NCAT Report 20-06

METHODS FOR ADDRESSING TACK TRACKING

LITERATURE REVIEW

Jim Musselman
Raquel Moraes
Travis Walbeck
Randy C. West

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National Center for Asphalt Technology
NCAT
at AUBURN UNIVERSITY

277 Technology Parkway ■ Auburn, AL 36830

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By

James A. Musselman, P.E.
Senior Research Engineer

Raquel Moraes, Ph.D.
Assistant Research Professor

Travis Walbeck, P.E.
Training Manager

Randy West, Ph.D.
NCAT Director, Senior Research Engineer

National Center for Asphalt Technology

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DISCLAIMER

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1 INTRODUCTION

1.1 Background

Long-term performance of asphalt pavements is fundamentally related to the bond developed between the pavement layers, as they are designed to behave as a single pavement layer in order to withstand traffic and environmental stresses. Asphalt pavements typically consist of multiple layers, and the bond strength of the interface between these layers is key to ensuring that that the pavement will act as a monolithic structure and not experience distress. When pavement layers are not properly bonded, the layers exhibit independence, resulting in an alteration to the stress distribution profile. Consequently, tack coats play a critical role in the overall performance of asphalt pavements. Distresses related to poor bonding typically occur in the form of delamination (Figure 1a), which can lead to both slippage cracking (Figure 1b) as well as fatigue cracking (Willis and Timm, 2006).


(a) (b)

Figure 1. (a) Delamination and (b) Slippage Cracking

Over the past several years, a renewed emphasis has been placed on tack coats and the corresponding interface bond strengths. Accordingly, there have been a number of research efforts on tack coats that have focused on a variety of areas such as the importance of tack coats, various types of materials used, application rates, equipment utilization, bond strength measurements, and construction best practices. In spite of these efforts, one aspect that has not been adequately addressed is in the area of tracking. Tack coat tracking occurs when the tack material sticks to the tires (or tracks) of vehicles driven over the tack material. This material is then removed from the pavement surface and is deposited inadvertently upon another pavement surface, either on the same project or elsewhere.

A survey conducted as part of NCHRP Project 09-40 (Mohammad et al., 2012) showed that 67% of respondents viewed pickup of tack coat material as a continuing problem. This creates a number of potential complications. First, the tack material is no longer available on the pavement surface and the ensuing bond strength is considerably weaker. Mohammad et al. (2012) suggested that the interface bond strength would be reduced by 50 to 70% when only 50% of the receiving surface was tacked or there was a loss of tack materials by haul truck and paving equipment tracking. A second concern is the potential impact of the tracked material when deposited elsewhere. In addition to creating an aesthetics problem of having unsightly tack material on adjacent roadways and bridges, the build-up of tack at stop bars and intersections can also create pavement friction problems and potential liabilities for the owner and the contractor. Figure 2 shows two examples of tracking.

Figure 2. Examples of Tracking (Decker, 2013)

Recognizing the vital role that tack coats play in achieving optimal structural performance of asphalt pavements, a number of agencies have refined their specifications to better define the materials and application steps that are required to achieve desired tack coats. Some require reduced-tracking tack materials, others develop specifications on break and cure times for emulsified asphalts, while others require the use of spray pavers for their paving projects. Unfortunately, these types of prescriptive method specifications make innovation by the contractor and advancements of new technologies exceptionally difficult. In addition, these method specifications are often not up-to-date with the latest technology advancements and best practices, which leads to continuing concerns regarding poor tack coats and interlayer bonding issues. Gierhart and Johnson (2018) reported that almost 60% of the respondents to a tack survey in the United States and Canada indicated that tracking continues to be a problem.

There are, in general, two types of tracking that can occur on a paving project. The first, and most common, is tracking that results from construction vehicles driving over the unbroken and/or uncured asphalt emulsion. The second type of tracking occurs after the asphalt emulsion has fully cured and the residual binder sticks to the tires of construction vehicles driving over it. According to the Gierhart and Johnson survey, the most common method to prevent the first type of tracking is to allow the tack coat to properly break and cure prior to driving or paving over it. To mitigate the second type of tracking, the two most common methods are to use reduced-tracking emulsions (which use a harder residual binder) or to use spray pavers.

Another potential approach for decreasing tracking involves the use of specially designed additives that accelerate the setting of the emulsion. These types of modifications can decrease the time it takes for the emulsion to break and cure, and also tend to improve the spray quality of the material with an increase in bond strength. An example of one such additive is NanoTac, which is derived from organosilane nanotechnology, and is designed to improve the water resistance and bonding of the tack coat interface (Taylor and Willis, 2011). Hot applied asphalt binders have also been used to successfully mitigate tracking in a number of states, as have specially designed additives that are used in hot-applied tack coat applications where the additive (e.g., wax) is added directly to a PG graded asphalt binder, reducing the viscosity of the base binder, and allowing the material to be applied at lower than traditional hot-applied temperatures. DOT-C-10 and DOT-C-LT are two examples of this technology.

1.2 Research Objectives

The objective of this research study is to develop an addendum to NAPA's QIP-128 publication titled "Best Practices for Emulsion Tack Coats" that will address the tracking of tack coats. The addendum will identify and report on the latest technologies, methods, and/or practices that can be employed to address tracking of tack coat materials. In addition, the project will provide guidance for owner agencies on how to appropriately specify tack materials to best ensure that the paving industry can address possible tracking of tack coats without the restrictions of method specifications, which will allow for innovation and use of the best technologies and/or practices for a project.

1.3 Report Objective and Organization

The objective of this report is to summarize the findings from a comprehensive literature review, assessing the factors affecting tack coat performance with respect to tracking and bond strength based on current practices on a national level.

2 TACK COAT MATERIALS AND SPECIFICATIONS

2.1 Background

One of the keys to ensuring that a tack coat provides a satisfactory bond between asphalt pavement layers is to make sure the proper materials are used. Historically, three broad classifications of bituminous materials have been effectively used as tack coats: straight run or polymer/additive modified straight run asphalt binders (often referred to as "hot-applied" tack), cutback asphalts, and emulsified asphalts. However, cutback asphalts (i.e., asphalts dissolved in solvents such as kerosene or diesel) are no longer commonly used for tack coat applications primarily due to environmental concerns (Mohammad et al., 2012) and will not be addressed in this report.

2.2 Materials Most Commonly Used for Tack Coats

Currently, emulsified asphalt comprises the vast majority of the tack material used worldwide. NCHRP Synthesis 516 *Tack Coat Specifications, Materials and Construction Practices* (Gierhart and Johnson, 2018) conducted a detailed survey of AASHTO Subcommittee on Materials members to determine current agency specifications, materials, and practices. Results indicated that approximately 79% of agencies use emulsions for their tack coat materials with

20% using reduced-tracking materials and less than 1% regularly using straight asphalt binders. A breakdown of the survey findings is shown in Figure 3 and Table 1.

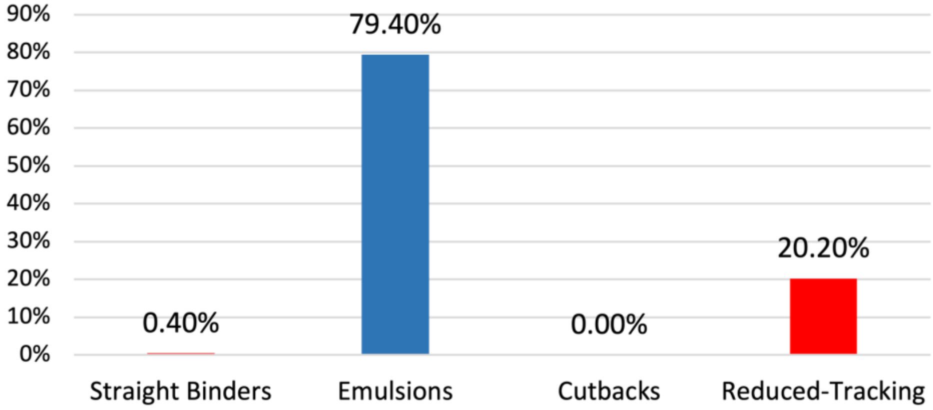


Figure 3. Percentage of Tack Coat Materials Used in U.S. (Gierhart and Johnson, 2018)

Table 1. Weighted Average use of Various Tack Coat Materials in U.S. and Canada (Gierhart and Johnson, 2018)

PG Binder	Weighted %	Emulsified Asphalt	Weighted %	Reduced-Tracking Material	Weighted %
PG 64-22	0.20	CSS-1h	18.40	RS-1h	11.10
PG 58-22	0.00	SS-1h	17.50	NTSS-1HM	5.30
PG 58-28	NR	RS-1	13.40	AE-NT	2.10
PG 64-28	0.00	Non-Standard	9.50	NTQS-1HH	1.00
PG 67-22	NR	CSS-1	8.40	Ultrafuse	0.50
		SS-1	5.80	CBC-iHT	0.40
		CQS-1h	2.10	NTCRS-1HM	0.40
		CRS-1	1.60	NTSS	0.40
		CRS-2	1.20	EM-50-TT	0.20
		CRS-2p	0.10	PATT	0.20
		HFMS-1	NR	CBC-1H	0.10
		HFMS-2h	NR	Cleanbond	NR
		MS-2	NR	CNTTC	NR
				CRS-1h	NR
				NTCQS-1HM	NR
				NTCRS-1HSP	NR
				NTHAP	NR
				PennDOT NT	NR

*NR signifies that at least one agency reported using the material but did not report a percentage used.

A worldwide survey on tack coat practices was conducted by Mohammad et al. (2012) in NCHRP project 09-40, showing that 100% of the responding agencies permit the use of emulsions while the percentages of respondents that permit the use of asphalt cement and cutback asphalts are 27% and 20%, respectively. The most commonly used emulsions were slow-setting grades: SS-1 (41%), SS-1h (39%), CSS-1 (37%), and CSS-1h (41%). PG 64-22 (11%) was the most commonly used hot applied asphalt binder.

2.3 Current Agency Specification Requirements

In order to determine current agency practices with respect to tack coat materials, an on-line review was conducted of existing agency specification requirements. A summary of allowable tack coat materials by state can be found in Appendix 1, while a summary of best agency specifications and practices can be found in Appendix 2.

2.4 Asphalt Emulsions

2.4.1 Emulsion Fundamentals

Asphalt emulsion is a liquid asphalt binder emulsified in water. It is a combination of three basic components: asphalt, water, and an emulsifying agent. During production, these components are introduced into a colloid mill, which shears the asphalt into tiny droplets. The emulsifier, which is a surface-active agent (surfactant), keeps the asphalt droplets in a stable suspension (Asphalt Institute, 2008; James, 2006).

Asphalt emulsions are identified by numbers and letters related to particle charge (prefix), set rate (prefix), viscosity of the liquid emulsion (suffix), hardness of the base asphalt binder (suffix), and/or the presence of polymer modification. The first designation for asphalt emulsion classification is based on the electronic charge surrounding the asphalt binder particles. The particle charges help to keep the asphalt particles in suspension and prevents them from coalescing. Cationic (positively charged) emulsions are identified with a “C”. If the C is not included, the emulsion is normally anionic (negatively charged). There are a few nonionic emulsions, and these emulsions have gained commercial significance over the past 10 years. The majority of asphalt emulsions are either anionic or cationic (Asphalt Institute, 2008; James, 2006).

After the charge designation, emulsions are further classified on the basis of how quickly the asphalt droplets will coalesce (i.e., revert to asphalt binder). The term “set” is closely related to how soon an emulsion will “break” (i.e., how long will it take so that the emulsion reverts to a continuous asphalt phase). These categories are rapid set (RS), medium set (MS), slow set (SS), and quick set (QS) (Decker, 2013). The numbers following the letter classification indicate the relative viscosity of the emulsion. For example, a CRS-2 emulsion is more viscous than a CRS-1 emulsion. The addition of “P” in the emulsion classification indicates polymer has been added to the emulsion. “L” means a latex polymer has been used. In certain grades, an “h” follows the number, indicating that a harder base binder was used in the formulation of the emulsion (Gierhart and Johnson, 2018). An “HF” that precedes the setting time designation indicates a High Float emulsion. HF emulsions are designed so the emulsifier forms a gel structure in the asphalt residue. The thicker asphalt film allows these emulsions to perform in a wider temperature range. High Float emulsions are typically used in chip seals, cold mixes, and road mixes (Asphalt Institute, 2008; James, 2006).

2.4.2 Breaking and Curing

An emulsified asphalt must revert to a continuous asphalt film in order to perform as an asphalt binder, and this process involves flocculation (setting) and coalescence (curing) of the emulsion droplets and removal of the water (James, 2006).

As can be seen in Figure 4, an asphalt emulsion has a brown appearance during storage and after application on the pavement surface, indicating that the microscopic-sized asphalt particles are still suspended in water (Mohammad et al., 2012). After the asphalt emulsion is applied onto the pavement surface, the emulsion begins to "break", and its color changes from brown to black. The breaking process indicates that the asphalt particles have now separated from the water, and two distinct phases now exist – asphalt and water. When all of the water has evaporated, the emulsion has "cured". Curing involves the development of the mechanical properties of the asphalt. For this to happen, the water must completely evaporate and the asphalt emulsion particles have to coalesce and bond to the intended surface. The curing process is complete when the water particles present in the emulsion are removed by evaporation and absorption and all that remains on the pavement surface is the asphalt binder.

Figure 4. Broken and Unbroken Tack Coverage Over an Un-Milled Pavement Surface (Washington State DOT, 2003)

Many factors can affect the breaking and curing times of an asphalt emulsion, such as ambient air temperature, relative humidity, wind speed, pavement surface temperature, application rate of the tack coat emulsion, dilution rate of the asphalt emulsion, and type of emulsifying agent used (Mohammad et al., 2012). A survey in NCHRP Report 712 indicated that ambient temperature and pavement temperature were the most important factors affecting the break and cure times of an emulsified asphalt (Mohammad et al., 2012).

2.4.3 Conventional and Standard Asphalt Emulsions

A more recent survey conducted as part of NCHRP Synthesis 516 among U.S. state and Canadian agencies revealed that the percentage of agencies using non-standard asphalt emulsions (such as reduced-tracking emulsions) is nearly the same as those using conventional emulsions such as CSS-1h (Gierhart and Johnson, 2018). This is shown graphically in Figure 5 and Table 2. Non-standard asphalt emulsions mean that an agency has come up with its own nomenclature for an emulsion outside of those specified in AASHTO. The asphalt content of the emulsions generally ranged between 50% and 65%.

