Tack Coat Best Practices

This Technical Brief provides an overview of tack coats and their vital role bonding multiple asphalt layers into one monolithic system. Poor tack coat techniques result in compromised bonding of the asphalt layers. This leads to pavement distresses. Possible slippage cracking and delamination are associated with poor bonding. Additionally, poor bonding can lead to structural distresses, namely fatigue cracking and potholes. Often this lack of sufficient bonding is not recognized as the source of failures.

TechBrief

The Asphalt Pavement Technology Program is an integrated, national effort to improve the long-term performance and cost effectiveness of asphalt pavements. Managed by the Federal Highway Administration through partnerships with state highway agencies, industry and academia the program's primary goals are to reduce congestion, improve safety, and foster technology innovation. The program was established to develop and implement guidelines, methods, procedures and other tools for use in asphalt pavement materials selection, mixture design, testing, construction and quality control.

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Introduction

A key, but sometimes overlooked, component of an asphalt pavement is the bond strength between asphalt pavement layers. Tack coat is a sprayed application of an asphalt binder upon an existing asphalt or Portland cement concrete pavement prior to an overlay, or between layers of new asphalt concrete. This thin membrane of asphalt binder provides the glue between the layers, creating a monolithic structure which performs as a unit as opposed to unbound, independent, layers. When properly built, a pavement will provide the desired characteristics for its users, while meeting the needs of an agency for an economical, environmentally friendly and sustainable material.

Poor bonding of a pavement surface layer is a direct result of inadequate tack coat practices resulting in slippage and shoving of the pavement, as seen in Figure 1. This type of failure is most frequently seen in locations where braking or acceleration is common, such as intersections. Other distresses can also be made related to poor tack coat bonding, most notably pavement fatigue cracking.

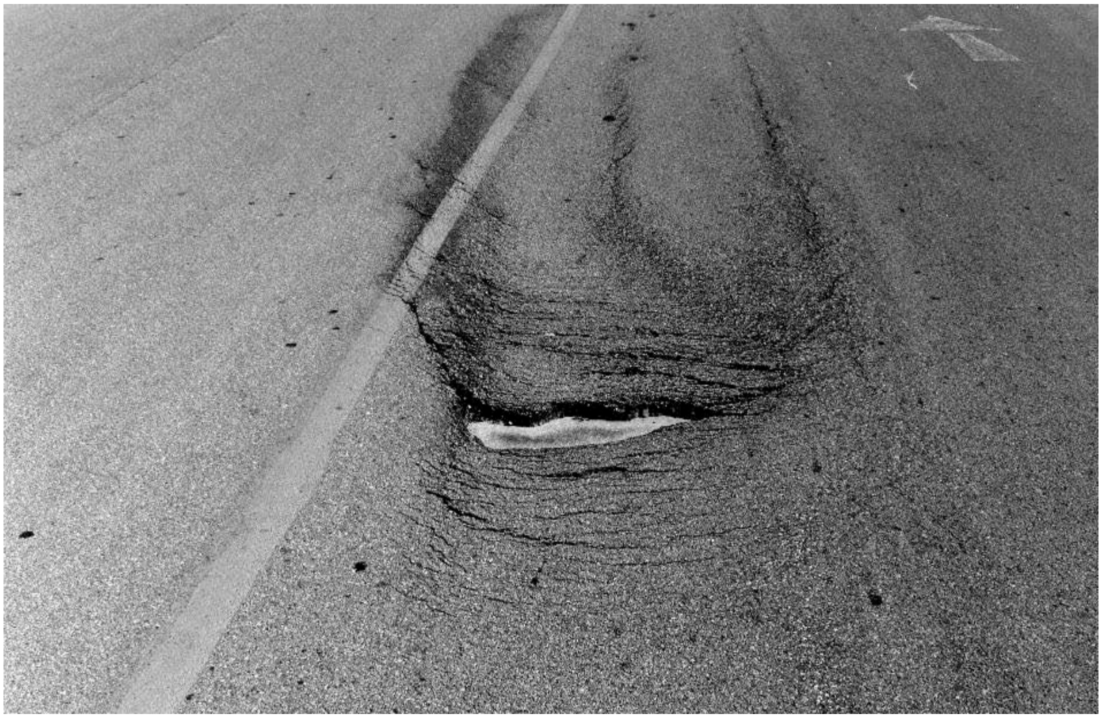

Figure 1. Slippage failure due to poor bonding of pavement layers.

