CHAPTER 2 – LITERATURE REVIEW OF HANDBOOKS

PRIME COAT

Definition

According to *ASTM D 8-02 Standard Terminology Relating to Materials for Road and Pavements*, a prime coat is "an application of a low-viscosity bituminous material to an absorptive surface, designed to penetrate, bond, and stabilize the existing surface and to promote adhesion between it and the construction course that follows" (1). The Asphalt Institute describes a prime coat as "a spray application of a medium curing cutback asphalt or emulsified asphalt applied to an untreated base course" (2). The U.S. Army Corps of Engineers (USACE), in their *Guide Specifications for Military Construction* (3), defines a prime coat as "an application of a low viscosity liquid asphalt material on a non bituminous base course before placement of a hot-mix asphalt (HMA) pavement" (3).

Purpose

ASTM D8 states that "the purpose of a prime coat is to penetrate, bond and stabilize the existing layer and to promote adhesion between the existing surface and the new surface" (1). The USACE describes the purpose of a prime coat as "to penetrate and reduce the voids in the surface of an unbound base course and to bind the particles together to form a tight, tough surface on which bituminous concrete can be placed" (3). According to the *Unified Facilities Criteria* (UFC) (4), developed by the USACE, "the main purposes of a prime coat are: 1) to prevent lateral movement of the unbound base during pavement construction, 2) to waterproof during pavement construction, and 3) to form a tight, tough base to which an asphalt pavement will adhere" (4).

The *Hot-Mix Asphalt Paving Handbook 2000* (5), a publication whose development was sponsored by numerous agencies including the USACE and the Federal Highway Administration, states that a prime coat prevents a granular base course from absorbing excess moisture during rain before paving and that its purpose is to protect the underlying materials from wet weather by providing a temporary waterproofing layer prior to paving. Additional benefits of prime coats were reported as allowing the use of the base by light traffic, binding together dust particles, promoting bond between the base and the new overlay and preventing slippage of thin overlying pavements (5).

The Asphalt Institute in MS-22 (2) lists the three purposes of a prime coat as: 1) filling the surface voids and protecting the base from weather, 2) stabilizing the fines and preserving the base material, and 3) promoting bonding to the subsequent pavement layers. Other important functions of prime coat are reported as: coats and bonds lose mineral particles on the surface of the base, hardens or toughens the surface of the base, waterproofs the surface of the base by plugging capillary or interconnected voids and provides adhesion or bond between the base and the asphalt mixture (6,7).

Erdmenger [8] reported that the primary use of a prime coat in an unbound base course is to provide a firm stable foundation to support the HMA layer. Additional benefits of prime were noted as 1) penetrating the unbound base and hardening the top surface, 2) helping to bind the base with the overlaying asphalt course, and 3) reducing the maintenance of untreated compacted base when the HMA layer is not laid for a long time. The Ohio Center for Asphalt Pavement Education (OCAPE) [9] also reports that a prime coat is beneficial in providing some weather proofing to an unbound granular base that may be exposed to the weather for an extended period of time.

Although the definitions and stated purposes of prime are similar, there are subtle differences that indicate the lack of consensus on the need for and proper use of prime coats.

Waterproofing/Penetration

From the above references it is obvious that one of the primary purposes of prime coat is to protect the pavement system from moisture. One of the older references found mentioned that the purpose of prime was to prevent moisture in the subgrade from working up into, or to halt the capillary movement of water up into, the HMA mix [10]. Other more current references did not specifically refer to this halting of capillary or upward movement of moisture.

To perform the above functions, the prime must adequately penetrate the base [5,6,7,10]. The OCAPE [9] states that regular asphalt emulsions are not suitable for use as prime coat because they will not penetrate the surface. The Asphalt Emulsion Manufacturers Association (AEMA) [6] reports that emulsions for priming almost always require dilution with water for adequate penetration. Dilution and application rates were reported to vary depending on the base material characteristics with dense materials requiring higher dilution rates, greater than one to one, or multiple applications at lower rates to prevent runoff. Bases with fine grained materials, passing 0.075 mm (#200) sieve, act as a filter and will not let emulsion asphalt particles penetrate. Mechanical mixing or scarification of the surface was recommended to produce an acceptable prime when emulsions are used [6].

Only one mention to a reference was found that stated the penetration depth required for prime to function effectively. Mantilla and Button [11] referenced a South African publication, *Guide on Prime Coats, Tack Coats and Temporary Surfacing for the Protection of Bases,* National Institute for Transportation Research, Pretoria, South Africa, 1970, that reported a prime coat must penetrate a granular base 5 to 10 mm (0.2 to 0.4 in) to be effective. No other reference to a minimum penetration depth was found.

Curing

If prime coat is used, it must cure completely to function properly [2]. No more prime should be applied than can be absorbed by the granular base in 24 hours [2,4,5,7]. Any excess prime should be removed from the surface prior to paving. Blotter sand is usually recommended [2,5,7] to absorb the excess prime. The loose blotter sand must be removed from the granular base prior to paving or a poor bond may result [2,7].

