GUIDELINES FOR USING PRIME AND TACK COATS

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Federal Lands Highway
Commitment to Excellence

Central Federal Lands Highway Division
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FOREWORD

The Federal Lands Highway (FLH) promotes development and deployment of applied research and technology applicable to solving transportation related issues on Federal Lands. The FLH provides technology delivery, innovative solutions, recommended best practices, and related information and knowledge sharing to Federal agencies, Tribal governments, and other offices within the FHWA.

The objective of this study was to produce a prime and tack coat guide publication developed for project development and field personnel to provide decision-making guidance on how to use, when to keep, and when to eliminate prime and tack coats.

The study included a literature search on prime and tack coats, a review of environmental considerations for prime and tack coat usage and a phone survey of current practice of state DOTs from the CFLHD region. Recommendations for improving CFLHD's specifications were made. Based on the information collected, a guideline for CFLHD project development and field personnel was developed. The guideline provides decision-making guidance on how to use, when to keep, and when to eliminate prime and tack coats.

The contributions and cooperation of the CFLHD personnel is gratefully acknowledged.

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Notice

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16. Abstract

Prime and tack coats have a purpose in the pavement construction process, yet many times they are misused or eliminated during the project. While most of the time no harm appears to occur to the roadway, technical guidance is warranted to assure appropriate usage. The objective of this study was to produce a prime and tack coat guide publication developed for project development and field personnel to provide decision-making guidance on how to use, when to keep, and when to eliminate prime and tack coats.

A literature search, which focused on handbooks and technical reports, was conducted to determine the applicability and benefits of prime and tack coat, prime and tack coat effectiveness, materials used and when and where they are used. CFLHD's current construction specifications were compared with best practices determined from the literature and phone surveys of current practice of state DOTs from the CFLHD region. Finally, a review of the potential harmful and positive environmental effects of the prime and tack coat process, including the various bituminous products used, was undertaken.

Based on the information collected, a guideline for CFLHD project development and field personnel was developed. The guideline provides decision-making guidance on how to use, when to keep, and when to eliminate prime and tack coats.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	Millimeters	mm
ft	feet	0.305	Meters	m
yd	yards	0.914	Meters	m
mi	miles	1.61	Kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	Hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	Milliliters	mL
gal	gallons	3.785	Liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	Grams	g
lb	pounds	0.454	Kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	Lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	Newtons	N
lbf/in^2	poundforce per square inch	6.89	Kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	Inches	in
m	meters	3.28	Feet	ft
m	meters	1.09	Yards	yd
km	kilometers	0.621	Miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	Acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	Gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	Ounces	oz
kg	kilograms	2.202	Pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	Poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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EXECUTIVE SUMMARY

BACKGROUND

Prime and tack coats have a purpose in the pavement construction process, yet many times they are misused or eliminated during the project. While most of the time no harm appears to occur to the roadway and thus may be viewed as acceptable, technical guidance is warranted to assure appropriate usage. Unfortunately, the Central Federal Lands Highway Division (CFLHD) had no guideline document that described the conditions when prime and tack coats are necessary, and when they may be eliminated with confidence.

The objective of this study was to produce a prime and tack coat guide publication developed for project development and field personnel to provide decision-making guidance on how to use, when to keep, and when to eliminate prime and tack coats. In order to meet the objectives, this report was prepared to summarize the information collected from a literature review as well as information supplied through interviews and documents from knowledgeable experts, bituminous materials suppliers, industry organizations, state departments of transportation (DOT), and other agencies.

The literature search was conducted to determine the applicability and benefits of prime and tack coat, prime and tack coat effectiveness, materials used and when and where they are used. This activity included searching the databases of Transportation Research Information Services (TRIS), National Technical Information Services (NTIS), International Construction Database (ICONDA), Engineered Material Abstracts, EI Compendex, South African National Road Agency and the Association of Australian and New Zealand Road Transport and Traffic Authorities. Publications from AASHTO, TRB, ASTM and NCHRP were reviewed as well.

A review of CFLHD's current construction specifications was undertaken to compare CFLHD's current specifications with best practices and proposals for improving CFLHD's specifications were made. Due to the scarcity of research reports specifically devoted to prime and tack coat, a phone survey of current practice of state DOTs from the CFLHD region was undertaken to provide information on current practice. CFLHD's current prime and tack coat specifications were compared with best practices, as determined by the above tasks, and with standard specifications of the state DOTs within the CFLHD region.