Materials used for tack coats are emulsified asphalt (most common) and performance grade asphalt. While cutbacks are still used, their usage is much less than other options, and will not be addressed in this TechBrief. Moreover, research has shown that cutbacks achieve lower bond strengths than other options. (*1*)

Tack Coat Definitions

It is important to use consistent language when discussing tack coats. Therefore, the following definitions are offered:

***Tack Coat*—**sprayed application of asphalt binder upon an existing asphalt or Portland cement concrete pavement surface prior to an overlay, or between layers of new asphalt concrete.

Undiluted Emulsion—an emulsion which consists primarily of a paving grade binder, water, and an emulsifying agent.

Diluted Emulsion—an emulsion with additional water added to it. The most common dilution rate is 1:1 (one part undiluted emulsion and one part additional water). (*1*)

Residual Asphalt—the remaining asphalt after an emulsion has set, typically 57-70 percent of the undiluted emulsion.

Tack Coat Break—the moment when water separates enough from the asphalt to show a color change from brown to black.

Tack Coat Set—when all the water has evaporated, leaving only the residual asphalt. Some refer to this as completely broken.

Literature Review: The Importance of Tack Coats

Failure to bond pavement layers is known to result in delamination and then sliding and shoving of surface layers of pavement. However, a reduction in fatigue life is also a very probable consequence of poor bonding. When pavement layers are not properly bonded, the layers exhibit independence, resulting in an alteration to the stress distribution profile. A variety of researchers have reported on this situation over the years. Some select examples are presented below. A more complete listing is found in NCHRP Report 712 (*l*).

Roffe and Chaignon (*2*) reported that if a pavement displayed no bonding within its layers, a 60% loss of life could be expected. Similarly, Brown and Brunton (*3*) reported that no bonding would cause a 75% reduction in pavement life, and at 70% bond strength, a 70% reduction in pavement life could occur. Moreover, King and May (*4*) reported that with only a 10% loss of bond, a 50% reduction in fatigue life would be expected.

While all of these examples are based primarily on computer models of pavement behavior, an extensive analysis was performed by Willis and Timm (*5*) of a bond failure at the National Center for Asphalt Technology's (NCAT) Test Track in Alabama. The failure analyses occurred during the 2003 test cycle in which two sections (N7 and N8) were constructed to test the ability of a rich bottom layer (RBL) to improve fatigue resistance. N8 had 0.5% added binder above its determined optimal value. All other aspects of N7 and N8 were identical, including instrumentation at depths of 5 and 7 inches (125 and 175 mm), a total asphalt thickness of 7 inches (175 mm), and an SMA surface for both. Surprisingly, N8 exhibited fatigue failure far sooner than N7, prompting a full forensic investigation. The results of an extensive analysis of the two sections led NCAT researchers to conclude that debonding had occurred between the layers within section N8 and the early fatigue failure was due to the inability of the pavement to behave as a monolithic unit as designers had intended.

In the state of Missouri (*6*) it was reported that an Interstate pavement experienced fatigue cracking early in its life, after 8-10 years of service, Figure 2. The state highway agency conducted a forensic analysis which included the collection of cores. As can be seen in Figure 3, bonding failure was found at various locations within this structure. Again, a pavement with unbonded layers will exhibit compromised performance.

Perhaps the most definitive research effort on optimization of tack coats for HMA was the National Cooperative Highway Research Project (NCHRP) 9-40 (*1*). As reported in NCHRP Report 712, bond strengths were tested for a variety of tack coat materials including emulsions and paving grade binders; various residual application rates from no tack coat to 0.155 gallons per square yard (gsy); various surface types including old HMA, new HMA, milled HMA, and grooved Portland cement concrete (PCC); and in shear, tension, and torsional configurations at a range of test temperatures. Test specimens were obtained from both field and laboratory produced materials.

Some of the recommendations from Report 712 include residual tack coat application rates for different surface conditions, shear bond strength testing, and milling of existing surfaces to improve performance. It noted that current common application rates may be too low.

Two American Association of State Highway and Transportation Officials (AASHTO) test methods have also been produced as a result of this work. Namely, TP-114 Standard Method for Determining Interlayer Shear Strength (ISS) of Asphalt Pavement Layers (*7*) and TP-115, Standard Method for Determining the Quality of Tack Coat Adhesion to the Surface of an Asphalt Pavement in the Field or Laboratory (*8*), were developed in the project.

Figure 2. Fatigue cracking on a Missouri pavement.

Figure 3. Cores showing layer debonding from Missouri.