There is not complete agreement as to the minimum cure time required for prime. However, this may have more to do with differing prime coat materials than with a disagreement in procedures. Prime coats generally take several days to properly cure so they can withstand construction traffic. The curing of prime coat depends upon the weather. It the weather is hot the prime coat will cure quickly and if the weather is cool and damp the prime coat will cure slowly. Emulsified products would cure faster and might only require 24 hours to fully cure [2], whereas cutbacks would require a longer time period, 24 to 72 hours [2,5].

According to the USACE, it is riskier to place a HMA layer over an uncured prime coat than an unprimed base because the uncured prime can cause more base movement than construction on an unprimed base [4]. The USACE's UFC [4] reports that excessive prime remaining on the surface can be absorbed into overlying asphalt layers contributing to pavement slippage or rutting. According to the USACE *Guide Specifications for Military Construction* [3], an excessive prime coat causes lateral movement of the asphalt concrete during rolling operations. They go on to recommend that a prime coat be omitted in cold weather because prime materials cure slowly in cold weather. When the asphalt layer is constructed without a fully cured prime coat, then the detrimental constituents of the prime coat can damage the asphalt layer quickly. Therefore, the USACE recommends not using prime coat if it can not be cured properly [3].

Structural Benefits

Increased Load Bearing Capacity:

There was no mention made in the handbooks reviewed supporting the notion that prime coat increases the load bearing capacity of a pavement. Prime coats are not considered structural applications [5,9]. OCAPE [9] states that anytime an unbound layer of material is stabilized there is a benefit; however, it would be an overstatement to claim substantial structural benefit.

Interface Shear Strength:

Numerous references were found stating that one of the purposes of a prime was to promote bond between the granular base and to prevent slippage [2,3,4,5,6,7,8]. The USACE reports that 1) an excessive amount of prime coat causes lateral movement of the asphalt concrete during rolling operations [3] and 2) excessive prime remaining on the surface can be absorbed into overlying asphalt layers contributing to pavement slippage or rutting [4]. OCAPE [9] reported that some paving personnel believe that prime coats limit the amount of mix sliding during compaction of HMA over aggregate base but that mix crawl was more related to mix formulation and that prime alone would not eliminate the phenomenon.

Usage

Granular Bases

No references were found that said prime coats are either mandatory in all cases or unnecessary in all cases. The 1991 version of the *Hot-Mix Asphalt Paving Handbook* [12] reports that in many cases prime coats are not needed and OCAPE [9] reported that the necessity for using prime coat in HMA pavement construction has long been questionable to pavement engineers. AEMA [6] recommends that prime coats should be considered when any doubts exist about the results if it were eliminated.

A prime coat is not a substitution for maintaining the specified condition of the granular base or subgrade prior to paving [5]. The majority of the handbooks reviewed mentioned that a granular base should meet all requirements for density, moisture content, smoothness and grade prior to paving or priming. Local conditions, local experience, type of base material and type of prime coat material available should all be considered before deciding on the application of a prime coat. The following subsections list the conditions under which the handbooks reviewed reported that prime coats could be safely deleted.

Weather, Construction Sequence:

Most of the handbooks stated that if there was no chance of rain before the granular base would be covered, and the granular base met all specification requirements, the prime could be deleted. The *Hot-Mix Asphalt Paving Handbook 2000* [5] reports that the purpose of prime coat is to protect the underlying materials from wet weather and if the underlying materials can be covered prior to rainfall, a prime coat is not needed. The USACE [3] states that if the construction of an HMA layer is started over a newly constructed unbound layer within seven days of construction, then the prime coat is not necessary. However, if the construction of an HMA layer is carried out after seven days, the unbound base course should be prime coated to protect it from weather and traffic [3].

NCHRP Synthesis of Highway Practice 47, *Effect of Weather on Highway Construction* [13] reported that most agencies did not permit the application of primes during cold weather. However, there was considerable variation in agency specifications regarding the lowest temperature allowed for prime work. The critical factor in late-season priming was reported as the curing time available before the prime is covered with asphalt [13]. When the asphalt layer is constructed without a fully cured prime coat, the detrimental constituents of the prime coat can damage the asphalt layer quickly [3].

Pavement Thickness:

Several publications noted that prime coats are being used less frequently, especially in thicker pavements, greater than 100 mm (4 in) of HMA [5,6]. With thicker pavements there is less chance of surface water penetrating into the base or pavement slippage on the base [6]. The Asphalt Institute [2] recommends a prime coat be used when the total HMA layer is less than 100 mm (4 in) thick, unless prevailing circumstances prevent it. Prevailing circumstances that would prevent the use of prime coat were listed as 1) when foot traffic is present, 2) when there is a strong possibility of runoff, or 3) when the project cannot be closed for proper curing time. Erdminger [8], in his guidelines for application of emulsified prime materials, suggested that prime coat may not be necessary when the subsequent pavement layers are either an asphalt stabilized base or any asphalt pavement thicker than 100 mm (4 in).

Traffic/Base Stability:

The *Hot-Mix Asphalt Paving Handbook 2000* (5) states that the performance of an HMA pavement is related to the properties of the materials underneath it. When HMA is placed over an untreated aggregate base, the base should be stable, dry, and the surface should not be distorted by construction traffic carrying mix to the paver. Prime coat material should be applied to a dust free unbound base. Before priming, the base should be compacted thoroughly and traffic should not be allowed on the unbound base. Allowing traffic on the unbound base will loosen the surface materials and the base course will not be stable (5).