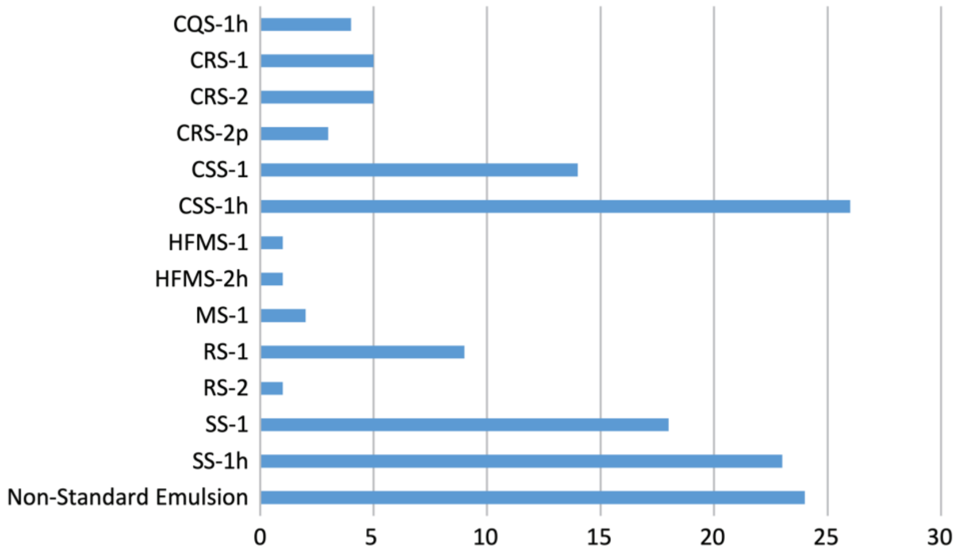


Figure 5. Number of U.S. and Canadian Agencies That Use Emulsions as Tack Coat Material (Gierhart and Johnson, 2018)

Table 2. AASHTO Standard Emulsions used as Tack Coat in the U.S. and Canada (Gierhart and Johnson, 2018)

Anionic Asphalt Emulsion (AASHTO M 140)	Used by Any Agency as Tack Coat?	Cationic Asphalt Emulsion (AASHTO M 208)	Used by Any Agency as Tack Coat?	Polymer Modified Cationic Asphalt Emulsion (AASHTO M 316)	Used by Any Agency as Tack Coat?
RS-1	✓	CRS-1	✓		
RS-2	✓	CRS-2	✓	CRS-2P	
HFRS-1		-		CRS-2L	✓
MS-1	✓	-			
MS-2		CMS-2			
MS-2h		CMS-2h			
HFMS-1	✓				
HFMS-2					
HFMS-2h	✓				
HFMS-2s					
SS-1	✓	CSS-1	✓		
SS-1h	✓	CSS-1h	✓		
QS-1h		CQS-1h	✓		

Some of the advantages emulsions offer is that they can be applied uniformly at temperatures ranging from 70-160°F (20-70°C), which make them safer to use and handle in comparison to hot asphalt binders. They allow greater construction flexibility and there are generally numerous suppliers available in most locations. In addition, most paving contractors are familiar with the handling, storage, and usage of conventional emulsions. Disadvantages include the time it takes for the emulsion to break and cure and the potential for tracking.

Decker (2013) reports that depending on the application rate and dilution, emulsions applied as a tack coat will typically break in 10 to 20 minutes. Complete curing of the emulsion typically requires from 30 minutes to more than 2 hours, depending on the conditions of the application.

Most agencies use AASHTO specification guidelines for acceptance of asphalt emulsions, with the three most commonly used asphalt emulsion specifications as follows:

- AASHTO M 140/ASTM D977, *Standard Specification for Emulsified Asphalt*: Includes only anionic asphalt emulsion grades including high-float chemistries.
- AASHTO M 208/ASTM D2397, *Standard Specification for Cationic Emulsified Asphalt*: Includes only cationic asphalt emulsion grades.
- AASHTO M 316**,** *Standard Specification for Polymer-Modified Emulsified Asphalt*: Includes both anionic and cationic chemistry.

2.4.4 Reduced-Tracking Asphalt Emulsions

Non-tracking (or reduced-tracking) tack materials are designed to improve pavement performance by minimizing the tracking problems associated with traditional tack coat materials. Reduced-tracking emulsions can still track, as they still require at least some time to break and cure, even though the time is reduced as compared to traditional emulsions. When a hot lift of asphalt mixture is subsequently placed over the tack, the harder tack residue is reactivated by the heat and bonds the new overlay with the existing surface.

Reduced-tracking emulsions are typically formulated with stiffer base binders and/or some type of chemical modification that leaves a less-tacky finish at ambient temperatures for reduced-tracking while still achieving good bond strengths when reactivated at overlay temperatures (Gierhart and Johnson, 2018). A significant variety of proprietary emulsions or additives are available and marketed as “trackless” or reduced-tracking. Although there has been no official standardization of the nomenclature for the non-tracking products to date, many state specifications are using “NT” or “TT” to designate a non-tracking material (Mohammad et al., 2012). Some polymer-modified asphalt emulsions have been developed that incorporate a hard base asphalt as part of the emulsion. This harder base asphalt, combined with the polymer additive, reduces the amount of tracking that may occur on the tires of the haul trucks as well as the tire or tracks of the asphalt paver. The application rate for reduced-tracking emulsions is similar to that of a normal, undiluted asphalt emulsion (Decker, 2013). Approximately 20% of state DOTs use some amount of reduced-tracking materials. Figure 6 shows the reduced-tracking emulsions used by agencies for tack coat (Gierhart and Johnson, 2018).

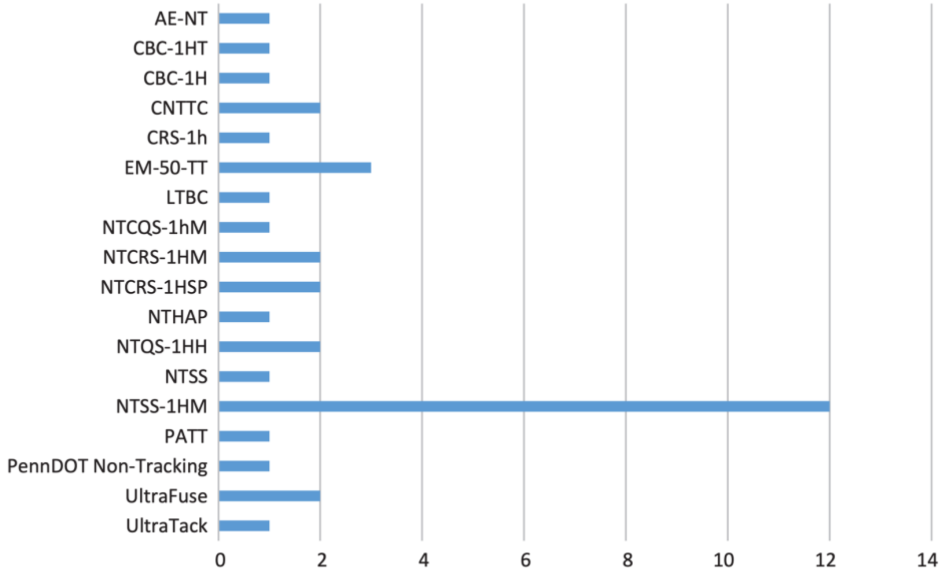


Figure 6. Number of US and Canadian Agencies That Use Reduced-Tracking Emulsions as Tack Coat Material (Gierhart and Johnson, 2018)

The obvious advantage of reduced-tracking materials is that there is less tracking on the project, ensuring there is adequate tack to provide a good bond between pavement layers. Other advantages include quicker break and cure times, thereby speeding up the time of construction (Chen et al., 2012). A summary of states that currently use non-tracking materials can be found in Figure 7.

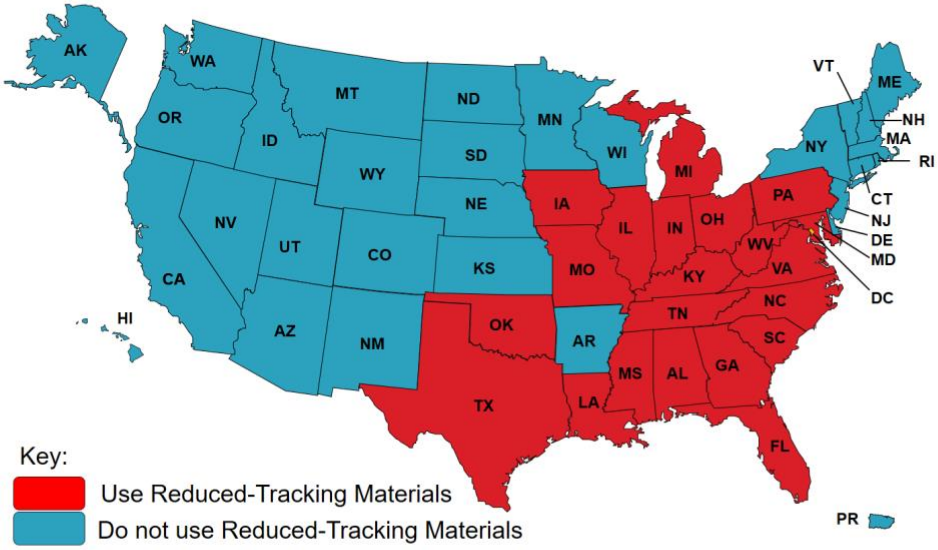


Figure 7. Map Showing Usage of Reduced-Tracking Materials

Reduced-tracking materials do not currently have an AASHTO specification and are typically developed by each individual state with input from the supplier. However, an ongoing NCHRP project (Project 09-64 Developing Laboratory Methods and Specifications to Test Tack Coat

Materials) should address a number of issues related to developing reduced-tracking specifications.

2.5 Asphalt Binders

Straight asphalt binders, typically paving grade, are sometimes used as tack in North America. Gierhart and Johnson (2018) found that eight states currently allow the use of asphalt binder for tack. The types of asphalt binders permitted range from PG 67-22 down to a PG 58-28 and are shown in Figure 8.

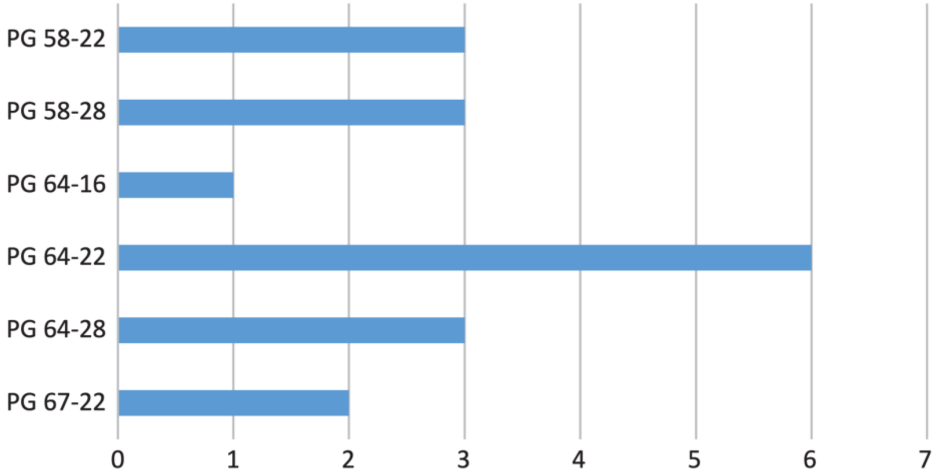


Figure 8. Number of U.S. and Canadian Agencies That Use PG Binders as Tack Coat Material (Gierhart and Johnson, 2018)

There are a number of noteworthy advantages to using a straight asphalt binder for tack. Once applied to the underlying pavement surface, the material cools to ambient temperatures very quickly, minimizing the potential for any tracking. Since there is no water to evaporate, paving operations can begin almost immediately, greatly speeding up the time of construction, particularly when paving at night or in cooler, more humid weather (U.S. Army Corps of Engineers, 2000). Another advantage is that if a standard paving grade asphalt binder is used, there is one less material for a contractor to have to purchase, store, and handle. Costs are another advantage of straight asphalt binder as on a per gallon basis, asphalt binder is less costly than an asphalt emulsion. In addition, application rates are typically 40% lower than those for emulsions, since there is no water to figure in when determining the amount of residue.

The disadvantages of using asphalt binders are primarily related to safety, as the binder must be heated to higher temperatures in order for the material to be applied uniformly with a distributor. This creates a potential safety concern with spraying a high-temperature (>350°F or 175°C) asphalt binder in close proximity to workers as well as the travelling public. It is essential that workers involved with the tacking operation be equipped with the appropriate personal protective equipment (PPE), such as face shields, gauntlet gloves and long sleeves, and also have the appropriate training.

With respect to governing specifications, typically asphalt binders that are used as tack coat materials must meet the requirements of AASHTO M 320 or M 332, depending on the agency.

2.5.1 Hot-Applied Non-Tracking Tack Coat Materials

Although not as common as non-tracking asphalt emulsions, hot-applied reduced-tracking products are becoming more popular. Hot-applied reduced-tracking tack materials typically use a very stiff base asphalt binder or polymer modified binder. Within seconds of application, the tack cools, hardens, and resists tracking under traffic. The advantages of using a hot-applied reduced-tracking product are similar to the advantages of straight asphalt binders and include less tracking, less delays for the paving operation, and lower application rates. Disadvantages include safety due to the higher application temperatures and costs. One hot applied non-tracking additive reduces the viscosity of the material when it is at application temperatures, allowing it to be applied at lower temperatures (approximately 230°F or 110°C).

3 TACK COAT CONSTRUCTION PRACTICES

In order to construct a durable, long-lasting asphalt pavement, it is critical to apply the proper type and rate of tack coat between pavement layers. According to Decker (2013), the key factors in ensuring a successful tack coat application include condition of the existing pavement, application rate, residual binder content, proper distribution operation, and emulsion break and cure times.

3.1 Evaluation of Existing Pavement Condition

The tack coat application rate will vary depending on the existing pavement surface. In order to properly determine the appropriate application rate, the following pavement surface characteristics must be considered: cleanliness, age, texture, milled, bleeding, and pavement type.

3.1.1 Cleanliness of Underlying Pavement

Prior to applying the tack coat material, it is essential that the underlying pavement surface be free of any substance that might inhibit a good bond. Surfaces that are dirty or dusty can result in the tack coat material sticking to the dust or dirt and not to the underlying pavement. This can easily result in tracking as well as having an overlay that will be prone to slipping and delamination (Texas Department of Transportation, 2001).

Results presented in NCHRP Report 712 indicated a statistically significant difference between clean and dusty conditions when evaluating bond strengths (Mohammad et al., 2012). Properly cleaning and sweeping the existing pavement surface is essential to avoid the negative effects of dusty conditions. The existing pavement can be cleaned either through mechanical brooming, by flushing the surface with water, or blowing off debris using high-pressure air (Mohammad et al., 2012). Allowing high-speed traffic on the underlying surface (if feasible) is another method of assuring that the surface is adequately cleaned.

3.1.2 Pavement Age

Pavement surfaces of different ages (i.e., different exposure to oxidative aging) may require different tack coat application rates to develop proper bonding between the existing layer and overlay. An aged, oxidized asphalt pavement surface will normally absorb a significant amount of the applied tack coat emulsion. Hence, the residual tack coat rate should be increased in order to have enough tack coat material remaining on the pavement surface to create an adequate bond between the old and new pavement layers. A new asphalt pavement surface, however, will typically not absorb a significant amount of asphalt emulsion and the residual application rate should therefore be reduced to compensate for reduced absorption.

3.1.3 Pavement Surface Texture

Pavement surface texture has a significant effect on the required residual tack coat application rate. A lower surface texture requires less residual tack coat than a higher surface texture. This is due to the lesser amount of exposed surface area. On the other hand, both raveled and aged pavement surfaces require an increase of the residual tack coat application in order to account for the rougher surface texture.