Structural Design

Pavement structures are designed based on a series of inputs. These inputs include the design life of the pavement, engineering properties of the materials, and the expected traffic over the life of the structure. The typical design life for an asphalt pavement is twenty years or more. Increasingly, engineers are seeking to extend the design period and are employing the principles of perpetual pavements. Perpetual pavements are designed thicker than traditional counterparts, but are expected to perform without deep structural maintenance or rehabilitation. Distresses in a perpetual pavement are expected to be confined to the uppermost layers thus requiring only periodic milling and replacement of the surface while retaining the underlying materials. Since 2001, many state highway agencies have been recognized for constructing perpetual pavements (*9*).

Regardless of the methodology employed, an assumption of all thickness design methods is that the pavement layers will be working together as a single monolithic unit. This is achieved only with proper layer bonding. When a traditionally designed asphalt pavement is properly bonded, the principal failure mechanisms are typically bottom-up fatigue cracking or rutting. If the pavement was designed and built as a perpetual pavement, the principal failure mechanism will be top down cracking at the surface, typically confined to the top layers. If layer bonding is not achieved, neither traditionally designed pavements nor perpetual pavements will perform as intended. Within a pavement structure containing unbonded layers, the strain profile will not match that of an equally thick, but properly bonded pavement. This non-uniform strain profile in the pavement structure will lead to decreased fatigue life as the strains at the bottom of the debonded layer will quickly become excessive which can result in fatigue cracking initiating at the bottom of that layer within the asphalt structure.

Tack Coat Costs

A recent Asphalt Institute investigation showed the cost of tack coats on new or reconstructed facilities was 0.1-0.2% of the total project costs. On the mill and overlay projects, tack coat was 1.0-2.0% of those project costs. If a bond failure occurred and the remedial action was needed, the cost to replace just the top lift was found to be between 30-100% of the original project costs. The lower end of the range was for new or reconstructed pavements which consist of multiple lifts, and the higher end was for a pavement that had seen a mill and overlay of just a single lift of material.   It's clear that the cost of a tack coat application is relatively insignificant, but the cost of repairing a bond failure is very significant. Add to that cost the additional disruption to the users of the facility, and tack is clearly low cost insurance for achieving good bonding between all layers of the pavement structure and good pavement performance.

Tack Coat Materials

Historically, tack coat selection has been based primarily on experience, convenience, and/or empirical judgement. The selection of the appropriate tack coat material should be based on a combination of material properties and availability. The most common tack coat materials are asphalt emulsions, with slow setting emulsions (SS-1, SS-1h, CSS-1, and CSS-1h) being the most common (*1*). Other asphalt emulsions which are increasingly used for tack coat including rapid-setting emulsions such as RS-1, RS-2, CRS-1 and CRS-2.

Some of the advantages emulsions offer is that they lend themselves to application uniformity, there are typically numerous choices in most locations, and contractors are familiar with their usage. Disadvantages include the time it takes for the emulsion to break and set and the potential for tracking, the transference of tack coat material to adjacent pavement typically via construction vehicles or equipment, of emulsified materials as seen in Figure 4. Excellent performance has been realized when asphalt emulsions are properly used which includes the proper asphalt residual and allowing the emulsion to break and set.

Figure 4. Pavement displaying tack coat which has tracked off the surface.

The main factors affecting the emulsion break and set times are the application rate and the climatic conditions, primarily sunny verses cloudy, and ambient, surface, and application temperatures. The higher the application rate, the longer it will take for the emulsion to break and set. Typically, the use of a diluted asphalt emulsion will require more time to both break and set compared to an undiluted emulsion, because of the increased amount of water present. As their names imply, the break and set times for a rapid set (RS) emulsion are typically shorter than slow set (SS) emulsion.

In an effort to combat tracking, emulsions are being formulated with stiffer base binders and/or chemical modifications. A significant variety of proprietary emulsions or additives are available and marketed as 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 these materials.

Polymer-modified asphalt emulsions (PMAE) are seeing an increase in their usage, especially for specialty applications, including spray-paver applications. The product may be identified as a conventional emulsion with a P following the designation such as SS-1hP.

Another tack coat material can be paving grade asphalt binders. Paving grades as tack coats are most commonly used in southern states. Nighttime paving projects also employ them as they do not have a break or a set time due to the lack of water within them. Excellent performance has been reported when using paving grade binders as well.