Erdminger (8) reported that the probability of a granular base being damaged by traffic depended on the characteristics of the granular base. A crushed limestone base has a tightly bonded, dense surface, whereas gravel bases and poorly graded crushed stone bases needed prime coat because they were poorly bonded and could be easily damaged by traffic and weather.

Stabilized Bases

By tracing the definition of prime coat over the years, one can get an indication of the variations of opinions on the use of prime coats and on the development of the current state of the practice. From as far back as the 1960s, the Asphalt Institute has indicated that prime coats are intended for non asphalt treated bases (7,14,15,16). The USACE (3) states that prime coats are for non bituminous base courses. Current Asphalt Institute literature states that prime coats are for untreated base course materials (2) or granular base courses (6). The *Hot Mix Asphalt Paving Handbook 2000* (5) recommends prime coats be limited to granular bases and Erdminger (8) suggested that prime coat may not be necessary when the subsequent pavement layers are asphalt stabilized base.

The *Basic Asphalt Recycling Manual* (BARM) (17), developed and published by the Asphalt Recycling & Reclaiming Association, does not recommend the use of prime coat on full depth reclamation (FDR) projects or cold in-place recycled (CIR) projects. To confirm this, several persons knowledgeable in FDR and CIR were surveyed either by phone or by e-mail. FDR and CIR contractor personnel included John Huffman, Brown & Brown Contractors, Inc.; Edward Kerney, Gorman Brothers, Inc.; and Jean-Martin Croteau, Miller Group. Consultants experienced with FDR and CIR included Leonard Dunn, author of the BARM; John J. Emery, Ph.D., P.E., consultant; and Doug Hansen, Assistant Director, NCAT.

The responses from the above listed experts can be summarized by stating that bituminous stabilized materials should not be primed. The major concern stated by those persons knowledgeable in FDR and CIR was that solvents in typical prime materials, cutbacks and asphalt emulsion prime (AE-P), could soften the bituminous stabilized base, weakening the pavement structure. The BARM (17) recommends, as well as the majority of those individuals surveyed, that FDR and CIR bases be tacked prior to placement of an HMA overlay. There appears to be a consensus that stabilized materials, especially bituminous stabilized materials, should not be primed.

Subgrades

The *Hot-Mix Asphalt Handbook 2000* [5] states there is no need to place a prime coat on a silty clay or clay subgrade soil because the low permeability of silty clay and clay soils would prevent absorption of the prime coat material. The use of prime coats on sandy subgrade soils was also questioned because sandy subgrades that are unstable under construction traffic would require stabilization rather than a prime coat to support construction traffic [5]. Subgrades should be maintained in to their specified moisture and density prior to placing subsequent pavement layers [5]. The Asphalt Institute does not recommend priming of subgrade soils [18]. Figure 1 shows the lack of penetration of an asphalt emulsion prime placed on a silty clay subgrade.

Figure 1. Photo. Lack of penetration of emulsified asphalt prime on silty clay subgrade.

Materials

Cutbacks

Low viscosity medium curing (MC) grades of liquid asphalt are generally used for prime coat when dense, hard to penetrate bases are to be primed, typically an MC-30 or MC-70 [2,5,6,7,10]. When the surface is sufficiently open, higher viscosity MC grades or low viscosity rapid curing (RC) grades of liquid asphalt may be used, provided penetration is achieved without depositing excessive asphalt on the surface. OCAPE [9] recommends the use of MC grade cutbacks over RC grade cutbacks because the distillates used in MC cutbacks (kerosene) is safer than those used in RC (gasoline or naphtha) cutbacks.

Asphalt Emulsions

OCAPE [9] states that regular asphalt emulsions are not suitable for use as prime coat because they will not penetrate the surface. However, there was some mention of using diluted slow set emulsions as a prime but the material would require mechanical mixing or working into the top 25 to 75 mm (1 to 3 in) to be effective [6,7]. Specially formulated penetrating emulsions, such as asphalt emulsion prime (AE-P) and penetrating emulsion prime (PEP) have been successfully used as prime coat materials [5] and MS-19 [6] reported that both are now generally available.

Application Rates

Primes coat materials are either cutback asphalts or emulsified asphalts, which are diluted or cut or with a petroleum solvent or emulsified with water, respectively. Further dilution is usually not required. Therefore, most agencies specify application rates based on the volume of the delivered product per unit area. Confusion rarely occurs unless the prime is diluted further to aid in application. To avoid confusion, the *Hot-Mix Asphalt Paving Handbook 2000* [5] recommends application rates be based on residual asphalt content. The shot rate or application rate to achieve the specified residual asphalt content can be determined using the following formula:

$$AR = RAR / RAC \qquad [1]$$

Where: AR = application or shot rate of undiluted prime
RAR = specified residual application rate
RAC = residual asphalt content of prime

There is good agreement in the literature on application rates. The Asphalt Institute [2,6] recommends application rates of 0.9 to 2.3 L/m^2 (0.2 to 0.5 gal/yd^2) for MC cutbacks and 0.5 to 1.4 L/m^2 per 25 mm of depth (0.1 to 0.3 gal/yd^2 /in depth) for asphalt emulsions. Others recommend from 0.65 L/m^2 to 2.0 L/m^2 (0.15 to 0.45 gal/yd^2) [5,19]. Application rates should vary based on the openness of the base and no more prime should be placed than can be absorbed by the granular base in 24 hours. Any excess should be removed with blotter sand [2,4,5].