A review of the potential harmful and positive environmental effects of the prime and tack coat process, including the various bituminous products used, was undertaken. General guidelines for the requirements for handling and storage of the bituminous materials as well as remedial action to take in the case of an accidental spill were reviewed.

Based on the information collected from the literature review as well as information supplied through interviews and documents from knowledgeable experts, bituminous materials suppliers, industry organizations, state DOTs, or other agencies, and summarized in the above tasks, a guideline for CFLHD project development and field personnel was developed. The guideline provides decision-making guidance on how to use, when to keep, and when to eliminate prime and tack coats.

LITERATURE REVIEW

The literature search focused on handbooks and technical reports. There were few technical reports found on prime or tack coat. Only two technical reports were found that were specifically related to prime coats; a total of 37 references were cited in these two reports. However, only four of those references were research studies, two relating to prime coats and two relating to tack coats. There were 13 technical reports found which were directly related to tack coat application and performance. A total of 74 documents are cited in the report. Due to the scarcity of research reports specifically devoted to prime and tack coats, a survey of current practice of state DOTs from the CFLHD region was undertaken to provide information on current practice. The results from the literature review and survey were sufficient to allow determination of state-of-the-practice, material selection, application rates, when and where prime and tack coats are applied, and when and where they are deleted.

ENVIRONMENTAL ISSUES

Environmental issues related to the use of prime and tack coat are complex due to the overlapping jurisdiction of several federal agencies and the fact that the regulations are subject to interpretation by the courts. Local, state and federal regulations should be consulted for specific regulations regarding environmental issues with use of cutback and asphalt emulsions. Environmental issues related to the use of prime and tack coats can be grouped under the concerns of air and water quality, hazardous materials and worker safety.

Air Quality Issues

The primary pollutants of concern from asphalt paving operations are volatile organic compounds (VOC). Cutback asphalts are the major source of VOCs as only minor amounts of VOCs are emitted from emulsified asphalts and asphalt cements. VOC emissions from cutback asphalts result from the evaporation of the petroleum distillate used to liquefy the asphalt cement. VOC emissions can occur at both the job site and the mixing plant; however, the largest source of emissions was reported as from the road.

Asphalt emulsions are typically used in place of cutback asphalts to eliminate VOC emissions. The use of cutback asphalt is regulated in many jurisdictions to help reduce VOC emissions. Prohibitions on the use of cutback, either permanently or during certain times of the year, are common in jurisdictions that have either reached, or are nearing non attainment for ozone requirements of the Clean Air Act.

Water Quality Issues

Water quality issues are much more complex than air quality issues because of the overlapping jurisdiction of several federal agencies, the complexity of many of the regulations, and the variability of regulations and jurisdictions on the state and local levels.

The Environmental Protection Agency (EPA) has interpreted asphalt emulsions and cutback as oil as defined in the Clean Water Act; therefore, there is no differentiation between spills of cutback or asphalt emulsion. The Clean Water Act, in part, requires that any spill of oil that could enter a waterway and violates applicable water quality standards or causes a film or sheen on the water, would require reporting to the National Response Center and local authorities. A direct spill into a waterway is not the only way prime and tack coat materials can enter a waterway. Entry is available through a spill that enters storm water and waste water sewers, drainage ditches or runoff from a rain shower. It is generally recommended that prime coat be omitted if there is a strong possibility of runoff.

The reporting requirements for a spill of oil on the ground that does not enter a waterway, for oil as defined by the clean water act, is more complicated due to the various agencies that could have jurisdiction. Under Spill Prevention, Control and Countermeasure (SPCC) regulations, a spill of oil must be reported to the National Response Center and local authorities if, in part, the spill is greater than 3,785 L (1,000 gal) or a spill of over 160 L (42 gal) of oil in each of two spills occur within a 12 month period. Local requirements could be more stringent.

Under the Resource Conservation and Recovery Act (RCRA), hazardous chemicals have an associated reportable quantity (RQ). If a spill or release of more than a RQ of a material occurs at a site, the spill must be reported to the National Response Center and local authorities. There can be RCRA regulated materials in cutback and occasionally in some asphalt emulsions. However, these RCRA hazardous materials are usually present in such low concentrations that those RQs would rarely be reached in normal paving operations. State and local jurisdictions can have lower RQ requirements and suppliers and local agencies should be contacted if there is a question concerning a reportable spill.