3.1.4 Milled Asphalt Surface

A study performed in Virginia showed that the rough surface texture of a clean milled surface may be sufficient to provide the required bond between the old pavement and the new overlay, avoiding the necessity of applying a tack coat material (McGhee and Clark, 2009). However, NCHRP Report 712 indicates that the bond generated between a milled surface and a new asphalt pavement with no tack coat is not sufficient to provide an adequate level of shear strength. The authors suggest that the residual tack coat rate should be reduced to prevent the emulsion from collecting in the striations when a tack coat is being applied to a milled asphalt surface (Mohammad et al., 2012).

3.1.5 Bleeding Surface

The tack coat application rate must be reduced when the application occurs on a pavement surface that is flushed or bleeding in order to account for the amount of asphalt material already on the pavement surface. Furthermore, if milling off the bleeding area is not an option, the tack coat application rate may have to be adjusted for differing pavement surface conditions transversely across a traffic lane. For example, less tack coat may be needed in the wheel paths of a pavement surface that is bleeding compared to the amount of tack coat needed between the wheel paths and along the outside edges of the lane. However, in the majority of cases when overlaying an existing asphalt pavement that is bleeding, the proper solution to the problem is to mill off the bleeding surface (Decker, 2013).

3.1.6 Portland Cement Concrete Pavement Surface

If the PCC surface has been diamond ground, an increase in the tack coat residual rate may be necessary due to the increased texture of the diamond-ground surface; however, it is essential that the dusty residue from the grinding process be completely removed prior to tacking. If the PCC surface has been milled, an increase in the tack coat residual rate may also be necessary for better bonding and performance of the overlay. In general, no increase in the residual tack coat rate is required to account for the joints or cracks in the PCC surface (Mohammad et al., 2012). It is important to highlight that allowing traffic to travel over diamond ground and milled pavements has been found to be very effective in helping to remove the fine dust left behind by those processes.

3.1.7 Surface Moisture Content

The Federal Highway Administration tech brief on tack coat practices states that the goal of pavement surface preparation before tack coat application is to produce a clean and dry surface (FHWA, 2016). On the other hand, NAPA publication QIP 128: Best Practices for Emulsion Tack Coats indicates that a small amount of moisture on the pavement surface should not be detrimental to long-term tack coat performance, although a damp pavement will slow the break and cure time of the tack coat emulsion (Decker, 2013). According to NCHRP Report 712 the pavement surface should be clean and dry before the tack coat application to avoid the negative effects of water on the bonding at the interface (Mohammad et al., 2012).

3.2 Tack Coat Application Rate

Pavement surfaces with different physical conditions (e.g., new, old, or milled) require different tack application rates to achieve a proper interface bond. Furthermore, the proper application rate also varies with the type of tack coat material being applied. The objective is to apply a sufficient quantity of tack coat, resulting in a thin, uniform coating of asphalt covering the entire pavement surface.

Excessive tack coat is detrimental since it can act as a lubricant, creating a slippage plane between the pavement layers (Flexible Pavements of Ohio, 2001). Additionally, the application of excessive material can cause it to be drawn into the overlay, negatively affecting mix properties and creating potential for bleeding in thin overlays. On the other hand, failure to use tack coat or insufficient tack coat can also cause pavement slippage and debonding problems (Texas Department of Transportation, 2001). Therefore, it is important to accurately estimate the amount of tack coat that will produce the optimum outcome.

3.2.1 Application Rate vs. Residual Asphalt Binder

Tack coat residual rate is the amount of asphalt binder remaining after the water has evaporated from the emulsion, while tack coat application rate is the total amount of liquid asphalt sprayed by the distributor (California Department of Transportation, 2009). The Hot-Mix Asphalt Paving Handbook 2000 recommends that application rates should be based on residual asphalt content (U.S. Army Corps of Engineers, 2000); this is intuitive since different tack coat materials contain differing amounts of residual asphalt binder. Calculation of the residual asphalt application rate is based on the percentage of liquid asphalt in the emulsion (the value provided by the emulsion supplier) and knowing the desired residual application rate.

NCHRP Report 712 indicates that it is very important to realize that the tack coat application rate must be determined by starting at the desired residual application rate for the type of asphalt material being used for tack and then work backwards to calculate the actual application rate (Mohammad et al., 2012). Table 3 presents a summary of the range of residual asphalt binder application rates for various pavement surface types with and without dilution, which is discussed in the next section. It is important to mention that many agencies have their own requirements for tack coat application rates apart from any general recommendations made in national publications. It is also important to note that in many instances, the bar rate will be dependent of the emulsion type and base asphalt in the emulsion. After a tack coat has been applied, the actual application rate should be verified by some method. According to a survey reported in NCHRP Synthesis 516 (Gierhart and Johnson, 2018), 20% of U.S. agencies and almost 30% of Canadian agencies do not verify tack coat application rates; most of the agencies that do use either a volume or mass applied calculation.

Table 3. Recommended Residual Asphalt, Undiluted and Diluted Emulsion Application Rates from Several Research Studies (Gierhart and Johnson, 2018)

FHWA Tech Brief (FHWA, 2016)			
Surface Type	**Residual Rate (g/sy)**	**Approximate Bar Rate Undiluted (g/sy)**	**Approximate Bar Rate Diluted 1:1 (g/sy)**
New Asphalt	0.02 – 0.05	0.03 – 0.07	0.06 – 0.14
Existing Asphalt	0.04 – 0.07	0.06 – 0.11	0.12 – 0.22
Milled Surface	0.04 – 0.08	0.06 – 0.12	0.12 – 0.24
PCC	0.03 – 0.05	0.05 – 0.08	0.10 – 0.16
NCHRP Report 712 (Mohammad et al., 2012)			
Surface Type	**Residual Application Rate (g/sy)**	**Approximate Bar Rate Undiluted* (g/sy)**	**Approximate Bar Rate Diluted 1:1* (g/sy)**
New Asphalt Mixture	0.035	*0.058*	*0.12*
Old Asphalt Mixture	0.055	*0.09*	*0.18*
Milled Asphalt Mixture	0.055	*0.09*	*0.18*
PCC	0.045	*0.08*	*0.15*
*NCHRP Report 712, Table 31, includes residual application rates only. Values in italics were supplied using an example emulsion with 60% residual asphalt binder for comparison purposes only.			
NAPA QIP 128: Best Practices for Emulsion Tack Coats (Decker, 2013)			
Existing Condition	**Residual Asphalt Binder (g/sy)**	**Applied Undiluted Emulsion (g/sy)**	**Applied Diluted Emulsion (g/sy)**
Dusty or Dirty	Clean the surface	Clean the surface	Clean the surface
New Asphalt	0.03 – 0.04	0.04 – 0.06	0.09 – 0.12
Old, Aged Asphalt	0.04 – 0.06	0.06 – 0.09	0.12 – 0.18
Milled Asphalt	0.03 – 0.05	0.04 – 0.07	0.09 – 0.15
PCC	0.04 – 0.06	0.06 – 0.09	0.12 – 0.18

3.2.2 Dilution of Emulsions

Diluting asphalt emulsions for tack coat is a common practice throughout both the United States and Canada and refers to adding a predetermined quantity of water to a known quantity of emulsion to allow for a greater volume of tack coat. The most common dilution rate is 1:1 (one-part undiluted emulsion and one-part additional water) (Gierhart and Johnson, 2018).

The prevailing justification for diluting the emulsion is to achieve a more uniform tack coat coverage on the pavement given the relatively low application rate and taking into account reasonable (safe) distributor speeds on the job. The primary drawbacks to dilution are: (1) the emulsion takes longer to break and cure, which can potentially lead to more tracking, and (2) controlling the rate of dilution impacts the residual application rate and can affect performance. For these two main reasons, the Asphalt Institute and FHWA Tack Coat Workshop (2014) recommended that emulsions used for tack coat should not be diluted. Modern distributor trucks are capable of applying a uniform tack coat without dilution. Furthermore, when diluting an emulsion, careful control is needed to properly account for the water added so that the residual application rate can be calculated. Based on these concerns, field dilution is not recommended. Moreover, only slow-setting emulsions are typically diluted. If allowed, dilution of the emulsion should only be performed by the supplier where a greater degree of control can be expected rather than in the field (Federal Highway Administration, 2016).

However, according to the survey reported in NCHRP Synthesis 516, about half (24) of U.S. state agencies allow dilution (Gierhart and Johnson, 2018). The same survey asked the agencies that allowed dilution to report where the dilution process was allowed to be performed, and the result of the survey is presented in Figure 9. Several agencies allow dilution only at the terminal, and others allow dilution at multiple locations. In general, dilution should be done under controlled conditions at the asphalt supplier's terminal.

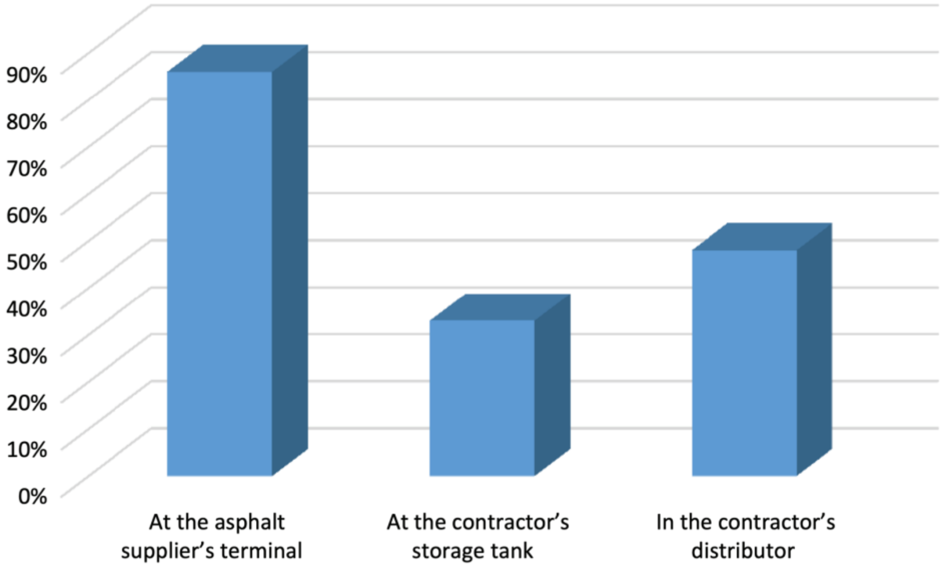
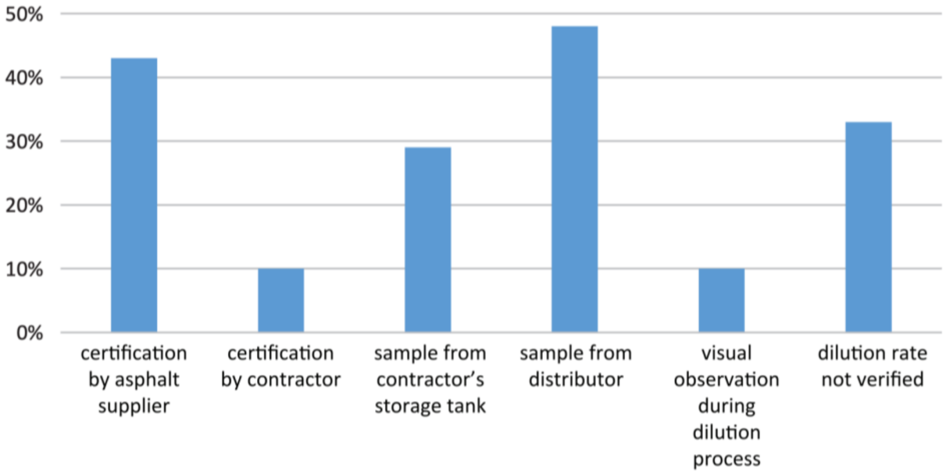
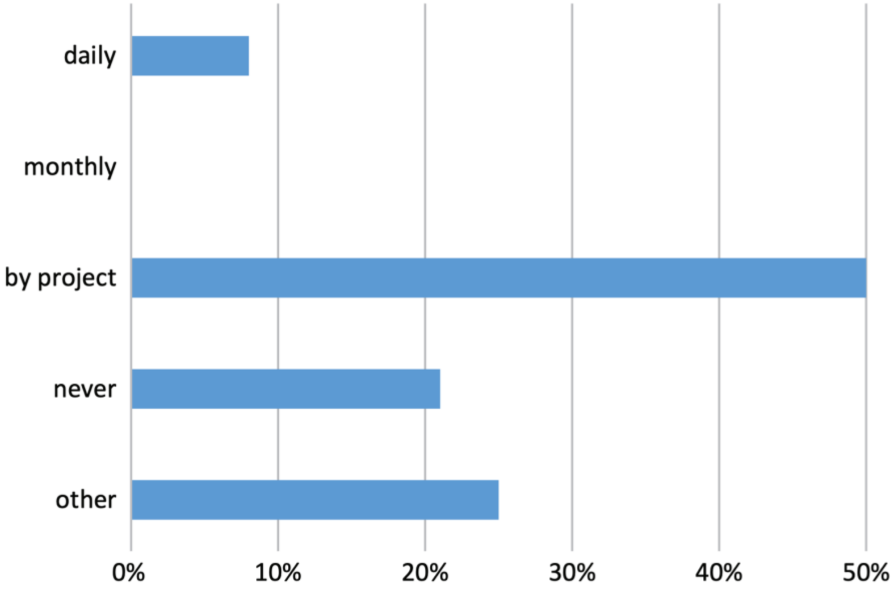


Figure 9. Percentage of U.S. Agencies That Allow Dilution at Given Locations (Gierhart and Johnson, 2018)

If dilution is allowed, it is important that agencies have some method of verifying the dilution rate, since without a verification process it is not possible to be assured that the diluted emulsion has the proper amount of additional water. Figure 10(a) from NCHRP Synthesis 516 shows the breakdown of agency verification methods among the 24 U.S. agencies that allow dilution. The same survey showed that most states simply verify dilution once per project and few states verify by quantity-based frequency, either once every given number of tons or once per tank. Results are presented in Figure 10(b).



(a) Percentage of U.S. Agencies That Specify Given Types of Dilution Verification



(b) How Often Dilution Rate Is Checked (U.S. and Canada Combined)

Figure 10. Tack Coat Specifications, Materials and Construction Practices (Gierhart and Johnson, 2018)

3.3 Tack Coat Breaking and Curing

It is generally recognized that allowing the emulsified asphalt tack coat material to set prior to placing the asphalt overlay will enhance the opportunity for the bond to occur. However, a complete agreement in the literature concerning the necessity of tack coat being completely cured before placing the HMA layer was not found, and certainly the successful use of spray pavers challenges this notion. Spray pavers will be discussed in the next section.

Many publications report that the tack should be either fully cured (Asphalt Institute, 2008; Asphalt Institute, 1989) or cured until tacky (Asphalt Institute, 2003) before placing the new pavement layer. However, NCHRP Report 712 reinforces that a new asphalt layer can usually be placed on top of unset tack coat and even over an unbroken tack coat emulsion with no detrimental effect on pavement performance (Mohammad et al., 2012).

