50	0.28	0.52	0.45	0.21	0.47	0.36	0.27	0.23	0.28
Air Temp (°C)*:	14	22	11	16	24	17	22	20	24	22
Humidity (%)*:	64	48	85	50	39	65	44	47	43	49
Weather Condition*:	Partly Cloudy	--	Sunny	--	Sunny	Sunny	Sunny	Partly Cloudy	Sunny	Sunny
Wind (km/h)*:	--	2	11	8	18	10	10	9	17	17

*Weather parameters from The Weather Network

Construction of the test sections was done according to the plan and layout outlined in the methodology section. The distributor used to apply the tack coat materials was a 2015 BearCat

Computer Rate Controlled Distributor and is shown below in Figure 9. The nozzles were set at a height of 15-20cm from the ground, with a nozzle angle of 30 degrees which allowed for triple overlap to be achieved. The distributor computer was set to spray a constant application rate independent of the truck's speed. The distributor's set application rate was adjusted based on the tack coat material's dilution percentage to aim for the same residual application rate for all products. The difficulty in spraying 10 products of both anionic and cationic varieties within a two day period was a challenge to the contractor as the distributor had to be flushed (cleaned) between products to ensure that there were no contamination between the products.

Figure 9. Tack Coat Distributor Truck

The tracking/pickup test was performed on six of the ten test sections. The four sections that were not tested were two test sections of SS-1h (both 50-50W) and two test sections of SS-1 (30-70W and 50-50W). The products took too long to break and set and these times could not be monitored fully. Performing a tracking test on these products before they set would not have offered any valuable information because the tracking would have been severe.

Figure 10 shows the road following coring and the eight four-inch cores taking from a coring area. Core holes were filled with a cold mix asphalt. Cores were drilled using a coring drill mounted on the back of a pickup truck. Following extraction, each core was labelled based on test section number (1-10), coring zone number (1 or 2), and location in the road (inner wheel path, centre, or outer wheel path. Cores were carefully wrapped in bubble wrap to prevent damage during transport and while in storage. Cores were stored at room temperature.

Figure 10. Cores

5. CONSTRUCTION OBSERVATIONS

The application rates selected for each tack coat product were determined based on best practices set out in the previous work completed and documented in the NCHRP 712 [1]. The paving contractor representatives commented that in general, the application rates that were being used for the test sections far exceed the application rates typically seen on SMHI projects. This is directly linked to the fact SS-1 takes a long time to break and set, and as a result, SMHI has traditionally used lower application rates to allow for faster setting, and to minimize pick up of material in wheel paths. Even though SMHI began to include specified minimum application rates two years ago, the practice of increasing rates for better bonding has not yet been widely adopted. This is also due to the fact that SMHI has been reluctant to enforce the minimum rates without having a variety of tack coat products approved and available for contractors to select from.

From the traditional tack coat emulsions that were tested, it was very clear that the CSS-1h broke and set faster than SS-1. The same was true for the MS-1 emulsion. Further, the three proprietary products tested were superior in their breaking and setting times.

Unfortunately, the first SS1-h section did not break even after several hours. When this was evident, an additional section of SS-1h was constructed, however, the same problem was encountered. It is suspected that either the dilution water affected the product, or there were possible residual chemicals in the totes in which the emulsion was shipped, which impacted the performance. Therefore, the SS-1h field observations are inconclusive.

The break and set times of the tested products were plotted with temperature readings to see if any trends can be observed. From Figure 11, it can be noted that break and set times showed some correlation to pavement temperature, air temperature, and product temperature. As application temperature, air temperature, and pavement temperature increase, the break and set times decrease. This indicates that temperature has an effect on these parameters. In addition, Figure 12 shows a correlation between humidity and break and set times. Figure 12 shows that lower humidity correlates to faster breaking and setting times. A lower humidity level accelerates the evaporation rate of water from the tack coat materials.