Tack Coat Best Practices

As has been demonstrated, a properly bonded pavement functioning as a monolithic unit is essential to achieve performance expectations. To produce the best opportunity for a pavement to achieve its performance expectation, good design and construction practices need to be followed. An excellent resource with greater details than is found here on tack coat best practices is QIP-128 Best Practices for Emulsion Tack Coats from the National Asphalt Pavement Association. (*10*)

The design phase for tack coats involves an evaluation of the surface to which it will be applied, selection of an appropriate tack coat material, and selection of the proper residual asphalt rate.

When evaluating the surface, designers should consider the following characteristics. Is the pavement a new or an existing facility? For existing pavement, will it be milled or not? If it is not going to be milled, then how weathered, raveled, or worn is it? In general, the more surface roughness and wear the pavement has, the greater the volume of tack coat needed for optimal bonding. The Asphalt Institute offers general recommendations for tack coat application rates on different common surfaces in Table 1. Further, the Asphalt Institute encourages use of the higher end of these application rates for best performance.

Table 1. Recommended Tack Coat Application Rates

Surface Type	Residual Rate (gsy)	Approximate Bar Rate Undiluted* (gsy)	Approximate Bar Rate Diluted 1:1* (gsy)
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**
Portland Cement Concrete	**0.03 – 0.05**	**0.05 – 0.08**	**0.10 – 0.16**

*Assume emulsion is 33% water and 67% asphalt.

It is of paramount importance that specifications be clear in their language as they relate to tack coats. For example, a specification may read, "*Apply the tack coat at a rate of 0.04 gsy*". Language such as this is too vague. It could be interpreted to mean 0.04 gsy residual binder, 0.04 gsy undiluted emulsion, or even 0.04 gsy diluted emulsion. Actual residual values will vary widely from each interpretation. As can be seen in Table 1, if 0.04 gsy residual is the desired application, then, with the assumptions shown, an application of 0.06 gsy undiluted, or 0.12 gsy of a 1:1 diluted emulsion would be needed to achieve the desired residual rate. It is recommended that all application specifications be in terms of <u>residual</u> asphalt.

While some researchers have indicated that tack coats may not always be needed to get good bonding, the preponderance of literature supports always using tack coats between lifts of asphalt. Moreover, as discussed previously, the cost of a tack coat application is relatively insignificant, but the cost of repairing a bond failure is very significant including the cost of the additional disruption to users of the facility.

Surface preparation is vital to provide the best opportunity to achieve a high bond strength. The goal of surface preparation is to produce a clean, dry surface. On existing pavements, milling is encouraged for its many benefits. First, milling removes the uppermost materials which are typically the most compromised by traffic wear and weathering. Second, milling helps to smooth out any irregularities in grade that may have developed within the pavement. And third, milling improves the bonding characteristics of the overlay to the existing pavement.

The negative aspects of milling are the cost associated with milling and the added cleaning typically connected to milling as it can produce excess fine material which may be difficult to eliminate by sweeping or other forms of removal. Milling may also increase the amount of tack coat needed as it increases the surface area (roughness) of the existing pavement. However, this additional surface area along with an increase in aggregate interlock promotes improved bonding characteristics.

On new or reconstructed pavements, or where multiple lifts are a requirement of construction, surface preparation between lifts is generally minimal. Sweeping may be the only preparation needed. However, if the freshly laid pavement has become dirty it is recommended the contractor clean any and all such locations prior to the next lift being tacked and paved.

Once the surface has been properly prepared, application of tack coat can proceed. Tack coat applications should be uniform and consistent both transversely and longitudinally. An example of a quality tack coat application can be seen in Figure 5. Unfortunately, frequently tack coat applications can be observed that are streaky or striped in appearance. Some refer to this as “zebra tack” or “corn rows” (*11*) (as seen in Figure 6) and it does not produce good bond strengths. As noted previously, some researchers reported that a mere 10% loss in bond strength resulted in a 50% loss in fatigue life.

Figure 5. A uniform tack application.

Figure 6. Examples of “Zebra Tack” or “Corn Rows”.

Historically, emulsified tack coats were diluted to assist contractors in achieving a uniform application of tack. This was required due to equipment limitations found in the past. However, today's modern distributor trucks are capable of applying a uniform tack coat without dilution. For all dilution operations, careful control is needed to properly account for water added by dilution so that the residual application rate can be calculated. Without such control, residual asphalt application rates are impossible to determine. 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.