3.3.1 Relative Humidity Effect on Tack Coat Breaking and Curing

Relative humidity is a measure of the current amount of water vapor in the air relative to the total amount of water vapor that can exist in the air at its current temperature and is expressed as a percentage. Relative humidity is also a key factor affecting the breaking and curing times of an asphalt emulsion. When humidity is high, the emulsion is exposed to a greater amount of water vapor. With more moisture in the air, the emulsion curing process takes longer, since the breaking and setting process for asphalt emulsion is at least somewhat dependent on the rate of evaporation of water from the system.

Mohammad et al. (2012) indicated that higher curing temperatures results in faster rates of curing, while higher levels of humidity results in slower rates of curing. For example, night paving can create problems with curing as the pavement temperature slowly drops after sunset and the relative humidity may begin to increase. Bahia et al. (2019) indicated that increasing curing temperature and decreasing humidity increases the curing rate and decreases the overall curing time of emulsions. Moreover, the authors found that the relative effect of humidity is dependent on the curing temperature, with curing at lower temperatures being more sensitive to humidity.

3.3.2 Tracking of Cured Asphalt Emulsions

Results presented in Wisconsin Highway Research Program (WHRP) Project 0092-17-06 *Investigation of Tack Coat Materials on Tracking Performance* indicated that tracking of cured emulsions is dependent on the residual asphalt properties of the emulsion (Bahia et al., 2019). Furthermore, the results indicated that pavement temperature is the most important factor affecting tracking behavior after the asphalt emulsions have cured. Moreover, the residual asphalt properties of emulsions appeared to be good indicators of tracking potential, with increased residue stiffness at a given temperature resulting in less tracking at that temperature. Bahia et al. (2019) further theorized that the tack coat residue would be considered “tracking” if the adhesion between the tire and tack coat is stronger than the cohesion of the tack coat material itself or stronger than the adhesion between the tack coat and the substrate. In other words, the residue from an asphalt emulsion will not track as long as it has the internal strength (cohesion) stronger (higher) than the adhesion to tires, and that the adhesion between the substrate and emulsion is also stronger than the adhesion to the tires. The testing equipment used to measure these conditions will be described in section 4.1.5.

NCHRP Report 712 suggested that the tracking of asphalt emulsions can be divided into two stages: tracking of the wet, uncured (unbroken and unset) emulsion, and pickup and tracking of the emulsion residue after curing (Mohammad et al., 2012). According to the authors, the first stage is mitigated by allowing the emulsion to substantially break and set before allowing traffic on the tacked surface. The second stage of tracking is dependent on the asphalt residue of the emulsion at the prevailing climatic conditions. Nonetheless, similar to the findings in the WHRP 0092-17-06 Project, pavement temperature was also found to be the most important factor affecting the tracking behavior after the emulsions have properly cured, as the higher pavement temperatures tend to soften the residue resulting in increased tracking.

3.4 Tack Coat Application Equipment

Tack coats are applied to the pavement surface using an asphalt distributor. Proper asphalt distributor operational procedures are required to prevent streaking, allow proper application rates, and ensure uniform coverage (Cross and Shrestha, 2005). The fundamentals of distributing tack coat on the pavement surface are relatively simple. A truck equipped with a tank pumps tack material through a spray bar onto the existing pavement (Figure 11). In order to achieve a uniform distribution of tack material across the pavement, the following factors are critical: speed of the distributor in feet per minute (ft/min or FPM), the flow rate from the pump in gallons per minute (gal/min or GPM), the application width in feet, and the nozzle type.

Figure 11. Tack Coat Application (Simpson, 2006)

The correct tack coat application begins with proper application equipment, inspection, and calibration. A trial tack coat application should be periodically placed over a test area to verify correct nozzle operation and configuration, and to ensure that the application of tack is uniform. Further, the distributor application rate needs to be calibrated, both in the transverse and longitudinal directions, using the procedure described in ASTM D 2995 - Standard Practice for Estimating Application Rate of Bituminous Distributors (2014). The distributor should be calibrated annually, as a minimum (FHWA, 2016). According to the survey reported in NCHRP Synthesis 516, it was found that over 50% of U.S. agencies and over 70% of Canadian agencies have no requirement to calibrate asphalt distributors (Gierhart and Johnson, 2018). Some agencies require annual calibration, while some require calibration before every project.

3.4.1 *Emulsion Tack Coat Temperature*

The temperature at which an emulsion is maintained in the distributor tank depends on the grade of the emulsion (Mohammad et al., 2012). Emulsions must be maintained in the distributor tank at the appropriate temperature in order to assure a uniform flow of the material through the nozzles on the spray bar. If the emulsion temperature is too low, the material will come out in strings instead of as a uniform spray. Table 4 presents a summary of guidelines of storage and application temperatures for emulsions.

Table 4. Guideline Temperatures for Tack Coat Emulsions

NAPA QIP 128 Best Practices for Emulsion Tack Coats (Decker, 2013)		
Emulsion Product	**Spraying Temperature**	**Storage Temperature, °F**
RS-1, SS-1h, SS-1h, CRS-1, CSS-1, CSS-1h	21-71°C (70-160°F)	21-60°C (70-140°F)
RS-2, CRS-2	60-85°C (140-185°F)	50-85°C (125-185°F)
Non-Tracking Tack	71-82°C (160-180°F)	49-54°C (120-130°F)
Polymer Modified Emulsion	60-82°C (140-180°F)	49-54°C (120-130°F)
NCHRP Synthesis 516 (Gierhart and Johnson, 2018)		
Grades	**Storage Temperature**	
	Minimum	**Maximum**
QS-1h, CQS-1h	10°C (50°F)	50°C (125°F)
RS-2, CRS-1, CRS-2, HFRS-2, CMS-2, CMS-2h, MS-2, MS-2h, HFMS-2, HFMS-2h	50°C (125°F)	85°C (185°F)
RS-1, SS-1, SS-1h, CSS-1, CSS-1h, MS-1	10°C (50°F)	60°C (140°F)

3.4.2 *Spray Bar*

In order to achieve proper interlayer bonding strength between pavement layers, it is necessary to apply the precise amount of tack coat onto the pavement surface. Several factors can affect tack coat application in the field, such as uniformity of the nozzle spray patterns, nozzle size, spray bar height, pressure of the application, and material temperature. The emulsion is applied to the pavement surface using the nozzles on the spray bar. Asphalt distributor manufacturers use different nozzle sizes and types for different application rates, and the application rate of the asphalt material is directly dependent upon the size of the nozzle. Table 5 provides information on the application rate (not residual rate) for various nozzle sizes for a Rosco distributor. Figure 12 shows nozzle types and sizes used by Etnyre. It should be noted that flow rates for nozzles vary by manufacturer.

Table 5. Guideline Application Rates for Various Nozzle Sizes (Mohammad et al., 2012)

Nozzle Size	**Recommended Flow Rate (GPM)**	**Application Rate (Gal/Sq. Yd.)**
00	1.2	0.03-0.08
0	3.0	0.05-0.20
1	4.0	0.10-0.30
1.5	6.0	0.15-0.40
2	8.5	0.25-0.55
3	13.5	0.35-1.00

Ref.	Part No.	Description	Application Gallons Per Square Yard	Application (Metric) Liters Per Square Meter	US Flow Gallons Per Minute Per Foot
1	3353788	V Slot Tack Nozzle	.05 - .20	.23 - .91	3.0 to 4.5
2	3351008	S36-4 V Slot	.10 - .35	.45 - 1.58	4.0 to 7.5
3	3351009	S36-5 V Slot	.18 - .45	.81 - 2.04	7.0 to 10.0
4	3352368	Multi-Material V Slot	.15 - .40	.68 - 1.81	6.0 to 9.0
5	3351015	3/32" Coin Slot	.15 - .40	.68 - 1.81	6.0 to 9.0
6	3352204	Multi-Material V Slot	.35 - .95	1.58 - 4.30	12.0 to 21.0
7	3352205	Multi-Material V Slot	.20 - .55	.91 - 2.49	7.5 to 12.0
8	3352210	End Nozzle (3352205)	.20 - .55	.91 - 2.49	7.5 to 12.0
9	3351014	3/16" Coin Slot	.35 - .95	1.58 - 4.30	12.0 to 21.0
10	3351010	1/4" Coin Slot	.40 - 1.10	1.81 - 4.98	15.0 to 24.0

Figure 12. Etnyre Spray Bar Nozzles and Associated Application Rate Ranges (Mohammad et al., 2012)

Alignment of the nozzles on the spray bar is also critical in achieving a uniform application of tack coat, and non-uniform application can lead to a lower bond strength. Clogged nozzles can have a significant impact on the uniformity of the tack application and should be checked periodically. Equally important is using the proper size nozzles and the correct spray bar height. There are usually three nozzles per foot of width of the spray bar, with nozzles set four inches apart. The opening angle of each nozzle must be set the same to achieve the proper amount of spray overlap for adjacent nozzles. If all the nozzles are not set at the same angle, the spray pattern from one nozzle will interfere with the spray pattern of the adjacent nozzle(s). This will result in a non-uniform emulsion application with some portions of the surface receiving excessive emulsion and other portions receiving insufficient emulsion (Decker, 2013). To prevent the spray of liquid asphalt from interfering with adjacent spray nozzles, the nozzles should be set at an angle of 15 to 30 degrees to the horizontal axis of the spray bar (Asphalt Institute, 2008). Most nozzles are set at 30 degrees (U.S. Army Corps of Engineers, 2000). Figure 13 shows a spray bar with the nozzles set to an angle of 30 degrees. In some low rate applications, it may be necessary to have two nozzles off per one nozzle on across the spray bar in order to achieve normal spray patterns and pressures. If the distributor does not maintain the proper pressure in the spray bar, the emulsion will simply dribble out of the nozzles.

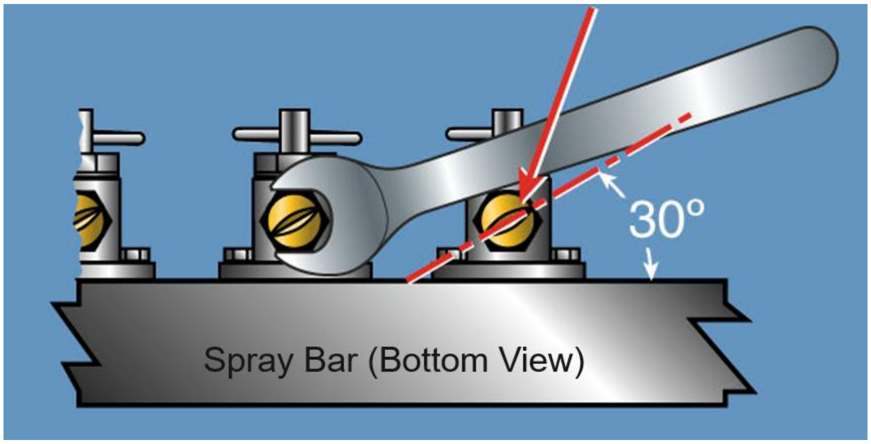


Figure 13. Spray Bar with Nozzles Set to 30 Degree Angle

It is very important to maintain the correct height of the spray bar in relation to the pavement during application of the tack coat in order to achieve consistent coverage. As the emulsion quantity in the distributor tank decreases during application, the weight of the tank decreases and the height of the spray bar will increase. This height, which depends (in part) on distributor type, is typically in the range of 9 to 12 inches (Decker, 2013). The height of the spray bar should be set to allow for an exact single, double, or triple overlap (Figure 14) (Asphalt Institute, 2008). A triple overlap is recommended for most tack applications (FHWA, 2016).

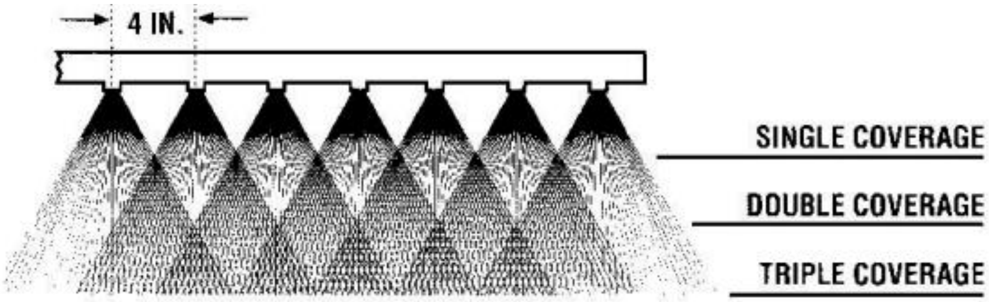


Figure 14. Display of Single, Double, and Triple Overlay Coverage (FHWA, 2016)

As can be seen in Figure 15, an on-going problem with tack coat application using distributor trucks is that haul trucks normally drive on the freshly applied tack coat, thus removing it from the pavement and tracking the tack coat material onto other areas of the roadway. One method of mitigating this problem is the use of spray pavers.

Figure 15. Tracking Problem with Typical Distributor (West et al., 2005)

3.4.3 Spray Pavers

A spray paver is a specialized asphalt paver that can significantly decrease (or eliminate) issues with tack tracking. It is a paver outfitted with heated asphalt storage tanks, a recirculation system and a spray bar, and it functions as both a distributor and an asphalt paver. On a spray paver the tack material (either an emulsion or asphalt binder) is applied to the pavement approximately one foot in front of the auger on the paver, and the paver places the new asphalt mixture directly on top of the freshly sprayed emulsion or asphalt binder in one continuous process (Figure 16). At this point in the paving process the emulsion (if used) is unbroken (not set), which contrasts starkly with the traditional standard practice which dictates that the tack should be fully cured before paving.

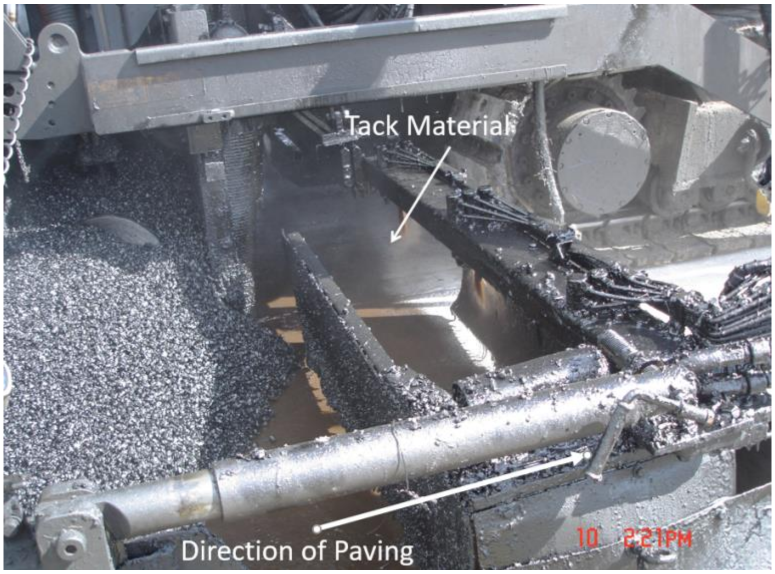


Figure 16. Tack Coat Application Using Spray Paver (Mohammad et al., 2012)

The advantages of the spray paver system for tack coats is primarily that the tack is applied directly in front of the screed. Consequently, it is not exposed to traffic before paving, meaning 100% of the tack sprayed on the underlying pavement is present during paving. Additional benefits of this process include the elimination of tack being tracked onto other pavements, higher bond strengths (potentially due to higher tack rates), and less equipment cleanup after paving. In addition, at least one field study in Illinois reported the cost-effectiveness of applying tack immediately before paving to save on equipment costs and also reduce paving operation times (Salinas et al., 2013).