Proper asphalt distributor construction procedures are required to prevent streaking, allow proper application rates and uniform coverage [2,5,6]. 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 [2,6], as shown in Figure 2.

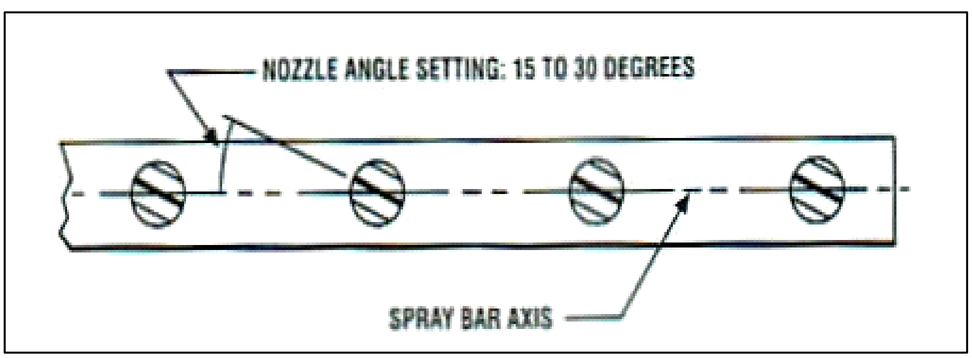

Figure 2. Schematic. Proper setting of spray-bar nozzles [6].

Most nozzles are set at 30 degrees [(5)]. The height of the spray bar should be set to allow for an exact single, double or triple overlap [(2,6)]. A double overlap is recommended for most prime applications [(4,6)]. For uniform application, proper spray bar height must be maintained during application. This requires that the spray bar height be adjustable to correct for the truck's rear springs rising as the load lessens [(2)]. Figure 3 shows the effect of incorrect spray bar height and the proper spray bar heights for double and triple coverage.

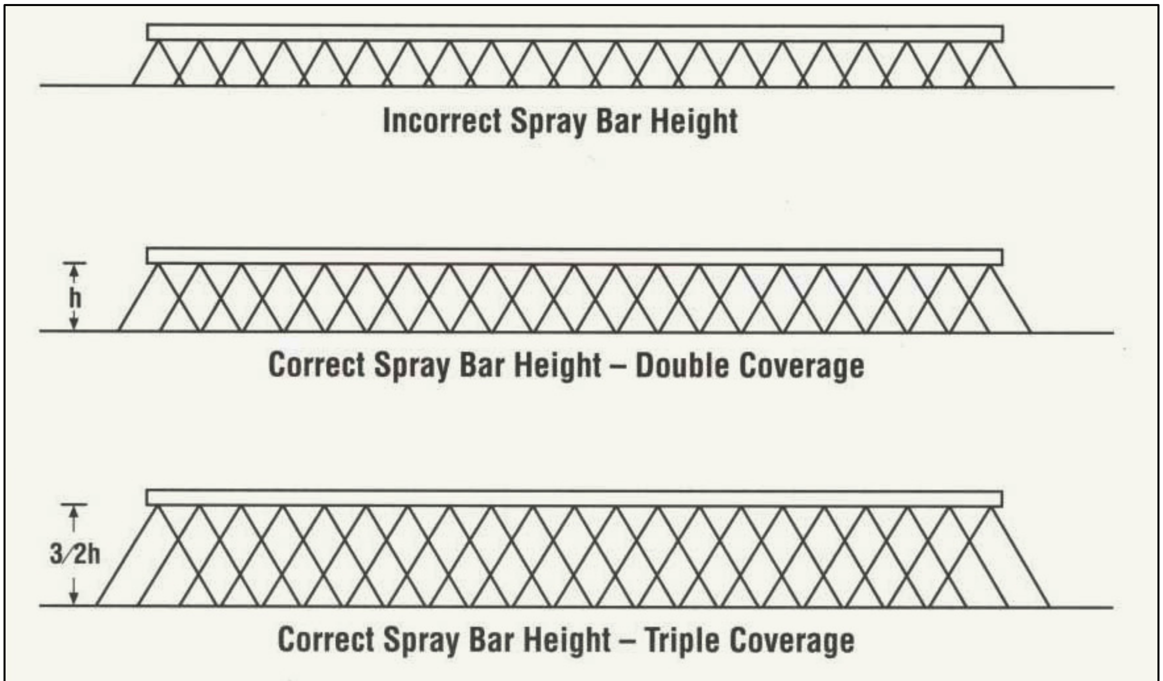

Figure 3. Schematic. Spray bar height and coverage [(2)].