Application Calculations

Residual asphalt application rates calculations need to account for not only the water that is present in an undiluted emulsion, but also any added water via dilution. For example, if an application rate of 0.10 gsy was applied to an emulsion diluted at 70:30 (70% undiluted emulsion to 30% additional water), containing initially 33% water, calculation of the residual application rate would need to account for both sources of water. Thus, the 0.10 gsy would be multiplied by 0.70, to account for the dilution, and 0.67, to account for the water in the undiluted emulsion. Therefore, the residual tack coat rate in this example would be 0.047 gsy.

When application calculations are done in terms of volume, a correction to the standard temperature of 60°F is required. This is to account for any expansion or contraction that will occur as an emulsion is heated or cooled. One such table is found in the Asphalt Institute's MS-19, *Basic Asphalt Emulsions Manual*, Table B.1. (*12*) To perform the correction, simply multiply the factor found in the table for the measured emulsion temperature by the volume applied at the measured temperature. This provides the 60°F volume.

Distributor truck calibration is also vital to the application of a proper tack coat. Periodically, a trial tack coat application should be placed over a test area to verify correct nozzle operation and configuration. Distributors should be calibrated annually as a minimum. Increasingly, owner agencies are requiring a valid certification of calibration to ensure the proper functioning of the distributor and its components. ASTM D2995 (described below) provides guidance for the calibration procedure.

The calculations needed to determine tack coat applications are rather straightforward. Most commonly, tack coat is specified in terms of volume (gallons/square yard). However, it might also be specified in terms of mass (pounds/square yard). The following steps can be applied with the volume method:

- Step 1: Determine the distance traveled.
- Step 2: Calculate the area sprayed = distance traveled X width sprayed and convert from sq. ft. to sq. yd. if needed.

- Step 3: Calculate the gallons of material applied = beginning volume – ending volume. The volumes may be determined by using a dipstick calibrated to the truck's tank or onboard meters.
- Step 4: Correct for temperature back to 60°F by applying correction factor. (See above.)
- Step 5: Account for any dilution. (See above.)
- Step 6: Calculate residual asphalt by accounting for the water in the undiluted emulsion. (See above.)
- Step 7: Calculate residual emulsion application rate, which is the gallons of residual emulsion applied divided by the area of application.

A formal method for determining application rates has been adopted by ASTM under their D2995 (*13*) procedure. D2995 offers two methods:

- Method A uses calibration pads that are pre-weighed and attached to the roadway surface (see Figure 7). The pads should be attached both longitudinally and transversely. The truck being calibrated drives over the pads while spraying its material. The pads are quickly removed and reweighed. The application rate is then determined by taking the difference between the post-sprayed and pre-sprayed weights. Any dilution needs to be accounted for, as should the water in the undiluted emulsion to get the application rate in terms of residual material.

Courtesy of Jim Scherocman

Figure 7. ASTM D2995 Method A pads following tack coat application.

- Method B uses containers which are placed under each nozzle on the distributor. The distributor then discharges material into the containers for a set period of time. The volume is then calculated. Transverse uniformity of application can be verified by checking the consistency in each container and the application rate becomes a function of the truck's ground speed.

With the various asphalt products that can be applied with a distributor truck, different nozzles are available to best match the material with the application rate (see Figure 8). The manufacturer of the distributor truck should be consulted to ensure that the most appropriate nozzles are installed for the tack coat material being applied. Also, nozzles can become plugged. Inspection of the nozzles before and during application can minimize any detrimental effects of clogging. Nozzles also need to be aligned properly. This requires a 15-30° offset from the spray bar as shown in Figure 9. The offset prevents the fan from one nozzle from interfering with the fan from another, thus improving uniformity of application.

Figure 8: Examples of different nozzle sizes for different application rates.

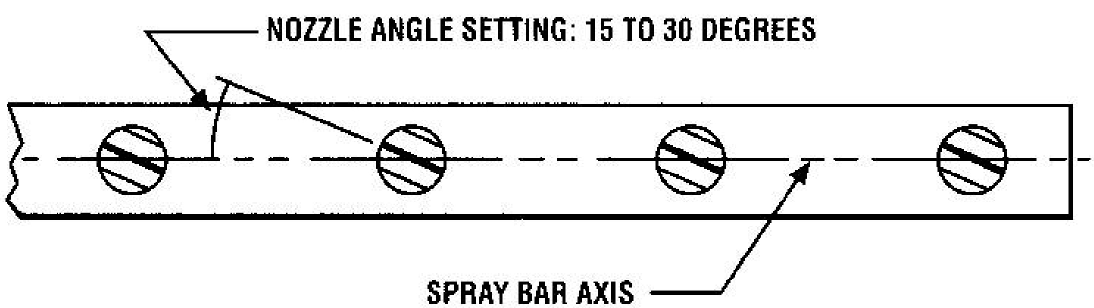

Figure 9. Proper spray bar nozzle orientation.