The effect of paving directly over a freshly placed emulsion on pavement performance has been evaluated in several studies. Spray pavers have been extensively marketed toward the "Ultrathin Bonded Asphalt Surface" rehabilitation process (NovaChip® is a commercial example of this), in which a relatively open or gap-graded mixture is placed on the freshly applied polymer modified emulsion (called the emulsion membrane). The emulsion is sprayed at a rate three to four times heavier than conventional tack at application rates of approximately 0.15 - 0.30 gal/yd^2 residue. It is hypothesized that in this process, the excess tack material 'wicks' up into the gap graded mixture, providing superior interlock and a stress absorbing membrane (Tran et al., 2013; Salinas et al., 2013; Ahmed et al., 2013).

NCHRP Synthesis Report 516 indicates that a number of concerns have been expressed by agencies over the potential for problems associated with paving over an unbroken emulsion when using more densely graded mixtures. As the spray paver is in operation, the hot asphalt mixture is placed directly on the unbroken emulsion and the heat from the mixture drives off the water in the emulsion as steam, which travels through the open voids in the asphalt mixture. There has been concern that either the steam or any residual moisture could affect the bond between the asphalt binder and the aggregate in the mixture. Consequently, there is concern that there could be stripping, layer slippage, bleeding/flushing, and trapped moisture while using more densely graded mixtures. However, these concerns are not supported in the literature. Several states including Kansas and Illinois have had good success with spray paving projects. One study from Illinois reported that mixtures constructed with a spray paver exhibited similar shear strength to those using traditional distributor trucks while using the same materials at similar application rates (Salinas et al., 2013).

According to the Ohio Department of Transportation there are currently two models of spray pavers on the U.S. market: the Vögele SprayJet Paver [Figure 17(a)], and the Roadtec SP-200 Spray Paver [Figure 17(b)] (Wilson et al., 2017). In addition, at least one equipment manufacturer has developed a method of modifying a conventional paver and converting it into a spray paver where the tack material is applied immediately in front of the paver.

(a) (b)

Figure 17. (a) Vögele SprayJet Paver and (b) Roadtec SP-200 Spray Paver

While there are significant advantages related to reducing and eliminating tracking when using a spray paver, there are also several disadvantages. When considering the drawbacks of spray pavers, Wilson et al. (2017) noted the following:

- Initial equipment costs are very high at approximately twice that of a standard paver.
- Frequently refilling the tack reservoir is inconvenient. Spray paver tanks have a capacity of ~500 gal. as compared to a capacity of 1,000 - 4,000 gal. on a distributor truck.
- Difficulty in checking the quality of tack coat during the paving operation includes determining if there is uniform application of the tack across the width of the paver (i.e., clogged nozzles) as well as visually assessing the tack material.
- Concern with inadequate time for emulsion curing, which has potential to create moisture related problems with the mixture.
- Not recommended for use with hard-pen base asphalt tacks.
- Limited equipment models available.

One additional disadvantage is the limitations the spray paver has on operations. The size of the equipment limits the spray paver to only mainline paving, which can be a significant limitation for many contractors, particularly smaller contractors who may only get a mainline project every two or three years.

4 TACK COAT TESTS AND EVALUATIONS

With the renewed emphasis on tack coat materials and pavement layer bonding, a number of new tests have been developed that help to characterize a material's propensity to track. In addition, there have also been a number of tests developed over the past 15 years that evaluate bonding characteristics of tack coat materials.

4.1 Laboratory Tests to Identify Tracking Potential

As a result of the issues associated with tracking, a number of new laboratory tests have been developed that have the potential to better identify a material's potential for tracking. These tests could prove significant as a method for agencies to approve reduced-tracking tack materials in a manner that is quantitative and less subjective.

4.1.1 *Track-Free Time Test*

A modified version of ASTM D 711-15 was proposed in a study performed in Virginia to test the tracking resistance and to determine the no-pick-up time of a tack coat material, as shown in Figure 18 (Clark et al., 2012). A metal cylinder with rubber O-rings is repeatedly rolled down a ramp over a freshly applied tack coat film until there is no transfer of the asphaltic material to the rubber rings. The elapsed time from tack coat film application to the point of no asphaltic material transfer is the no-pick-up time. Key variables to be controlled during testing are film thickness, temperature, humidity, and air flow. To quantify tracking, a visual rating scale was developed where a value of 10 was assigned for full pickup and tracking along the length of the drawdown sample, while a value of 0 was assigned when no pickup or tracking was visible, and a value of 5 was assigned when tracking was present for either one rubber gasket for the entire length of the paper or both gaskets for approximately half the length of the paper.

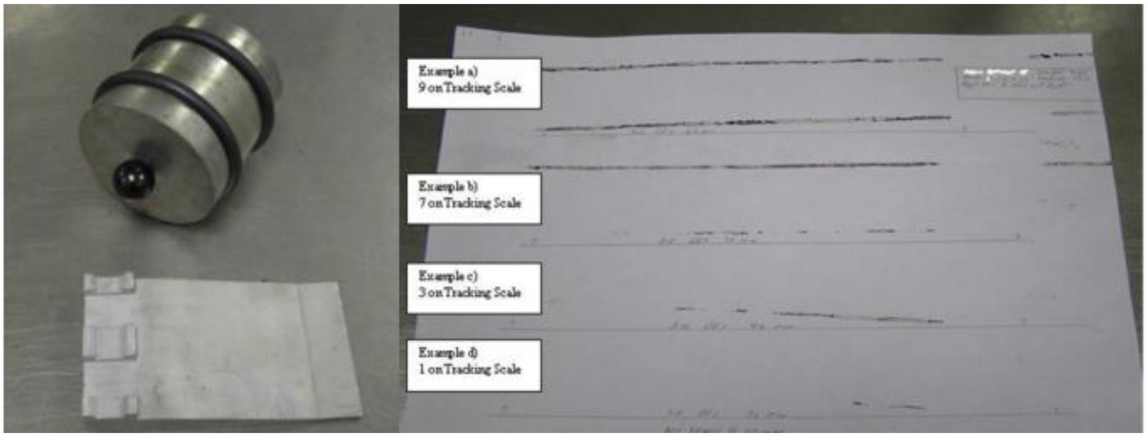


Figure 18. Tack Coat Tracking and Pickup Device Proposed by Clark et al. (2012)

4.1.2 *BASF Roller*

Another modified version of ASTM D 711-15 was proposed by the BASF SE Chemical Company to evaluate the breaking rate of emulsified tack coats, as shown in Figure 19. An asphalt emulsion is drawn to 15 to 30 mils and tested at ambient temperature conditions. The typical breaking results are more than 60 minutes for slow setting tacks, 45 to 60 minutes for medium setting tacks, and less than 30 minutes for reduced-tracking tacks.

Figure 19. BASF Modified ASTM D711 Testing Equipment

4.1.3 DSR Tackiness Test

A method for testing the tackiness of tack coat materials was developed at Akzo Nobel (now Nouryon) and Blacklidge Emulsions. The test consists of loading a sample onto a 25 mm stainless steel bottom plate of the dynamic shear rheometer (DSR), lowering an 8 mm top plate until contacting the sample surface, applying 10.5 N normal force for 30 seconds, and then elevating the top plate at 15 micro millimeters per second up to 600 seconds or until detachment. The normal force is then plotted versus time, and the shape of the plot indicates the material's tackiness properties (Figure 20).

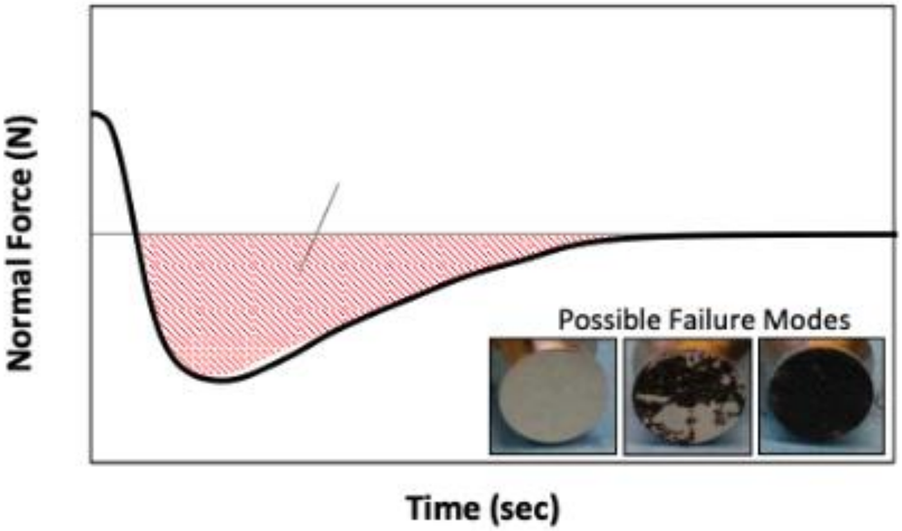


Figure 20. Calculating Tack Energy from DSR Tackiness Test

4.1.4 Binder Bond Strength Test

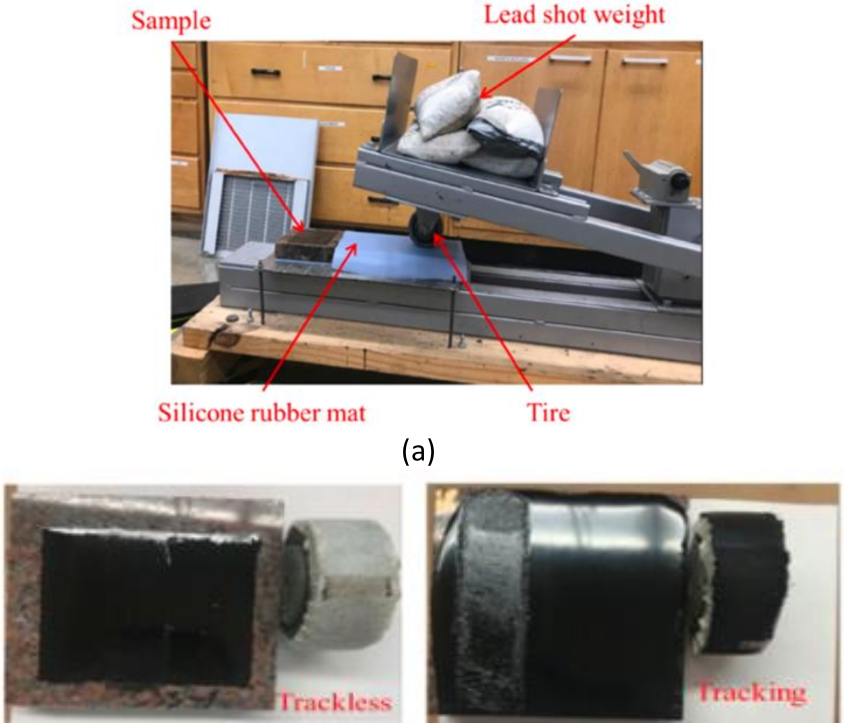
Bahia et al. (2019) modified the binder bond strength (BBS) test to evaluate the tracking of tack coat materials. Figure 21(a) shows the differences in the pull-off stub geometry between the original AASHTO T 361 procedure and the suggested modifications. To apply pressure to the pull-off stub, an ISSA TB139 cohesion test device [Figure21(b)] was used to apply uniform pressure to the stub onto a substrate made of frosted glass. The piston was calibrated during this study to apply 100 psi of pressure, as recommended in AASHTO T 361. The tracking potential is determined based on the pull-off tensile strength (POTS) and visual inspection of the failure type. If no cohesive failure happens (i.e., no residue of tack coat is found on the pull-off stub and on the substrate in the same areas), the tack coat is reported as reduced-tracking. By contrast, if cohesive failure occurs, the tack coat is considered to be tracking.

(a) (b)

Figure 21. (a) Stubs Used in AASHTO T 361 and Modified Test, (b) ISSA TB139 Cohesion Test Device (Bahia et al., 2019)

4.1.5 Loaded Wheel Tracking Test (Modified ASTM D 6372-15)

Bahia et al. (2019) modified the test device used in ASTM D 6372-15 to better simulate the tracking of tack coat materials by a moving wheel in the field, as shown in Figure 22. Before testing, the wheel is wrapped with a rubberized tape to facilitate easier cleaning and provide a uniform surface between tests (a new tape is used for each test). After conditioning, a tack coat sample is tested for 10 loading cycles. The tracking potential is then evaluated by visual inspection of the surface of the sample and the rubberized tape.



(a)

(b)

Figure 22. (a) Loaded Wheel Tracking Test Setup, (b) Results for Trackless and Tracking Tack Coat Materials (Bahia et al., 2019)

4.2 Test Methods for Evaluation of Interlayer Bond Strength

Numerous studies have evaluated interlayer bonding using different failure-mode performance tests including direct shear, pull-off, and torsion tests. These tests use laboratory-prepared or field-cored specimens and can be performed either in the field or the lab. While evaluating bond strength tests is beyond the scope of this project, Table 6 presents a summary of several interface bond strength and tack coat film test devices used in the laboratory and in the field to characterize tack coat application and performance found during the literature search.

Table 6. Interface Bond Strength Tests

Apparatus	Significance and Use
ATacker^{TM} Test	Shear and/or tensile strength of tack coat material are measured to evaluate its bonding property.
Florida Direct Shear Test	Bond strength of the tack coat interlayer is measured to evaluate the performance of tack coat.
Leutner Shear Test	The maximum shear load and corresponding displacement are measured to evaluate the bonding property of interface.
Louisiana Interlayer Shear Strength Tester (LISST)	Developed for the characterization of interface shear strength of cylindrical specimens.
Louisiana Tack Coat Quality Tester (LTCQT)	Covers the determination of the tack coat spray application quality as measured by the tensile strength of tack coat materials on a free surface of asphalt concrete in the field or laboratory.
LTRC Direct Shear Test	Shear strength of the tack coat interlayer is measured to evaluate the bonding property of tack coats.
NCAT Shear Test	The interface shear strength of core samples is measured to evaluate the bonding property of pavement layers.
Torque Bond Test	Torque force at failure is measured to evaluate the in-place bond effectiveness of a wearing course system.
UTEP Pull-Off Test	Tensile strength of a tack coat material is measured to determine its bonding property.
UTEP Simple Pull-Off Test	Tensile strength of a tack coat material is measured to determine its bonding property.
Virginia Shear Test	The number of shear loading cycles at failure is used to determine the optimum application rate of asphalt binder tack at interface between two layers.

4.3 Performance of Tack Materials

Numerous studies have been conducted over the past 20 years that have looked at various bond strength tests and various tack coat materials. A summary of the studies, as well as the performance of different tack materials, follows.