Adequate viscosity of the liquid asphalt is required for proper spray application. This is achieved by heating MC cutbacks and occasionally emulsions or diluting emulsions with water. Table 1 shows recommended application temperatures for typical prime coat materials. Figure 4 shows the results of applying prime at too high a viscosity.

Table 1. Recommended spray temperature range for prime and tack coat.

Type and Grade of Asphalt	Temperature Range	
	^{o}C	^{o}F
SS-1, SS-1h, CSS-1, CSS-1h[1]	20-70	70-160
MS-1, MS-2, MS-2h, CMS-2, CMS-2h[1]	20-70	70-160
MC-30[1]	30+	85+
MC-70[1]	50+	120+
MC-250[1]	75+	165+
AE-P[2]	49-82	120-180
EAP&T[2]	15-38	60-100

[1] Reference [(6)]
[2] Reference [(20)]

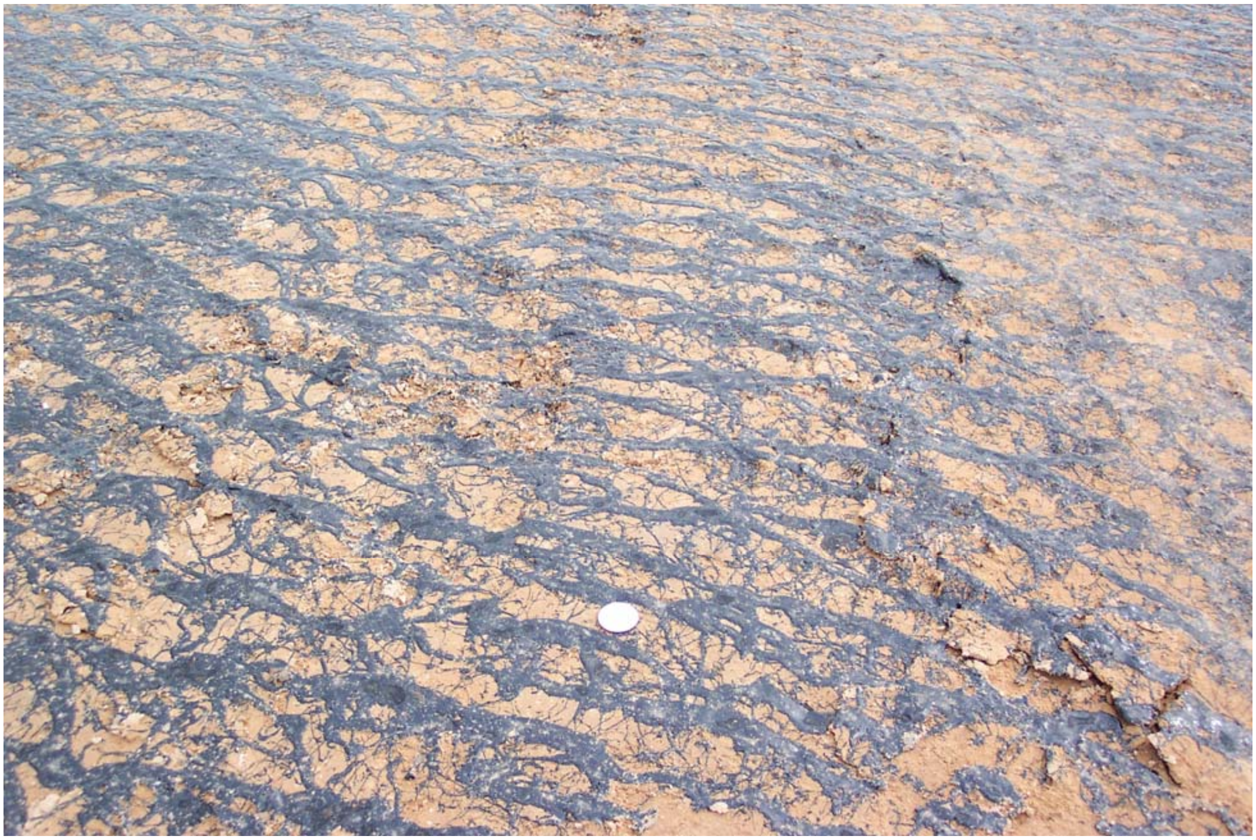

Figure 4. Photo. Prime applied at too high a viscosity.

TACK COAT

Definition

According to *ASTM D 8-02 Standard Terminology Relating to Materials for Road and Pavements*, "Tack coat (bond coat) is an application of bituminous material to an existing relatively non absorptive surface to provide a thorough bond between old and new surfacing" (1). According to AEMA, "a tack coat, also known as bond coat, is a light application of asphalt emulsion between hot mix asphalt layers designed to create a strong adhesive bond without slippage" (6).

The USACE defined tack coat as "a heated Rapid Setting (RC) liquid asphalt or an emulsified asphalt (normally SS or RS grades), which is applied to the clean existing surface before the new course is constructed to ensure a good bonding between the two layers" (3). The USACE's UFC defined tack coat as "an application of diluted asphalt emulsion or cutback asphalt placed on an existing HMA or old concrete surface to provide a bonding with a new HMA layer" (4).