While modern distributor trucks have excellent capabilities and are typically computerized to help minimize errors, calibration of the truck, as described above, is still needed to further verify residual application amounts.

Proper spray bar height is also important. Setting this height to provide a double, or preferably, triple overlap as seen in Figure 10 is also crucial to achieving application uniformity. Moreover, this overlap helps to maintain coverage if any of the nozzles were to become compromised during the application. Triple coverage is maintained with a spray bar height of about 1-foot.

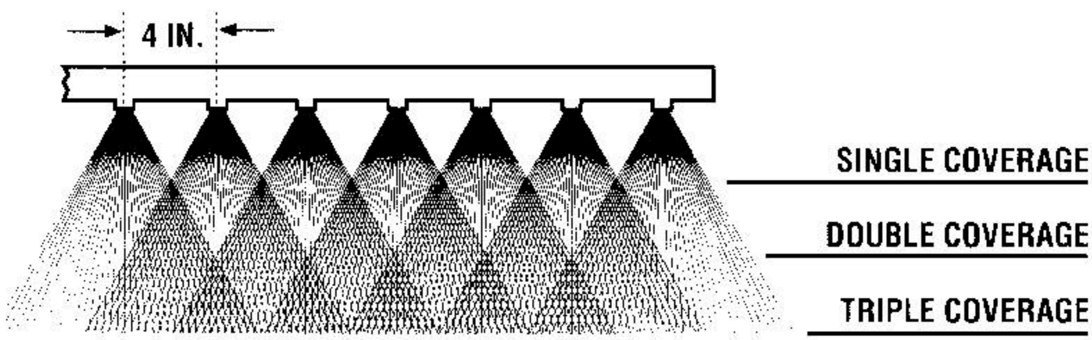

Figure 10. Display of single, double, and triple overlay coverage.

Contract Language

Contract language for tack coats needs to be clear and non-ambiguous. Required application values should be in terms of residual asphalt application rates (see Table 1). This helps to assure that the right amount of tack is applied. Whether dilution of an emulsion is allowed or not, by whom, and to what extent, needs to be clearly stated. This helps to induce the needed control over any addition of water to the undiluted emulsion to be able to accurately calculate residual values. Agencies are encouraged to include tack as a separate bid item as opposed to being treated as an incidental component of paving. This helps to increase the amount of attention that is placed on the tack coat by both the contractors and agencies.

Conclusion

Bonding of pavement layers is vital to the creation of long life asphalt pavements. With proper bonding of the layers, a monolithic structure is formed, greatly improving a pavement's resistance to stress and fatigue. This is consistent with the assumptions common to all pavement thickness design methods. Failure to achieve adequate bond strength results in increased potential for pavement layer slippage, shoving, and/or fatigue cracking. Moreover, the cost of tack coats relative to project costs is relatively minor. But the cost of a bond failure can quickly escalate to where it could potentially match the cost of the original project. It is, therefore, most advantageous to properly select and install tack coats so that overall pavement costs are minimized.

Selection of an appropriate tack coat material, applied in the recommended residual ranges provides the glue necessary to bond the pavement layers. Surface preparation creating a clean and dry surface is required for bonding. Milling of existing surface materials will further improve bonding capabilities, thus typically improving pavement performance. Maintaining, and calibrating the distributor truck is also needed to provide the desired uniform application. It is important to select the appropriate nozzles sizes to match both the material and the target residual application rate. Additionally, the spray bar should be set to achieve either a double or triple overlap to ensure uniform coverage. Poor uniformity can be due to many factors, including blocked nozzles, improper angle, improper nozzle size, improper distributor truck speed, or inadequate pump pressure.

A uniform application of a high quality tack coat at the appropriate residual asphalt rate to a clean dry surface is key to successfully bond pavement layers together for peak long-term performance.

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Tack Coat Best Practices

Contact—For more information, contact:

Federal Highway Administration (FHWA)
Office of Asset Management, Pavements and Construction
John Bukowski - john.bukowski@dot.gov

FHWA Office of Technical Services – Resource Center
Christopher Wagner – Christopher.wagner@dot.gov (Pavement & Materials Technical Service Team)

Federal Highway Administration http://www.fhwa.dot.gov/resources/pubstats/

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