Buchannan and Woods (2004) evaluated three different emulsions (SS-1, CSS-1, and CRS-2) along with one performance grade binder (PG 67-22) using the prototype tack coat evaluation device (TCED) ATacker^{TM}. Results showed that the device could distinguish between different tack coat applications. Tensile and torque-shear strength tests indicated that for the four tack coats tested, PG 67-22 yielded the highest strengths and CRS-2 yielded the highest strength of the emulsions. When emulsions were not fully broken, tensile and torque-shear strengths were highest at low application rates. When emulsions were fully broken, application rates of 0.09 gal/yd^2 yielded the highest tensile and torque-shear strength. A laboratory bond interface strength device, similar to the direct shear devices, was developed to assess interface shear strength and reaction index of laboratory-prepared specimens at 25°C. Tensile and torsional-shear test results showed that the PG 67-22 yielded the highest overall strengths, while the CRS-2 yielded the highest and the CSS-1 the lowest strengths of the emulsions. Results indicated that application rate, tack coat type, and emulsion set time affect the tensile and torsional-shear strength.

Deysarkar and Tandon (2004) reported using the UTEP Pull-off Device (UPOD) on both lab and field samples. In the study, CSS-1h, CSS-1, SS-1h, SS-1, PG 64-22, and residual application rates of 0.4 and 1.0 gal/yd^2 were used for testing purposes. In general, test results indicated that the gained strength increased with an increase in set time, application rate, and test temperature. In addition, the measured strength was higher with an increase in load levels, indicating that compaction efforts during placement of an overlay will further increase bond strength.

Mohammad et al. (2002) investigated the influence of different tack coat materials, application rates, and test temperatures on the interface shear strength when using a direct shear device mounted inside the Superpave Shear Tester (SST). Tests were conducted on asphalt binders (PG 64-22 and PG 76-22M) and on residues of emulsified asphalts (CRS-2P, SS-1, CSS-1, and SS-1h) used as tack coats at various application rates. The study evaluated tack coats through the simple shear test at temperatures of 25°C (77°F) and 55°C (131°F). From the laboratory study, the statistical analysis indicated that among the six different tack coat materials used, CRS-2P provided significantly higher interface shear strengths, and was therefore identified as the best performer. The optimum application rate for CRS-2P emulsion was 0.02 gal/yd^2.

Sholar et al. (2004) developed a bond strength shear device test apparatus and procedure in Florida in an effort to quantify the effects of moisture, tack coat application rate, and aggregate interaction on bonding performance. For the study, cores were extracted from multiple highway test sections throughout Florida and evaluated at various time intervals. Interface bond strength characteristics investigated included water effects and variation of bond strength with time. Results indicated that water applied to the surface of the tack coat, representing rainwater, significantly reduced the shear strength of the specimens when compared to equivalent sections without water applied. Varying tack coat application rates within the range of 0.02 to 0.08 gal/yd^2 had less of an effect on shear strength. The use of a tack coat to increase bonding strength was more effective for fine graded mixtures compared to coarse graded mixtures. Aggregate gradations of the mixtures being bonded together played a critical role in the magnitude of the shear strengths achieved. Fine graded mixtures achieved significantly lower shear strengths than the coarse graded mixtures. A field project containing a milled interface achieved the greatest strengths of the projects tested.

West et al. (2005) performed a study using the NCAT bond strength test. The NCAT bond strength device is a shear type test and loading can be performed with a universal testing machine or a Marshall press. Three test temperatures were studied: 50, 77, and 140°F (10°C, 25°C, and 60°C). The high temperature, 140°F, was considered a critical test temperature for slippage. The 50°F temperature was selected because of possible delamination at low temperatures. The 77°F temperature was selected as an intermediate temperature. For the laboratory work, the following were evaluated: two types of emulsions (CRS-2 and CSS-1) and a

PG 64-22 asphalt binder; three residual application rates (0.02, 0.05, and 0.08 gal/yd^2); and two mix types [19 mm nominal minimal aggregate size (NMAS) coarse-graded and 4.75 mm NMAS fine-graded]. Specimens were allowed to stabilize at the test temperature for four hours prior to testing. From the laboratory study, the main conclusions were as follows:

- Mixture type is a significant factor. Overall, analysis shows that the fine-graded, smaller NMAS mixture has higher bond strengths than the coarse-graded, larger NMAS mixture.
- PG 64-22 provided higher bond strengths than the two emulsion tack coats.
- Higher bond strengths were generally evident at the lower application rate for each of the tack coat materials.

For the field study, three tack coat test sections with different application rates were constructed for seven projects using the same tack coat material as the laboratory study. For projects using an emulsified asphalt tack coat material, the target application rates were 0.05, 0.075, and 0.10 gal/yd2 based on total emulsion (assuming a 60% residual asphalt content for the emulsions, the target application rates based on residue were 0.03, 0.045, and 0.06 gal/yd2). For projects using a paving grade binder as the tack coat material, the target application rates were 0.03, 0.05, and 0.07 gal/yd2. After the tack coat sections were set up, three distribution methods (hand wand sprayer, distributor truck spray bar, and Novachip^{TM} spreader) were employed. The Novachip^{TM} spreader featured a spray bar attached to the asphalt paver. After the HMA overlay was placed and compacted, three to five cores were obtained from each section and returned to the NCAT laboratory for bond strength testing using the draft procedure. The main observations of the field study were as follows:

- Milled HMA surfaces appear to significantly enhance bond strength with a subsequent asphalt pavement layer.
- Despite the fact that paving-grade asphalt tack coats appeared superior to emulsified asphalt tack coats, the differences were not statistically significant. Based on one project, there was not a significant difference in bond strength for cores taken from within the wheel path and cores taken between wheel paths.
- Bond strengths in sections that used the Novachip^{TM} spreader for application of tack coat were significantly higher than similar sections that applied tack coat using a distributor truck.

McGhee and Clark (2009) performed a study to identify a test method and acceptance criteria for bonding of HMA layers. Three tasks were performed to help achieve the study's objective: a laboratory comparison of the bond strength of typical tack materials, a field study of the effect of tack on bond strength between a new HMA overlay and a milled surface, and a laboratory investigation of a torque-shear field test to measure bond performance. A typical dense-graded asphalt mix from a local producer was used in the laboratory specimens. For the laboratory work, the following were evaluated: CRS-2, CSS-1h, and non-tracking tack (NTT), with 15 minutes of setting time and an application rate of 0.075 gal/yd2. The existing surface was milled and samples were tested at 50, 68, and 86°F. The main findings of the study were as follows:

- Bond strength between a new HMA overlay and a milled underlying surface is not affected by the application of tack coat. Poor bond is associated with an unsound and/or dirty underlying surface.
- CSS-1h produced the highest average strength in the lab, followed by CRS-2.

Clark et al. (2012) found that reduced-tracking tack coat materials outperformed conventional tack material (CRS-1) in laboratory tests of tracking potential. Compared to the conventional material, the reduced-tracking products were found to be superior performers under both normal laboratory testing temperatures and oven dried conditions. Reduced-tracking tack coat materials also provided better shear and tensile strengths compared to CRS-1 and CRS-2.

Bahia et al. (2019) conducted a study in Wisconsin that looked at the bond strength and tracking characteristics of different types of tack materials. The study focused on six different emulsions: CSS-1, CSS-1h, CRS-1, CSS-1hL, CQS-1h, and NTQS-1hh (a reduced-tracking product). The study also looked at various application rates, dilution levels, curing temperatures, and relative humidity levels. They found that the reduced-tracking temperature ranking of the six tack coats evaluated in this study were: reduced-tracking > CSS-1hL > CSS-1h and CQS-1h > CRS-1 and CSS-1. They also noted that this ranking is the same as the high temperature PG of the six tack coat residues: reduced-tracking tack coat (PG 88) > CSS-1hL (PG 70) > CSS-1h and CQS-1h (PG 64) > CRS-1 and CSS-1 (PG 58). With respect to bond strength, emulsion type did not appear to have a practically significant effect on the ISS. The reduced-tracking product (NTQS-1hh) showed slightly higher ISS values for the low texture mixture but had a very similar strength to the other three emulsions for the high texture mixture. They also found:

- Tracking performance of the tack coat is controlled more by the rheological properties of the residue of the tack coat than by the curing time. In other words, the tracking performance of the tack coat is a temperature dependent property due to the change in the rheological behavior of the emulsion residue.
- Pavement temperature is the most important factor affecting tracking behavior after the emulsions have reached terminal mass loss. The residual asphalt properties of the emulsion appear to be good indicators of tracking potential, with increased residue stiffness at a given temperature resulting in greater resistance to tracking at that temperature.

Wilson et al. (2018) conducted a study for the Texas DOT on reduced-tracking tack materials. The purpose of this study was to 1) evaluate the tracking resistance of different reduced-tracking tacks, and 2) evaluate bond strength of different reduced-tracking tacks and other construction parameters (e.g., surface type, temperature, compaction effort). The study looked at one conventional (cationic) emulsion, five reduced-tracking emulsions (two cationic and three anionic), and one hot-applied reduced-tracking product. For tracking resistance, a track-free time test and a dynamic shear rheometer (DSR) tackiness test both distinguished between reduced-tracking tack and conventional tack. The DSR test further distinguished among stiff residue and soft-residue reduced-tracking tacks. For bond strength of laboratory samples, all samples had acceptable bonding, but stiff-residue reduced-tracking tack had the highest bond energy followed by soft-residue reduced-tracking tack, conventional tack, and then no tack. The researchers recommended adopting the DSR tackiness test and track-free time test to qualify reduced-tracking tack materials.

Amelian et al. (2017) conducted research to evaluate and compare the effectiveness and performance of different tack coating approaches in Nebraska. The study focused primarily on bond strength. Various tack coat materials were investigated including different types of emulsified asphalt and asphalt binders at multiple application rates and dilution ratios. Emulsified asphalts and binders were applied to a field test section by varying application rates. The study included five types of materials: three emulsified asphalts (CSS-1h, CRS-2P, and CFS-1, which is a modified CSS-1 that provides a faster set), PG 64-22, and PG 64-22 modified with a wax additive as a reduced-tracking tack coat. In addition, a section with no tack was also placed. Breaking times for the emulsions were also determined. The direct shear test was performed under a monotonic loading condition at three different testing temperatures. Interlayer shear strengths were then used to rank the performance of the tack coats. In general, the test results showed superior interlayer performance from CFS-1 and CRS-2P at the double application rate (i.e., 0.16 gal/yd2 residual application rate) and CFS-1 at the standard application rate (i.e., 0.08 gal/yd2 residual application rate). Moreover, CRS-2P provided the shortest breaking time among all the emulsified tack coats.

Wilson et al. (2018) with the Texas A&M Transportation Institute looked into quantifying the benefits of tack coats, reduced-tracking tack coats, spray paver underseal membranes, and underseals. This study evaluated the performance of bonding and sealing treatments for bond strength, resistance to reflection cracking, and permeability, estimated the life-cycle cost for each treatment, and provided a reference guide for bonding and sealing treatments. Laboratory samples and field samples from 42 test sections on five overlay projects were tested for bond strength (Texas shear bond strength test), cracking resistance (modified Texas overlay test and compact tension test), and permeability (Florida falling head permeability test). All tests were sensitive to treatment type. Hot-applied reduced-tracking tack had the highest bond strength and spray paver membranes and underseals were the weakest, though all treatments demonstrated acceptable performance. Bond strengths varied significantly among the projects. Bonding was very sensitive to sample age with older samples having higher strength. Most of the bond strength was likely gained in the first month. The highest cracking resistance and also the lowest permeability was from high-residual treatments (underseal, spray paver membrane, and hot-applied reduced-tracking tack).

5 SUMMARY OF FINDINGS

5.1 Materials Most Commonly Used for Tack Coats

Currently, emulsified asphalts comprise the vast majority of tack coat materials used worldwide. Approximately 79% of U.S. state highway agencies use asphalt emulsions for their tack coat materials with 20% using reduced-tracking materials and less than 1% using straight asphalt binder. The most commonly used emulsions are slow-setting grades: SS-1, SS-1h, CSS-1, and CSS-1h. When considering straight asphalt binders, the most commonly used is a PG 64-22.

Reduced-tracking emulsions are generally formulated with stiffer base binders and/or chemical modifications that leave a less-tacky finish at ambient temperatures for reduced-tracking while still achieving good bond strengths when reactivated at overlay temperatures. Approximately 20% of state DOTs use some amount of reduced-tracking materials. The most commonly reduced-tracking material is NTSS-1HM, produced by Blacklidge Emulsions, Inc.

5.2 Tack Coat Breaking and Curing

Many factors can affect breaking and curing times of an asphalt emulsion, such as ambient air temperature, relative humidity, wind speed, pavement surface temperature, application rate of the tack coat emulsion, dilution rate of the asphalt emulsion, and type of emulsifying agent used. With higher humidity and more moisture in the air, the emulsion curing process takes longer since the breaking and setting process for the emulsion is dependent on the rate of evaporation of water from the system. Increasing curing temperature (air and pavement) and decreasing humidity increases the curing rate and decreases the overall curing time of asphalt emulsions. Moreover, the relative effect of humidity is dependent on the curing temperature, with curing at lower temperatures being more sensitive to humidity. Diluted emulsions significantly increase the curing time.

5.3 Tracking of Cured Asphalt Emulsions

Tracking of cured emulsions is dependent on the residual asphalt properties of the emulsion, with increased residue stiffness at a given temperature resulting in less tracking at that temperature. An asphalt emulsion will not track as long as it has the internal strength (cohesion) stronger (higher) than the adhesion to tires, and that the adhesion between a substrate and the emulsion is also stronger than the adhesion to the tires.

The tracking process of asphalt emulsions can be divided into two stages: tracking of the wet, uncured (unbroken and unset) emulsion, and pickup and tracking of the emulsion residue after curing. The first stage is mitigated by allowing the emulsion to substantially break and cure before allowing traffic on the tacked surface. The second stage of tracking is dependent on the asphalt residue of the emulsion at the prevailing climatic conditions, i.e., stiffer residual asphalts track less. Pavement temperature was found as the most important factor affecting tracking behavior after the emulsions have properly cured.

5.4 Tack Coat Application Rate

For proper tack coat application, calibrated application equipment is imperative. At typically specified application rates, the application rate had only a small influence on the developed interface shear strength. However, higher than recommended application rates resulted in slightly lower interface shear strengths. Moreover, either excessive or insufficient tack coat can cause pavement slippage and debonding problems. In general, the rougher the pavement surface, the higher the required tack coat application rate. Dilution rates are critical in determining the final application rates of tack coats, since problems such as delayed emulsion break can result from improper dilution. One-part undiluted emulsion and one-part additional water is the most commonly used dilution rate.

5.5 Methods for Addressing Tack Tracking

There are a number of items that can result in tracking on a paving project, and each must be considered when determining potential solutions. The three most critical areas that can result in tracking include surface cleanliness, paving over an unbroken/uncured asphalt emulsion, and inadequate stiffness of the residual asphalt binder. Possible solutions to each of these issues is shown in Table 7. A tabulation of various products and technologies that can be used to address tracking, along with the pros and cons of each one can be found in Appendix 3.