Worker Safety and Hazardous Materials Issues

According to RCRA, asphalt cement is not considered a hazardous material. However, occasionally RCRA defined hazardous materials are contained in diluents used to make cutback asphalts or in additives added to emulsifying agents or performance enhancing agents in asphalt emulsions. The concentrations of these RCRA defined hazardous materials in MC cutbacks and asphalt emulsions are usually in such small quantities that a major release, much larger than would be likely to occur on a typical CFLHD paving project, would be required to meet or exceed RCRA reportable quantity (RQ) limits.

Other worker safety issues concern health risks to workers from exposure to the product, fire danger and stability or reactivity of the product. The majority of the materials typically used for prime or tack is reactive or pose more than a slight health risk. There is a health risk associated with worker exposure to fumes from heated asphalt products, mainly in confined spaces. This is not usually an issue when applying prime or tack coat if workers stay a reasonable distance away from the spray bar during application. Fire can be a concern when using MC for prime coat or rapid cure cutbacks (RC) for tack coat as application often involves heating the material above its flash point. This should not be a serious issue for CFLHD as they do not specify RC cutback for prime or tack.

Contractor Liability Issues

There is the possibility of civil liability and public relations/public perception issues associated with accidental spills or releases of oils. Many local jurisdictions, including cities and counties, are routinely deleting prime coat, often at the request of the contractor. The rational for deleting prime coat appears to be that the benefits of prime do not outweigh the increased liability associated with handling liquid asphalts.

CONCLUSIONS

Based on the literature review and information supplied through the phone survey, interviews with knowledgeable experts, bituminous materials suppliers, industry organizations, state DOTs, and other agencies, the following conclusions for prime and tack coat usage are warranted.

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 must adequately penetrate the base to function properly.
4. Medium cure cutbacks are normally used for prime. Medium cure cutback asphalts penetrate deeper than conventional emulsified asphalts. Dilution of emulsified asphalts with water helps penetration but emulsified asphalts generally require mixing into the base to function properly.
5. Prime coats need to be allowed to cure completely before covering with HMA. Cutbacks generally take longer to cure than asphalt emulsions.
6. Excess prime not absorbed into the base after 24 hours should be absorbed with blotter sand and removed from the surface.
7. Prime is often deleted in cold weather because it is riskier to pave over uncured prime than over unprimed base.
8. 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 is greater than 100 mm (4 in) thick.
9. Prime coat increased the bond strength at the interface between a compacted base and asphalt layer over that of no prime coat. The reported differences were not always statistically significant.
10. At higher static normal stresses, shear strength at the interface is not appreciably affected by the type or even the presence of a prime coat. This supports the practice of deleting prime at a minimum HMA thickness, typically 100 mm (4 in).
11. Use of prime coat is not a substitute for maintaining the specified condition of the base or subgrade.
12. Prime should not be applied to stabilized bases or subgrade.
13. The main environmental concern with prime coat applications is air pollution associated with the release of VOCs into the air.

14. The EPA treats spills of cutbacks and emulsified asphalts the same; therefore, priming with emulsified asphalts or specially formulated penetrating asphalt emulsions does not result in reduced oil spill reporting regulations or requirements.
15. Deleting prime would lessen the amount of liquid asphalt contractors must handle, lessening the associated liability with handling these products.
16. Prime may be omitted if there is a strong possibility of runoff entering a waterway.