Purpose

There was little disagreement in the literature on the purpose of tack coat; the main purpose of tack coat is to ensure good bonding between an existing pavement surface and a new pavement surface (2,3,4,5,6,7,10,21,22). The existing layer could be either a properly prepared older pavement surface or a recently placed lift of a multi-lift asphalt pavement [7]. *The Aggregate Handbook* [23] states the purpose of a tack coat is to ensure a bond at interfaces between asphalt layers. Asphalt material used as tack coat should be easily sprayable, cured readily prior to subsequent construction and generate adequate bond between layers.

According to *The Asphalt Handbook* [7], the two essential properties of a tack coat are it must be thin and it must uniformly cover the entire surface of the area between new and old HMA layers so they act as a monolithic system withstanding the traffic and environmental loads. The handbook states that many tack coats have been placed too heavy, leaving a surplus of asphalt which flushes into the overlying course, resulting in a tendency to avoid their use. A thin tack coat was reported to do no harm to the pavement and would properly bond the courses [7].

Usage

Existing and New Pavement Surfaces

There was good agreement in the literature on when and where tack coats are necessary and when and where they can be safely deleted. Tack coat is essential when an HMA overlay is placed over an existing pavement surface, whether it be HMA or PCC [5,19]. The BARM [17] recommends a tack coat be placed for all HMA overlays over FDR and CIR mixtures and the USACE's UFC [4] reported that a tack coat may be required on a primed base course when the primed base has been subjected to construction traffic or other traffic. In all cases, regardless of whether tack is applied, the existing surface must be clean and dust free and tack should not be used in lieu of cleaning the existing surface [5,21,22].

The Asphalt Institute reports that tack coats are recommended for all overlays with the only possible exception being when an additional course is placed within two to three days on a freshly-laid asphalt surface that has not been turned over to traffic [6,7]. Lavin [19] states that tack coats are used to bind new layers together; however, a tack coat may not be necessary and is usually not needed if constructing the courses days or even weeks apart. The *Hot-Mix Asphalt Paving Handbook 2000* [5] states that tack coat is essential when an overlay is placed over an old, existing pavement surface, either HMA, PCC or surface treatment. However, when a layer of new mix is being placed over another layer of asphalt pavement that has been laid within a few days, as long as the underlying new layer has not become dirty under traffic or from windblown dust, a tack coat may not be necessary [5].

Longitudinal and Transverse Joints

There was good agreement in the literature consulted indicating all vertical surfaces should be tacked, including curbs, gutters, cold pavement joints, structures, and vertical surfaces of patches [2,6,7,10,19,21,24]. MS-22 [2] specifically stated that the vertical surface of transverse joints should be tacked along with the vertical surface of longitudinal joints. However, not all longitudinal joints are constructed with a vertical face.

The *Hot-Mix Asphalt Paving Handbook 2000* [5] specifically addressed the situation of tacking joints by reporting that all vertical surfaces should be tacked, including transverse and longitudinal joints. For longitudinal joints, it was recommended that if the free edge of the longitudinal joint was not cut back to a vertical surface, and if the mix along the joint was clean, then a tack coat would not normally be needed. There has been no reported evidence that the use of tack coat significantly increases the durability of the longitudinal joint under traffic. Other operational techniques generally affect the longevity of the joint more than the presence or absence of a tack [(5)].

Materials

The most common materials for tack coat are diluted, slow set asphalt emulsions. Diluted emulsions are reported to give better results for following reasons: 1) diluted emulsified asphalt provides the additional volume needed for the distributor to function at normal speed when lower application rates are used and 2) diluted emulsion flows easily from the distributor at ambient temperatures allowing for a more uniform application [(2)]. However, Flexible Pavements of Ohio [(21)] reports that only slow set emulsions should be diluted with water. The Texas Department of Transportation [(22)] recommends that emulsions used for tack not be diluted; however, if the emulsion is diluted it must be diluted with water by the supplier. The contractor is not allowed to dilute the emulsion at the work site.

Cutback asphalts are occasionally used as tack and can be used in colder climates than emulsions [(4)]. However, environmental concerns limit their use in some locations [(21,22)]. Asphalt cements are occasionally used; however, they must be heated sufficiently to allow spray application. Asphalt cements would cool quickly, requiring application immediately in front of the paver [(5)].

Application

The Aggregate Handbook [(23)] states that the application rate of tack coat should be within limits to prevent puddling of material that may result in potential slippage between layers. Lighter application rates of tack coat are generally preferred since heavy application can cause serious pavement slippage and bleeding problems [(4)]. Excessive tack coat can act as a lubricant creating slippage planes and excess tack can be drawn into an overlay detrimentally affecting mix properties [(21)]. Failure to use tack coat or insufficient tack coat can also cause pavement slippage and debonding problems [(6,7,22)].

Surface Preparation

There was general agreement among the handbooks consulted on the required surface condition of an existing pavement prior to applying tack. Tack should be applied to a clean, dry surface and sweeping with a power broom was the recommended method [(2,5,7,21,22)]. Tack should not be used in lieu of cleaning the existing surface [(5,21,22)].