Table 7. Methods for Addressing Tack Tracking

Source of Tracking	Description	Method of Addressing
Underlying surface is dirty or dusty	If the underlying surface is dirty or dusty, the tack coat material will adhere to the dust or dirt and not to the underlying pavement surface.	Properly clean the surface through techniques such as mechanical brooming, flushing the surface with water, blowing off debris using high-pressure air, or a combination of these. Allowing traffic on the underlying surface (if feasible) is another method of assuring that the surface is adequately cleaned.
Unbroken/uncured asphalt emulsion	If an emulsion has not had adequate time to break and fully cure, the residual asphalt will not adhere to the underlying surface and the material will track if any vehicles drive on it.	Allow the tack coat emulsion to properly break and cure before driving or paving over it.
		Make certain that the application rate for the emulsion is correct and the emulsion has not been diluted outside of the producer's recommendations.
		Use a reduced-tracking tack product with a shorter set time.
		Use a hot-applied product, either straight asphalt binder or a hot-applied reduced-tracking product.
		Use a spray paver.
Inadequate stiffness of the residual asphalt binder	Once an emulsion has fully broken and cured, any tracking that occurs is likely due to the residual asphalt of the emulsion being too soft. High air and pavement temperatures are the most important factors affecting this type of tracking behavior.	Use a reduced-tracking emulsion, which has a harder residual binder.
		Use a hot-applied product, either straight asphalt binder or a hot-applied reduced-tracking product.
		Use a spray paver.

5.6 Pavement Condition for Tack Coat Application

Applying tack is not a substitute for properly cleaning the existing HMA surface. Therefore, prior to the tack coat application, the surface should be clean, dry, and free from loose material. In general, a milled surface provides a greater interface shear strength compared to an unmilled surface.

5.7 Tack Coat Tests and Evaluations

New and emerging laboratory tracking tests have the potential to better identify a materials' potential for tracking. These tests could prove significant as a method for agencies to approve reduced-tracking tack materials in a manner that is quantitative and less subjective. The majority of studies conducted to evaluate bond strength showed that straight asphalt binder and polymer modified emulsions typically had the highest bond strength. In many cases, reduced-tracking tack coat materials outperformed conventional tack coat materials in terms of bonding and reduced tracking, likely due to their stiffer residues.

6 RECOMMENDED RESEARCH

Reduced-tracking materials often have problems maintaining stability during handling and storage. While the manufacturers have recommended fairly stringent storage and handling guidelines, longer available storage times with reduced agitation requirements would make the materials more user-friendly and decrease the possibility of emulsion separation issues.

Emulsions with a hard penetration base may become brittle at lower temperatures, increasing the risk of bond failure or top-down cracking. Future research in this area could either resolve existing questions in this area or find ways to maintain flexibility at lower temperatures.

Another potential issue is with respect to the use of spray pavers with emulsions. As the spray paver is in operation, the hot asphalt mixture is placed directly on the unbroken emulsion, and the heat from the mixture drives off the water in the emulsion as steam, which travels through the open voids in the asphalt mixture. There has been concern that either the steam or any residual moisture could affect the bond between the asphalt binder and the aggregate in the mixture, particularly if a dense-graded asphalt mixture is used.

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Appendix 1 - Summary of Allowable Tack Coat Materials

State	Spec Date	Allowable Emulsion Materials	Allowable Non-Tracking Materials	Allowable PG Binders	Dilution allowed
Alabama	2018	CRS-1h, CRS-2, CRS-2h, CMS-1hp, CSS-1, CSS-1h, CQS-1h, CQS-1hp, CRS-2p, CRS-2l, MS-1	CBC-1HT, NTSS-1HM,CNTT-1hs, NTQS-1HL	PG 58-22, PG 64-22, PG 67-22, PG 76-22	No
Alaska	2017	STE-1 (Special Tack Emulsion)		PG 52-28	No
Arizona	2008	RS-1, RS-2, SS-1, CRS-1, CRS-2, CSS-1, Emulsified Asphalt (Special Type) - Diluted SS-1 or Diluted CSS-1, CRS-2P, HFE-150P, HFE-300P			Yes
Arkansas	2014	Anionic emulsions AASHTO M 140, Cationic emulsions AASHTO M 208, CRS-2P, CRS-2L		AASHTO M320 Table 1	Yes
California	2018	CSS-1, CSS-1h, SS-1, SS-1h, QS-1h, CQS-1h, CRS-1, CRS-2, RS-1, RS-2, QS-1, CQS-1, PMRS-2, PMCRS-2, PMRS-2h, PMCRS-2h			Yes
Colorado	2019	CSS-1h, SS-1h			Yes
Connecticut	2020	RS-1, RS--1H, (SS-1, SS-1h when temps >80F), CRS-1, (CSS-1 or CSS-1H when temp > 80°F)			No
Delaware	2016	CRS-2P		PG 64-22 (Thin lift < 1.5")	Yes
Florida	2020	Non-tracking tack	CBC-1HT, EM-50-TT, NTCRS-1HM, NTSS-1HM, PATT	PG 52-28	No
Georgia	2016	CQS-1HP, CRS-1H, CRS-2H, CMS-1P, CMS-1PR, CMS-2, CRS-2L, CRS-3, SS-1H,CSS-1H, AEP	NTSS-1HM, ETAC-H	PG 58-22, PG 64-22, PG 67-22	No
Hawaii	2005	SS-1, SS-1h, CSS-1, CSS-1h			Yes
Idaho	2018	CQS-1HP, CRS-2r, CRS-2L, CRS-2P, STE-1			Yes
Illinois	2019	SS-1, SS-1h, RS-1, RS-2, CSS-1, CRS-1, CRS-2, CSS-1h, HFE-90, SS-1hP, CSS-1hP	SS-1vh (NTEA)		Yes
Indiana	2019	SS-1h	AE-NT	PG 64-22	No
Iowa	2016	SS-1, SS-1H, CSS-1, or CSS-1H; RC-70 and MC-70 may be used after October 1	AE-NT	PG 64-22 (Thin lift < 1.5")	Yes
Kansas	2015	RS-1H, RS-1HP, SS-1H, MS-1, SS-1HP, CRS-1H, CRS-1HP, CSS-1H, CSS-1HM, CMS-1, CSS-Special, Emulsion Bonding Liquid			Yes
Kentucky	2019	SS-1, SS-1h	NTSS-1HM, KTEC,		No
Louisiana	2016	SS-1H, CSS-1H, CSS-1HP, (PET or SS-1L for spray paver)	NTSS-1HM, NTHAP (DOT-C-LT, Ultrafuse, eTac), CBC-1HT (eTac)		No
Maine	2020	RS-1H			Yes

State	Spec Date	Allowable Emulsion Materials	Allowable Non-Tracking Materials	Allowable PG Binders	Dilution allowed
Maryland	2018	CRS-1, CRS-1h, CSS-1h, EM-50	NTTC (Non-Tracking Tack Coat), NTCQS-1HM, NTSS-1HM, NTQS1, CNTTC, EM-50TT		No
Massachusetts	2020	RS-1h, CRS-1h			
Michigan	2012	SS-1h, CRS-1h, LTBC	LTBC-1, LTBC-2		
Minnesota	2018	MC-250 (when temps may drop below 32ºF), CSS-1, CSS-1h			No
Mississippi	2017	SS-1H, CSS-1H, CSS-1HP, (PET or SS-1L for spray paver)	Ultrafuse, BC-1HT, CBC-1H (eTac), CBC-1HT, NTSS-1HM	PG 76-22	No
Missouri	2019	SS-1, SS-1h, SS-1hp, CRS-1P, CRS-2, CRS-2P	NTSS	PG 46-28	Yes
Montana	2020	SS-1h, CSS-1h, CQS-1h, SS-1, CSS-1			Yes
Nebraska	2017	CFS-1, FS-1, RS-2, SS-1, SS-1H, CMS-1, CSS-1, CSS-1H, CRS-2, CRS-2P, CRS-2L			Yes
Nevada	2014	SS-1h, SS-1, CSS-1h, CQS-1nv, CSS-1, CMS-2s			Yes
New Hampshire	2016	RS-1, RS-1h, RS-2, HFMS-2, MS-4, MS-5, CRS-1, CRS-1h, CRS-1P			No
New Jersey	2019	RS-1, RS-1h, CRS-1, CRS-1h, CRS-1P		PG 64-22	No
New Mexico	2019	CSS-1, CSS-1h, SS-1, SS-1h			No
New York	2020	RS-1, RS-1h, RS-2, HFRS-2, MS-2, HFMS-2, HFMS-2h, HFMS-2s, SS-1, SS-1h, CRS-1, CRS-1h, CRS-2, CMS-2, CMS-2h, CSS-1, CSS-1h, CQS-1h			Yes
North Carolina	2018	CRS-1, CRS-1H	NTSS-1HM, CNTSS-1HM, Ultrafuse, Viaflex HA, CNTT, EM-50-TT, NTCQS-1hM, Emulvia Clean, DOT-C10	PG 58-28, PG 64-22	No
North Dakota	2019	SS-1h, MS-1, CSS-1h			Yes
Ohio	2019	RS-1, SS-1, SS-1h, CRS-1, CSS-1, CSS-1h	Non-tracking (NTSS-1HM, AE-NT, NTT)		No
Oklahoma	2019	SS-1, CRS-1p, CRS-2, PMCRS-1s, PMCRS-2s, PMCSS-1h	NTSS-1HM, NTQS-1HH, CBC-1H, NTHAP		Yes
Oregon	2018	CSS-1, CSS-1h, CMS-2, CMS-2S, CMS-2h, CRS-1, CRS-2, HFRS-2, HFMS-2			Yes
Pennsylvania	2020	CNTTC, NTSS-1HM, Tack, NTT, CNTT	NTT, CNTT, NTSS-1HM		
Rhode Island	2018	RS-1			

State	Spec Date	Allowable Emulsion Materials	Allowable Non-Tracking Materials	Allowable PG Binders	Dilution allowed
South Carolina	2007	RS-1, MS-1, MS-2, HFMS-1, HFMS-2, SS-1, CRS-1, CRS-2, CRS-3H, CMS-2, CSS-1	Generic non-tracking, QCT-NTRS-1P	PG 64-22	Yes
South Dakota	2015	SS-1h, CSS-1h			Yes
Tennessee	2015	SS-1, SS-1h, CSS-1, CSS-1h, TST-1P, CQS-1h, CQS-1hp, TTT-1, TTT-2	Trackless NTCRS-1HSP, NTSS-1HM, eTac (BC-1HT), SS-1VH, CRS-1HM, NTT (No Track Tack), DOT-C-10, Ultrafuse		
Texas	2014	SS-1h, CSS-1h, EAP&T	CBS-1h, NTSS-1HM, NTQS-1HH, Ultrafuse, Ultraseal, CBC-1H, Zydex Nanotec, CATT-TR, eTac-HB, DOT-C-LT	PG Binders	
Utah	2017	CSS-1h, CQS-1h		PG 58-22 or PG 64-22 (for paving fabrics)	Yes
Vermont	2018	RS-1, CRS-1, RS-1h, CRS-1h			
Virginia	2016	CRS-1, CRS-2, CRS-1h, CSS-1h, CQS-1h allowed only Nov-Apr (colder months)	NTCQS-1HM, NTCRS-1HSP, CNTTC, UltraTack, UltraFuse, EM-50TT, DOT-C-10, NTCRS-1hM		Yes
Washington	2020	CSS-1, CSS-1h		PG asphalt	
West Virginia	2017	SS-1, SS-1h, CSS-1, CSS-1h	QCT (NTCRS-1hSP), EM-50-TT, NTSS-1HM, NTT		Yes
Wisconsin	2020	MS-2, SS-1, SS-1h, CSS-1, CSS-1h, QS-1, QS-1h, CQS-1, CQS-1h			Yes
Wyoming	2010	SS-1, CSS-1, SS-1h, or CSS-1h			Yes

Appendix 2 - Summary of Best Agency Specifications and Practices

A review was conducted of tacking specifications for all 50 states. The following is a summary of some of the best practices identified that are related to tracking.

Alabama DOT

- Does not allow dilution of emulsions
- Low temperatures and humid or damp conditions will retard the breaking or setting of all emulsions
- NTSS-1HM may become slippery when wet
- Tack coat materials shall be fully cured before application of the overlying asphalt pavement layer is placed
- Permits the use of spray pavers with OGFC

Alaska DOT

- Limits the application of tack coat so it will be covered by paving within one day

Arkansas DOT

- Tack coat shall be applied sufficiently in advance of the asphalt course to allow the proper curing of the asphalt material but not applied so far in advance as to lose its adhesiveness as a result of being covered with dust or foreign material

California DOT

- Requires that areas receiving tack coat be closed to traffic
- Does not allow the tracking of tack coat onto pavement surfaces beyond the job site

Colorado DOT

- Asphalt material shall not be placed on any surface where traffic will travel on the freshly applied material

Connecticut DOT

- A thin uniform coating of tack coat shall be applied to the pavement immediately before overlaying
- Tack coat shall be allowed sufficient time to break prior to any paving equipment or haul vehicle traffic

Delaware DOT

- Requires PG 64-22 for thin lift maintenance contracts, typically less than 1½” thick

Florida DOT

- Uses non-tracking tack coat materials exclusively
- Stipulates the following requirements for trackless materials to be added to their approved products list:
    - A material being evaluated for use as a tack coat will need to be applied between a recently paved asphalt structural layer and a dense graded asphalt friction course layer
    - A SMO representative or delegate must be present for the field test section to visually confirm the material’s tracking properties

  - The department will direct the contractor to obtain five 6” diameter roadway cores from the field test section for testing at the SMO for bond strength in accordance with Florida Sampling and Test Method *Determining the Interlayer Bond Strength between Asphalt Pavement Layers*
  - The material must show little to no tracking and have a minimum bond strength value of 100 psi for approval

Georgia DOT

- Paving can proceed only after the anionic emulsified asphalt NTSS-1HM has cured to the engineer’s satisfaction
- Failure to break within 30 minutes after application or other than minor tracking of the tack once it has broken may subject the non-tracking tack product to re-evaluation for QPL 7 Georgia’s List of Approved Bituminous Materials
- After applying the tack coat material, allow it to break until it is tacky enough to receive the surface course
- Do not allow traffic on the tack

Hawaii DOT

- Once water has evaporated from asphalt emulsion, tack coat is said to have set
- Place HMA overlay after tack coat has set and within four hours of application and squeegee excess tack coat from surface

Illinois DOT

- Bituminous material for the tack coat shall be placed one lane at a time
- If a spray paver is not used, the tacked lane shall remain closed until the tack coat is fully cured and does not pickup under traffic
- When placing tack coat through an intersection where it is not possible to keep the lane closed, the tack coat may be covered immediately following its application with fine aggregate mechanically spread at a uniform rate of 2 to 4 lb/sy
- Tack or prime coat shall be fully cured prior to placement of HMA to prevent pickup by haul trucks or paving equipment; if pickup occurs, paving shall cease in order to provide additional cure time and all areas where the pickup occurred shall be repaired

Indiana DOT

- Asphalt material shall be uniformly applied across the entire width of pavement to be overlaid and shall cover a minimum of 95% of the surface
- Asphalt material shall be given sufficient time to break and set to minimize tracking from hauling and laydown equipment
- Areas of inadequate coverage that create streaking or areas of excessive coverage that create ponding shall be corrected to obtain an even distribution

Iowa DOT

- Allow tack coat to adequately cure prior to placement of HMA
- With each distributor, provide the manufacturer's instructions for use, including specific recommendations for the following:
  1. Spray bar height above road surface

2. Nozzle size and angle of spray fan with spray bar axis
3. Tables showing rates of distribution in gallons per square yard for tachometer readings, spray bar pressure, pump revolutions, and various widths of spray bars