Tack Coat

1. The purpose of tack coat is to ensure bond between the existing pavement surface and a new pavement surface.
2. A loss of bond between HMA layers can cause crescent-shaped slippage cracks or debonding to occur, leading to reduced pavement life.
3. Prior to tack application the surface should be clean, dry and free from loose material.
4. Applying tack is not a substitute for properly cleaning the existing HMA surface.
5. 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.
6. If possible, all traffic should be kept off tacked surfaces.
7. Tack should be applied to old existing HMA surfaces and PCC surfaces.
8. Tack has been successfully deleted between new lifts of HMA when the existing surface is still clean and tacky.
9. There is not complete agreement regarding the requirement that tack coat be allowed to break and set before placing the HMA layer.
10. Many factors were shown to affect laboratory interface shear strength, including rate of shear, magnitude of normal force, temperature and joint construction.
11. In a few studies, tacked surfaces were shown to have slightly lower interface shear strengths than untacked surfaces. However, in these studies the statistical significance of the difference in interface shear strength was not reported. In reports where the statistical significance of the differences in interface shear strength was evaluated, tacked interfaces were either stronger or not significantly different from untacked interfaces.
12. The higher the viscosity of the bituminous binder in the tack, the higher the reported interface shear strength.
13. At typically specified application rates, application rate had little effect on interface shear strength. Higher than recommended application rates resulted in slightly lower interface shear strengths.
14. Diluted slow set emulsions are typically used for tack coat.

RECOMMENDATIONS

CFLHD Specifications

Based on the literature review and information supplied through the phone survey, interviews with knowledgeable experts, bituminous materials suppliers, industry organizations, state DOTs, and other agencies, the following changes to CFLHD's *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects, FP-03,* are proposed.

1. Specifications for AE-P and PEP should be added to *Section 702. – ASPHALT MATERIAL* under subsection *702.03 Emulsified Asphalt*.
2. In *Section 412. – ASPHALT TACK COAT*, asphalt binder, meeting the requirements of subsection *702.01 Asphalt Cement*, could be added to subsection *412.02*. This would allow contractors the option of tacking with the paving grade asphalt cement.
3. A reference to the requirements for tacking longitudinal and transverse joints, placed in the *Construction Manual* or *Field Materials Manual*, would remove questions regarding the necessity of tacking joints. This could be most helpful with longitudinal joints.
4. A table placed in either the *Construction Manual* or *Field Materials Manual* with recommended application rates for different surface conditions, similar to those shown in Tables 2 and 8, could assist CFLHD field personnel with initial tack coat application rates.

Guidelines for Prime and Tack Coat Usage

A decision tree and flow chart included in Chapter 7, were developed to provide CFLHD project development and field personnel decision-making guidance on how to use, when to keep, and when to eliminate prime and tack coat.

CHAPTER 1 - STATEMENT OF WORK

PROBLEM STATEMENT

Prime and tack coats have a purpose in the pavement construction process, yet many times they are misused or eliminated during the project. Current practice in many areas appears to allow the deletion of prime coat and occasionally tack coat on projects for convenience, time constraints, and/or contractor pressure without consideration of need from a technical perspective. Environmental concerns and regulations relating to the use of cutback asphalts and asphalt emulsions have impacted the use of prime and tack coats. Due to air pollution concerns, in many jurisdictions the use of cutback asphalts is restricted either entirely or during certain times of the year. Oil spill regulations and requirements have resulted in a reluctance to use liquid asphalt products in all but essential operations.

While most of the time no harm appears to occur to the roadway from the deletion of prime or tack, and thus may be viewed as acceptable, technical guidance is warranted to assure appropriate usage. Many state departments of transportation (DOT) have moved away from using prime, and to some extent, tack. Unfortunately, the Central Federal Lands Highway Division (CFLHD) has no guideline document that describes the conditions when prime and tack coats are necessary and when they may be eliminated with confidence. A review of CFLHD's current practices, especially as they apply to low volume roads in varying terrains, was warranted.

OBJECTIVE

The objective of this study was to produce a prime and tack coat guide publication for project development and field personnel to provide decision-making guidance on how to use, when to keep and when to eliminate prime and tack coats. The guidance report should summarize the information collected from a literature review as well as information supplied through interviews or documents from knowledgeable experts, bituminous materials suppliers, industry organizations, state DOTs and other agencies.

Additionally, a review of CFLHD's current construction specifications was requested. The objective of the review was to compare CFLHD's current specifications with best practices and make proposals for improving CFLHD's specifications.

TASKS

In order to accomplish the objectives in this study the following tasks were performed:

Task 1 - Literature Search

A literature search was conducted to determine the applicability and benefits of prime and tack coat, prime and tack coat effectiveness, materials used and when and where they are used. The relevant literature reviewed and cited is documented in the report. This activity included searching databases and AASHTO, TRB, ASTM, and NCHRP publications. Data bases searched included the Transportation Research Information Services (TRIS), National Technical Information Services (NTIS), International Construction Database (ICONDA), Engineered Material Abstracts, EI Compendex, South African National Road Agency and the Association of Australian and New Zealand Road Transport and Traffic Authorities.