The Asphalt Institute provides a good summary of weather conditions and surface preparation for proper tack application. MS-19 [(6)] reports that the best results are obtained when tack coat is applied to a dry pavement surface with a temperature above 25^{o}C (77^{o}F). The surface must be clean and free of lose material so it will adhere. MS-22 [(2)] reports that tack coat applications are made under the same weather conditions as HMA paving and that the surface should be clean and dry prior to application.

The same weather conditions for prime coats are generally applicable to tack coats. However, because tack coat application rates are considerably less than for prime coat, curing is less of a problem. Tack is occasionally omitted in late season paving to facilitate construction progress but only if a good bond can be achieved without the tack coat (13).

Application Rates

There was general agreement found in the handbooks on tack coat application rates. The only confusion seems to be determining if application rates are total application rates, including water added for dilution, or residual asphalt contents. The shot rate or application rate to achieve the specified residual asphalt content can be determined from the following formula:

$$AR = (RAR / RAC) / (D / 100) \qquad [2]$$

Where: AR = Application or shot rate of undiluted tack
RAR = Specified residual application rate
RAC = Residual asphalt content of tack
D = Percent dilution

Tack coat application rates were most often reported as being 0.25 to 0.70 L/m^2 (0.05 to 0.15 gal/yd^2) for an emulsion diluted with one part water to one part emulsion (2,6,7). The USACE's UFC recommends application rates 0.23 to 0.68 L/m^2 (0.05 to 0.15 gal/yd^2) of residual asphalt (4). The lower application rates are recommended for new or subsequent layers while the intermediate range is for normal pavement conditions and on an existing relatively smooth pavement. The upper limit is for old oxidized, cracked, pocked, or milled asphalt pavement and PCC pavements (2,4,6,7). The exact application rate should be determined in the field (2).

Lavin (19) recommended application rates of 0.2 to 1.0 L/m^2 (0.04 to 0.22 gal/yd^2) and that tack be diluted to a final asphalt binder content of around 30% to improve uniformity of spray. This would typically require dilution with one part water to one part emulsion. Lavin (19) further suggested that milled pavements have a larger surface area due to the grooves left by milling and can require application rates of 1.0 L/m^2 (0.22 gal/yd^2) or more and that tack between new HMA layers usually requires less than 0.3 L/m^2 (0.07 gal/yd^2).

The *Hot-Mix Asphalt Paving Handbook 2000* (5) recommends application rates be based on residual asphalt content. The residual asphalt contents should range from 0.18 to 0.27 L/m^2 (0.04 to 0.06 gal/yd^2). Open-textured surfaces were reported to require more tack coat than a surface that is tight or dense. Dry, aged surfaces require more tack coat than a surface that is "fat" or flushed. A milled surface would require even more residual asphalt because of the increased surface area, as much as 0.361 L/m^2 (0.08 gal/yd^2). Only half as much residual asphalt is typically required between new HMA layers, 0.09 L/m^2 (0.02 gal/ yd^2) (5).

The USACE's UFC (4) recommends a Saybolt Furol viscosity of between 10 and 60 seconds for proper application of tack coat. Dilution with water for emulsified asphalt or heating for cutback asphalts is usually required. Recommended application temperatures for tack coat materials were shown in Table 1. Table 2 shows typical application rates for slow set asphalt emulsions containing approximately 60 percent bituminous materials, as reported by Flexible Pavements of Ohio [21].

Proper asphalt distributor construction procedures are required to prevent streaking, allow proper application rates and uniform coverage [2,5,6]. 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 [2,6], as shown in Figure 2. Most nozzles are set at 30 degrees [5]. The height of the spray bar should be set to allow for an exact single, double or triple overlap (*2,6*). A double overlap is recommended for most tack applications [4,6]. For uniform application, proper spray bar height must be maintained during application. This requires that the spray bar height be adjustable to correct for the truck's rear springs rising as the load lessens [5]. Figure 5 shows the non uniform application that results from incorrect spray bar height and/or pump pressure. Figure 6 however, shows the proper overlap and spray bar height.

Table 2 - Typical tack coat application rates [21].

Existing Pavement Condition	Application Rate (gallons/yd^2)		
	Residual	Undiluted	Diluted (1:1)
New Asphalt	0.03 to 0.04	0.05 to 0.07	0.10 to 0.13
Oxidized Asphalt	0.04 to 0.06	0.07 to 0.10	0.13 to 0.20
Milled Surface (asphalt)	0.06 to 0.08	0.10 to 0.13	0.20 to 0.27
Milled Surface (PCC)	0.06 to 0.08	0.10 to 0.13	0.20 to 0.27
Portland Cement Concrete	0.04 to 0.06	0.07 to 0.10	0.13 to 0.20
Vertical Face*			

1 L/m^2 = 0.2209 gal/yd^2

* Longitudinal construction joints should be treated using a rate that will thoroughly coat the vertical face without running off.

Uniformity

Uniformity of application and proper application rate are the keys to achieving a successful tack coat [5,21,22]. If a non uniform or spotty application of tack coat is encountered, as shown in Figure 5, several passes with a pneumatic roller were reported to help spread the asphalt, lessen the probability of fat spots and give uniform coverage when the tack was unevenly applied [4,6,7,21,22].