<u>Kansas DOT</u>

- Specifies bond strength testing requirements for their projects

<u>Kentucky TC</u>

- Requires that tack material be placed on the longitudinal and transverse joints prior to placing asphalt materials
- Ensure that the tack material overlaps onto the adjoining surface no more than 3”

<u>Maine DOT</u>

- Weather limitations bituminous material shall not be applied on a wet or frozen surface or when conditions are otherwise unfavorable to proper construction procedures
- One-way passage of vehicles may be maintained on the untreated portion of the roadway, and bituminous tack coat shall not be placed on any surface where traffic will be forced to travel upon the uncovered tack coat
- All tack coat shall be covered on the day it is applied

<u>Maryland SHA</u>

- Exclude all traffic from sections treated with NTTC until the tack has cured and will no longer track onto adjacent non-treated areas
- Adjacent pavement surfaces shall show minimal visible evidence and pavement markings shall show no visible evidence of tracking

<u>Massachusetts DOT</u>

- All nozzles on the distributor shall be open, functioning, and turned at the same angle to the spray bar
- Nozzles shall be offset at an angle determined by the manufacturer of the distributor spray bar to prevent the fan from one nozzle from interfering with the fan from another
- The spray bar shall be adjusted so that it is at the proper height above the pavement surface to provide a triple overlap spray for a uniform coverage of the pavement surface where the nozzle spray patterns overlap one another such that every portion of the pavement receives spray from exactly three nozzles

<u>Michigan DOT</u>

- Bond coat is applied ahead of the paving operation, allowing it to cure before placing HMA
- During normal traffic operations, bleeding or moderate tracking is unsatisfactory
- If sanding and sweeping do not eliminate bleeding or moderate tracking, apply, roll, and broom a heated aggregate with the physical properties specified in Table 902-8

<u>Minnesota DOT</u>

- All tack must break (turn from brown to black) before paving the subsequent lift or course
- Do not allow vehicles to drive on tack that has not broken

- The engineer will compare the freshly sprayed emulsion to a brown sheet of construction paper or a black sheet of construction paper for broken tack to determine conformance with tack application uniformity

Missouri DOT

- Coldmilled surfaces shall be swept or vacuumed prior to tack coat application unless traffic is allowed onto the surface and it is considered clean by the engineer
- Hot applied PG graded asphalt binders may be used as tack coat in lieu of emulsified asphalt, applied uniformly with a pressure distributor to provide complete coverage of the preceding course or layer with safety procedures of hot applied asphalt addressed in the contractor's safety plan; a pre-construction meeting shall be held to address all safety procedures and protocols of hot applied asphalt prior to tack coat application
- Tack coat shall be applied in such a manner as to cause the least inconvenience to traffic and to permit one-way traffic without tracking of asphalt emulsion
- A bituminous mixture shall not be placed upon a tacked surface that is not uniformly covered or surfaces that have experienced excessive loss of tack due to tracking, and re-application of tack due to excess tracking or non-uniform coverage shall be at the contractor's expense
- All exposed tack coat shall be covered with bituminous mixture prior to opening to traffic

Montana DOT

- Apply tack coat to a dry surface
- Do not place plant mix on any surface with a tack coat until the tack coat has cured (breaks) as determined by the project manager

Nebraska DOT

- Asphaltic concrete shall not be placed over emulsified tack coat until the emulsion has broken and all free moisture has evaporated or drained off the surface

Nevada DOT

- Use the correct size nozzles and application pressure for the type and grade of asphalt and speed of distributor
- Nozzles shall be free from damage, unclogged, freely spraying, and uniformly angled from spray bar such that the spray fans do not interfere with other spray fans
- Special end-nozzles or shields installed on the end of the spray bar shall be adjusted to provide clean, uniform application and edges without streaks.
- Adjust and maintain the spray bar height to provide uniform double or triple lap coverage of bituminous material spread while preventing wind or other distortion
- Apply the emulsified asphalt in such manner as to offer the least inconvenience to traffic and to permit one-way traffic without pickup or tracking of the bituminous material
- Place the covering course over tack that is clean, free of tracking and adequately set

New Hampshire DOT

- Bituminous material shall not be applied on a wet surface or when weather conditions would prevent the proper application and curing of the coat

New Jersey DOT

- Correct uncoated or lightly coated areas and blot areas showing an excess of tack coat with sand or other similar material (remove blotting material before paving)
- Ensure that the material is not streaked or ribboned
- Before paving, allow tack coat to cure to a condition that is tacky to the touch

New Mexico DOT

- The contractor shall not apply tack coat on a wet surface or apply emulsified asphalt when the air temperature is below the manufacturers recommended application temperature
- The contractor shall uniformly apply asphalt material with a pressure distributor at a rate determined by the project manager to provide a "residual" asphalt cement content of from 0.04 gal per square yard to 0.08 gal per square yard
- The contractor shall ensure that the nozzles on the pressure distributor are fully open and at the same angle from the spray bar, approximately 30° while keeping the spray bar at a height above the pavement surface to provide for a double or triple lap of the applied asphalt material
- The contractor shall keep traffic off of the tack coat unless otherwise approved by the project manager
- If the roadway being paved is closed to traffic, the contractor may place tack coat a maximum of 24 h ahead of the laydown operation; if the roadway is open to traffic, place the tack coat only over the area that can be paved during that day's laydown operation
- If the contractor uses an emulsified asphalt tack coat, the contractor may begin paving operations after the emulsified asphalt is cured.
- Reapplication of tack coat damaged by traffic or construction equipment will be at no cost to the department

New York DOT

- Tack coat not be applied on a wet pavement surface or when the pavement surface temperature is below 40°F

North Carolina DOT

- Apply tack coat only when the surface to be treated is dry and when the atmospheric temperature measured at the location of the paving operation away from artificial heat is 35°F or above
- Do not apply tack coat when the weather is foggy or rainy
- Take necessary precautions to limit the tracking or accumulation of tack coat on either existing or newly constructed pavements; excessive accumulation of tack coat requires corrective measures
- After the tack coat has been applied, protect it until it has cured for a sufficient length of time to prevent it from being picked up by traffic

North Dakota DOT

- Allow tack coat to cure before applying surfacing material

- Provide data showing the manufacturer's instructions and recommendations for spray bar height above the road surface, nozzle size, and angle of spray fan with the spray-bar axis

Ohio DOT

- Do not use equipment that cannot obtain the correct tack application
- Apply the asphalt material in a manner that offers the least inconvenience to traffic
- Only apply the asphalt material to areas that will be covered by a pavement course during the same day
- Ensure the tack breaks before releasing to construction traffic unless the paver is equipped with a spray bar system to apply tack just prior to mat placement
- Provide certified non-tracking asphalt emulsion material per Supplement 1128 and Supplement 1032; emulsion will comply with all specification requirements for at least 30 days after sample date

Oklahoma DOT

- Do not apply tack coat during wet or cold weather, or in windy conditions that would cause the tack coat emulsion to drift
- Do not apply tack coat to wet surfaces with free standing water; the department will allow tack coat application to damp surfaces
- Allow tack coat to cure undisturbed before applying hot mix asphalt
- Ensure the tack coat breaks before the application of the next surfacing layer

Oregon DOT

- Do not place hot mixed asphalt concrete pavement or emulsified asphalt concrete pavement on the tack coat until the emulsified asphalt separates from the water (breaks) but before it loses its tackiness

Pennsylvania DOT

- Correct all uncoated or lightly coated areas as directed to the representative's satisfaction; at designated locations, correct areas with an excess of emulsified asphalt material by covering the area with sufficient dry fine aggregate to blot up or remove excess tack coat
- Allow the tack coat to break and set without being disturbed and do not begin paving until the representative determines the tack coat has cured to the point that tracking is minimized

Rhode Island DOT

- Tack coat shall be applied using the proper nozzle settings and the "double coverage" or "triple coverage" techniques as outlined in Chapter 5 of Asphalt Institute Publication MS-22, *Construction of Hot Mix Asphalt Pavements*
- The newly placed tack coat shall be allowed to break and set prior to paving, defined as the separation of the asphalt from the water from within the emulsion that is signified by a change in color of the material from brown to black, the evaporation or removal of the resultant surface water, and the adherence of the tack material to the underlying pavement; the contractor will be required to wait for this process to complete for up to

one hour and if the tack coat has not fully transformed as defined herein, the contractor may proceed to pave over the tacked area

South Carolina DOT

- Ensure that all nozzles on the distributor are fully open and operational and are turned at the same angle to the spray bar, which is approximately 30 degrees
- Place the spray bar at the proper height above the pavement and apply the proper pressure to provide a uniform double or triple lap of the liquid asphalt material

South Dakota DOT

- The tack coat shall be allowed a cure period, as determined by the engineer, prior to asphalt concrete placement

Tennessee DOT

- Allow the tacked surface to dry until it is in a proper condition to receive the next course
- Apply tack coat only so far in advance of the paving operations as is necessary to obtain a proper condition of tackiness
- Protect the tack coat from damage until the next course is placed

Texas DOT

- Certain tracking-resistant asphalt interlayer materials are pre-approved for use on department projects to be applied to asphalt pavement surface as a tack coat or sealant before the installation of new asphalt concrete
- Approval is based on successful use on trial construction projects in Texas, preferably on at least three TxDOT projects, and successful use is determined based on the observations and any testing conducted by the receiving agency to determine the suitability of the product
- Documentation must include the new and existing pavement types and the application rate

Utah DOT

- Select emulsion according to the time constraints required for maintenance of traffic and the ability to fully cure before allowing traffic on the roadway
- Allow prime or tack coat to fully cure before allowing traffic

Vermont DOT

- The application shall be made just prior to the placement of the bituminous concrete mixture and shall progress sufficiently ahead of the paving so that the surface to be paved will be broken such that the surface consists of residual asphalt only
- The application shall not be made on more than 50% of the width of the road surface at a time, unless all traffic is detoured, in which case the application may be full width

Virginia DOT

- Care shall be taken to prevent splattering adjacent items during the application of tack coat
- The distributor shall not be cleaned or discharged into ditches or borrow pits, onto shoulders, or along the right of way

- When not in use, the contractor shall ensure equipment is parked so that the spray bar or mechanism will not drip asphalt on the surface of the traveled way
- The tack coat or non-tracking tack coat shall be applied in a manner to offer the least inconvenience to traffic and to permit one-way traffic without pick up or tracking of the asphalt onto adjacent non-treated areas.
- All traffic, including construction traffic, shall be excluded from tacked sections until the tack has cured
- The contractor shall apply nontracking tack coat between May 1 and October 1 and may use tack coat as specified herein at other times
- Adjacent surfaces shall show minimal visible evidence and white or yellow pavement markings shall show no visible evidence of the asphalt tack material tracking at the end of the production shift; tracking of the tack material on pavement markings will require the contractor to immediately restore the markings to their original pre-tack condition.
- The contractor shall remove build-up of the tacking material on existing pavement surfaces
- If the engineer suspects the contractor is failing to apply good bond promoting procedures or adequately tacking the existing surface per the manufacturer’s recommendations, the engineer may core a minimum of six locations to determine the shear and tensile strength at the interface by using a stratified random selection process; the department’s laboratory will test cores in accordance with the procedures described in report VTRC 09-R21 and will test a minimum of three cores for shear strength and three cores for tensile strength

Washington State DOT

- Do not operate equipment on tacked surfaces until the tack has broken and cured
- Tack coat damaged by contractor’s operation must be repaired prior to HMA placement

West Virginia DOT

- Tack coat shall be applied only when the weather and existing surface are satisfactory to the Engineer and when the temperature of the surface is 40°F (4°C) or above; when the temperature is less than 50°F (10°C), care must be exercised to ensure that the tack coat “breaks” prior to the application of the hot-mix asphalt
- Tack coat “break” is the process in which water separates from the asphalt emulsion and the color of the tack coat begins to change from brown to black and the time required for breaking will depend on the type and grade of the emulsion, the application rate, the temperature of the existing pavement surface, and environmental conditions
- Tack coat “set” refers to the final stage of the process when water has completely evaporated from the emulsion leaving a thin film of asphalt binder on the pavement; the rate of set depends on the same conditions that control the rate of break of the emulsion
- Any tack coat material applied in excess of the requirements shall be removed or covered with a blotter course of dry sand or stone chips as directed by the engineer

Wisconsin DOT

- Remove tack coat tracked by construction traffic immediately

- Correct nonconforming tack coat where applied tack coat is tracked either offsite or to other areas of the construction site, where excess tack coat accumulates in puddles, or in areas with insufficient residual asphalt content

Wyoming

- When traffic is present in construction areas, apply tack coat on one half of the application surface at a time
- Do not allow traffic on the tack coat until it has cured sufficiently to prevent picking up or tracking

Appendix 3 – Tabulation of Available Products and Technologies

Available Products and Technologies			
Product Category	**Most Common Products**	**Pros**	**Cons**
Conventional Asphalt Emulsions	SS-1, SS-1h, CSS-1, CSS-1h, CRS-1	• Applied at relatively lower application temperatures • Readily available • Contractor familiarity with handling, storage, and usage • Current approved for use by most agencies	• Longer break and cure times (hot, dry day: 5 – 10 minutes to break and 15 – 20 minutes to cure; (cool, humid day: > 60 minutes to break and cure) • Greater opportunity to track • Slightly lower bond strengths
Non-tracking Asphalt Emulsions	NTSS-1HM, CBC-1HT, EM-50-TT, AE-NT	• Shorter break and cure times (hot day: 5 minutes to break and 10 – 15 minutes to cure) • Harder residue and less tackiness, reduced tracking • Improved bond strength over conventional emulsions	• Increased cost as compared to conventional emulsions • Materials tend to be more sensitive with more stringent storage and handling requirements • May require agency approval • Requires emulsion to break and cure
Asphalt Binders	PG 67-22, PG 64-22, PG 64-28, PG 58-22	• Once applied, cools quickly, reducing potential for tracking • Eliminates the breaking and curing process and speeds up paving operations • Eliminates the need to store and handle emulsions (one less material) • Good bond strengths • Less costly than emulsions • Applied at lower application rates than emulsions	• High application temperatures are a safety concern to workers and motorists • Distributor operators need to be properly trained and have correct PPE, similar to the training required for emulsions • May still track if high PG grade of the binder isn't high enough for pavement temperature it experiences • Time required to reheat cooler material
Hot-Applied, Non-Tracking Tack Coat	Ultrabond, e-Tac-HB, DOT-C-10, DOT-LT, Underseal	• Once applied, cools quickly, reducing tracking potential • Eliminates the breaking and curing process and speeds up paving operations • Good bond strengths • Typically use harder base asphalt (minimal tracking)	• High application temperatures are significant safety concern to workers and motorists • Distributor operators need to be properly trained and have correct PPE • More costly than straight asphalt binder • May require agency approval
Spray Paver	Vögele SprayJet Paver, Roadtec SP-200 Spray Paver, Caterpillar Integral dx	• Tack material applied immediately in front of the screed, totally eliminating tracking • No delays due to waiting on the emulsion to break and cure and speeds up paving operations • Higher application rates are feasible • Good bond strengths	• Equipment costs are very high • Equipment can be more complex to operate • Storage tanks need to be refilled more frequently, resulting in more stops and starts for the paver • Difficult to assess quality of tack application and material • Potential impact to mixture of paving over unbroken/uncured emulsion