Task 2 - DOT Survey of Current Practice

Due to the anticipated scarcity of research reports specifically devoted to prime and tack coats, a survey of current practice of state DOTs from the CFLHD region was undertaken to provide information on current practice. States in the CFLHD include California, Nevada, Arizona, Utah, Wyoming, Colorado, New Mexico, North Dakota, South Dakota, Nebraska, Kansas, Oklahoma and Texas. The results from the survey were used to assist in determining state-of-the-practice and addressed material selection, application rates, when and where prime and tack coats are applied, and when and where they are deleted.

Task 3 - Review of CFLHD Specifications

CFLHD's current prime and tack coat specifications were compared with best practices, as determined by the above tasks, and with standard specifications of the state DOTs within the CFLHD region. The purpose of the review was to make proposals for improving CFLHD's specifications for prime and tack coat if the review showed improvements could be made.

Task 4 - Environmental Issues

A review of the potential harmful and positive environmental effects of the prime and tack coat process, including the various bituminous products used, was undertaken. General guidelines for the requirements for handling and storage of the bituminous materials as well as remedial action to take in the case of an accidental spill were reviewed. Trade association literature, Environmental Protection Agency (EPA) regulations, and supplier/manufacturer's literature were consulted.

Task 5 – Prepare Guidelines for Prime and Tack Coat Usage

Based on the information collected from the literature review as well as information supplied through interviews and documents from knowledgeable experts, bituminous materials suppliers, industry organizations, state DOTs and other agencies, a proposed guideline for CFLHD project development and field personnel was developed. The guideline provides decision-making guidance on how to use, when to keep, and when to eliminate prime and tack coat.

REPORT ORGANIZATION

The report is organized into the following sections. The results from Task 1, *Literature Search*, are reported in Chapters 2 and 3. Chapter 2 contains the review of the literature from handbooks and Chapter 3 contains the review of literature from technical reports. The results from Task 4, *Environmental Issues*, are found in Chapter 4 of the same name. The results from Tasks 2 and 3 **-** *DOT Survey of Current Practice* and *Review of CFLHD Specifications*, respectively, are found in *CHAPTER 5 – REVIEW OF CFLHD SPECIFICATIONS*. The results from Task 5, *Prepare Guidelines for Prime and Tack Coat Usage,* are contained in *CHAPTER 6 – CONCLUSIONS* and *CHAPTER 7 – RECOMMENDATIONS*. Appendix B contains *Prime and Tack Coat Inspection Bullets.* These bullets were prepared to support the development of an inspection guide by CFLHD.

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.

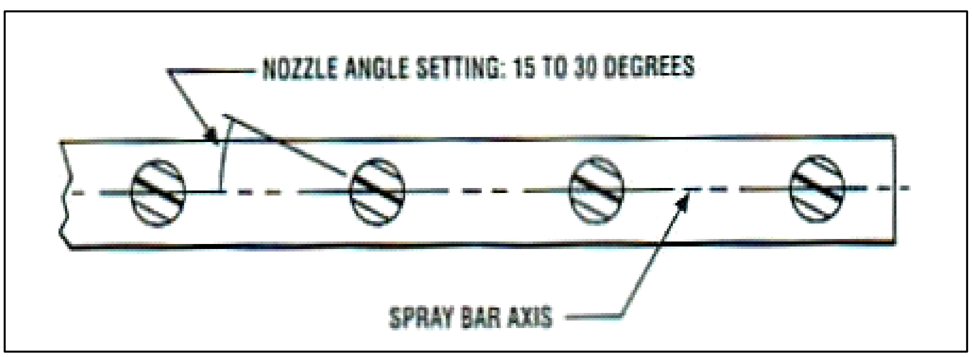

Figure 2. Schematic. Proper setting of spray-bar nozzles [6].

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.