Figure 5. Photo. Non uniform coverage resulting from incorrect spray bar height and/or pump pressure.

Figure 6. Photo. Proper overlap and spray bar height.

Curing

There was not complete agreement in the handbooks concerning the necessity of tack coat being completely cured before laying the HMA layer. Many publications reported that the tack should be either cured (3,4,6,7,21) or cured until tacky (2,22) before placing the new pavement layer. The Asphalt Institute reports that tack placed too far out in front of the paver can lose its tack characteristics and would require additional tack (2). No more tack should be applied than can be covered in one day (2,4,6,7) and any tack that was not covered that day should be retacked prior to paving (2).

The *Hot-Mix Asphalt Paving Handbook 2000* (5) devoted a section to the question regarding the necessity of tack curing before placing the new pavement layer. In it they reported that an asphalt emulsion will typically break in 1 to 2 hours and in the past it was generally believed that the emulsion should be completely set before new mix is laid on top of tack coat material. Experience has shown that new HMA can usually be placed on top of an unset tack coat (some of the water is still on the pavement surface) and even on an unbroken tack coat emulsion (water and asphalt still combined) with no detrimental effect on pavement performance; the bond will still be formed (5).

The *Hot-Mix Asphalt Paving Handbook 2000* (5) goes on to state that in Europe the emulsion tack coat is often applied to the pavement surface underneath the paver just before the head of HMA in front of the paver screed. With this tack coat application point, the emulsion will be unbroken when the mix is placed on top of it, but the emulsion will break immediately upon contact with the new HMA. The water, 0.36 L/m^2 (0.08 gal/yd^2) typically, will evaporate and escape as steam through the loose hot mix. There is not enough water to lower the mix temperature significantly (5).

Lavin (19) reported that an overlay can be applied either directly after the tack has been applied or after it has changed from brown to black (breaks). The bond between the layers will still be created regardless of whether the asphalt emulsion broke prior to paving the subsequent layer.

Traffic

The handbooks were in general agreement that traffic, both construction and otherwise, should be kept off uncured tack coat, as well as cured tack coat, if at all possible (4,5,21). The Asphalt Institute reports that a tack coat surface is slick (2,6,7) and that freshly tacked pavement is generally too slick for safe driving, particularly before the asphalt emulsion has broken (6,7,21). They go on to recommend that traffic should be kept off the tack coat until no hazardous conditions exist and that drivers be warned of the probability of the asphalt emulsion spattering when traffic is permitted on a tack coat (2).

The *Hot-Mix Asphalt Paving Handbook 2000* (5) reported that tack coat should not be left exposed to traffic and if doing so was necessary, proper precautions, such as reducing the posted speed limit on the roadway and sanding the surface should be taken. Recommended sand application rates were 2.2 to 4.4 kg/m^2 (4 to 8 lb/yd^2). Excess sand should be broomed from the surface before the overlay is placed to ensure a proper bond (5).

The magnitude of tack coat tracking by traffic is reported as being dependent on the type of tack coat used and whether the emulsion has set. Rubberized tack material readily adheres to vehicle tires and will track worse than conventional emulsions, especially if not allowed to fully set [21].

SUMMARY

The following conclusions are warranted based on the literature reviewed.

Prime Coat

1. The major purpose of prime coat is to protect the underlying layers from wet weather by providing a temporary waterproofing layer.
2. Additional benefits of prime coat are stabilizing or binding the surface fines together and promoting bond to the HMA layer.
3. Prime coats must adequately penetrate the base to function properly.
4. Prime coats need to be allowed to cure completely before covering with HMA. Cutbacks generally take longer to cure than asphalt emulsions. Prime is often deleted in cold weather because it is riskier to pave over uncured prime than over unprimed base.
5. Excess prime not absorbed into the base after 24-hours should be absorbed with blotter sand and removed from the surface.
6. Prime should not be applied to stabilized bases or subgrade.
7. Prime coats are often deleted if no wet weather is anticipated and the base can be covered within seven days. Prime may not be necessary if the HMA layer is greater than 100 mm (4 in) thick.
8. Prime may be omitted if there is a strong possibility of runoff entering a waterway.
9. Medium cure cutbacks are normally used for prime. Asphalt emulsions generally require mixing into the base to function properly.
10. Use of prime coat is not a substitute for maintaining the specified condition of the base or subgrade.

Tack Coat

1. The purpose of tack coat is to ensure bond between the existing pavement surface and a new pavement surface.
2. Tack coat should be applied in a thin coat and uniformly cover the entire surface, including all vertical surfaces of joints and structures. Too little tack coat can cause debonding and too much tack coat can cause slippage.
3. Tack should be applied to an old existing HMA surface and a PCC surface. Tack has been successfully deleted between new lifts of HMA when the surface of the existing lift is still clean and tacky.
4. Prior to tack application the surface should be clean, dry and free from lose material.
5. There is not complete agreement regarding the requirement that tack coat be allowed to break and set before placing the HMA layer.
6. Applying tack is not a substitute for properly cleaning the existing HMA surface.
7. Diluted slow set emulsions are typically used for tack coat.
8. If possible, all traffic should be kept off tacked surfaces.