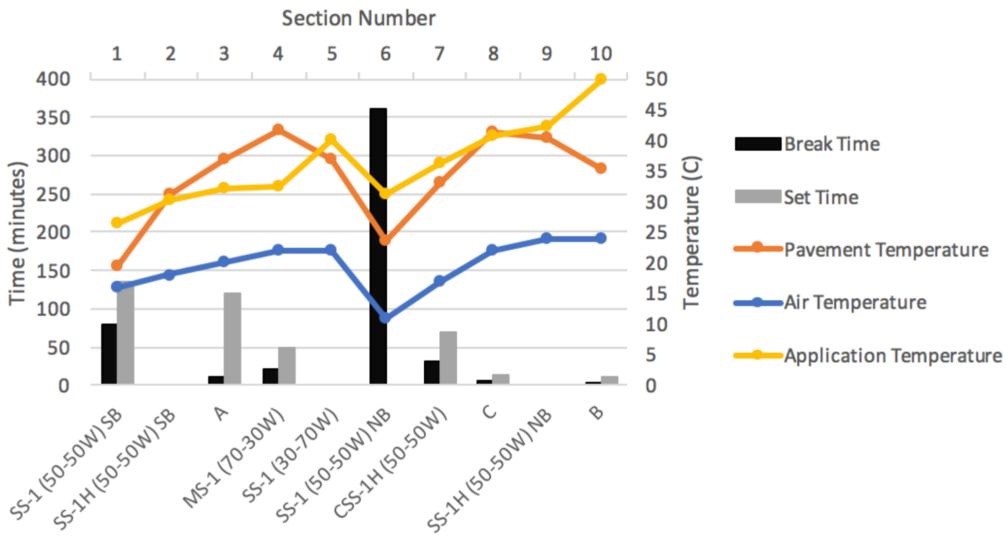

Figure 11. Plot of Break and Set Times with Temperature

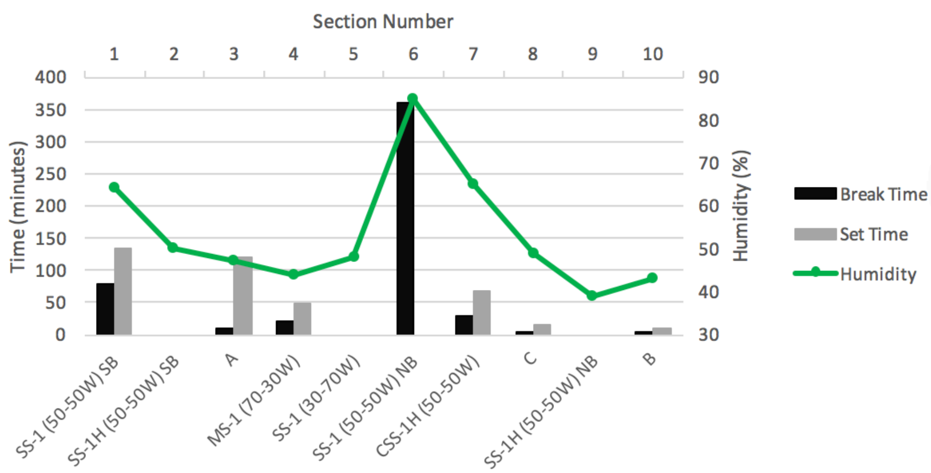

Figure 12. Plot of Break and Set Times with Humidity

6. SUMMARY & FINDINGS

This research project is comprised of a field study and laboratory testing program. The field study examined the performance and contractibility parameters for seven products: SS-1, SS-1h, CSS-1h, MS-1, and three supplier proprietary tack coat products. The seven products were installed in ten test sections. A post-construction distress survey was conducted one month after construction completion and indicated no deficiencies due to construction. At the same time as the post-construction distress survey, cores were collected from each of the ten test sections to measure the initial bond strength of the tack coat materials. Monitoring of the field test sections will continue until 2021.

The field cores will be tested in the laboratory for bond strength of tack coat materials (interlayer shear strength) according to AASHTO TP 114: Determining the Interlayer Shear Strength (ISS) of Asphalt Pavement Layers. Part of the post-construction cores will be subjected to accelerated conditioning in the laboratory under freeze thaw cycling prior to bond strength testing.

Early results show reduced tracking for proprietary products which have faster breaking and setting times than slow setting tack coat materials. The slow setting emulsions CSS-1h and MS-1 broke and set faster than SS-1. These early results indicate that using any of the tested products instead of SS-1 may be beneficial. Supplier proprietary products were the fastest to break and set and proved superior in tracking and pick-up performance. Bond strength testing and long-term resistance to freeze-thaw cycling will confirm if these materials are superior in their performance as well. Finally, the data recorded during construction of the test sections shows that break and set times are correlated to air temperature, pavement temperature, application temperature, and humidity.

7. ACKNOWLEDGEMENTS

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