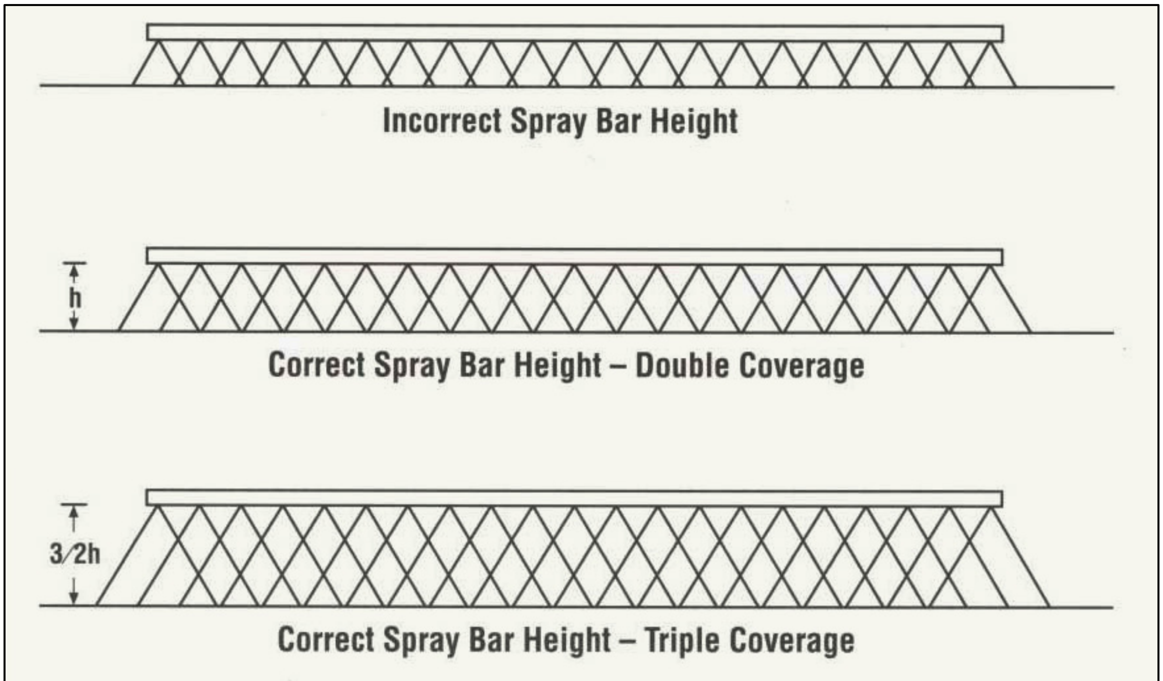

Figure 3. Schematic. Spray bar height and coverage [2].

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	
	°C	°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]

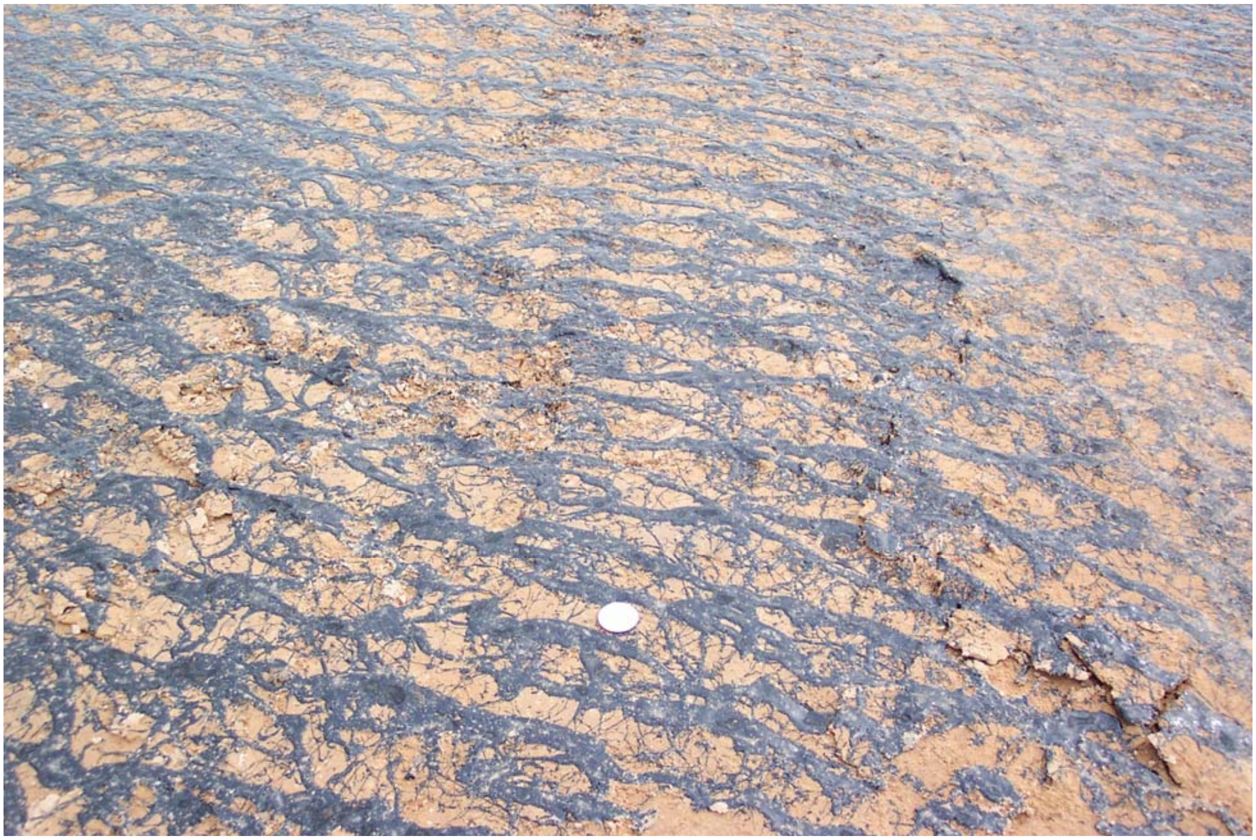

Figure 4. Photo. Prime applied at too high a viscosity.

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°C (77°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:

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

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.

CHAPTER 3 – REVIEW OF TECHNICAL REPORTS

PRIME COAT

There were few research reports found on the use or benefits of prime coat. The majority of the research papers found were published during the 1970s and 1980s when there were increased concerns about possible negative environmental impacts with the use of cutback asphalt primes. Only two research reports were found that were specifically related to prime coats; a total of 37 references were cited in these two reports. However, only four of those references were research studies, two relating to prime coats and two relating to tack coats.

Ishai and Livneh [(25)] performed a study to evaluate the functional and structural necessity of prime coat in a pavement structure and to evaluate the use of asphalt emulsion as a replacement for cutback asphalts. The objectives of this study were to determine if prime coat provides a significant contribution to the functional and structural performance of a pavement and to compare the performance of asphalt emulsion with cutback asphalt primes. Mantilla and Button [(11)] performed a study to develop prime coat methods and materials to replace cutback asphalt primes. The main focus of this study was the development of test procedures for evaluation of primed bases and a field and lab evaluation of different prime coat materials. The importance of the bond between base and surface courses was evaluated as well. The findings from these two studies are summarized below.

Curing

Ishai and Livneh [(25)] evaluated the liquid evaporation rates of MC-30 and MC-70 cutback, and MS-10 asphalt emulsion as a measure of cure time. Prime was applied at 0.5, 1.0, 2.0 and 3.0 kg/m^2 (0.92, 1.84, 3.68 and 5.52 lb/yd^2) to 15 cm (5.9 in) diameter tin covers and allowed to evaporate or cure at 25^{o}C (77^{o}F). The amount of liquid lost was determined by weighing daily over a seven-day period. The results at 1.0 kg/m^2 (1.84 lb/yd^2), the amount typically used, are reproduced in Figure 7 [(25)].

As can be seen in Figure 7, the MS-10 asphalt emulsion had a higher liquid evaporation rate than either cutback asphalt. The authors reported that the asphalt emulsion lost about 70 percent of its liquid (mainly water) after one day of curing and up to 90 percent after two days of curing. After one day of curing, the MC-70 and MC-30 cutbacks lost 27 and 15 percent, respectively, of its liquid, mainly kerosene. After seven days of exposure, the MC-70 lost 58 percent and the MC-30 lost 40 percent of its liquid. The authors concluded that under standard curing condition of three days, the MS-10 asphalt emulsion loses almost all of its liquid whereas most of the liquid (kerosene) remains in the cutback prime. The laying of HMA within a period shorter than three days after priming with cutback may cause about 55 to 85 percent of the kerosene of the prime to be trapped in the base. This trapping may lead to detrimental effects from the direct contact between the kerosene and its vapors and the asphalt concrete layer above it.

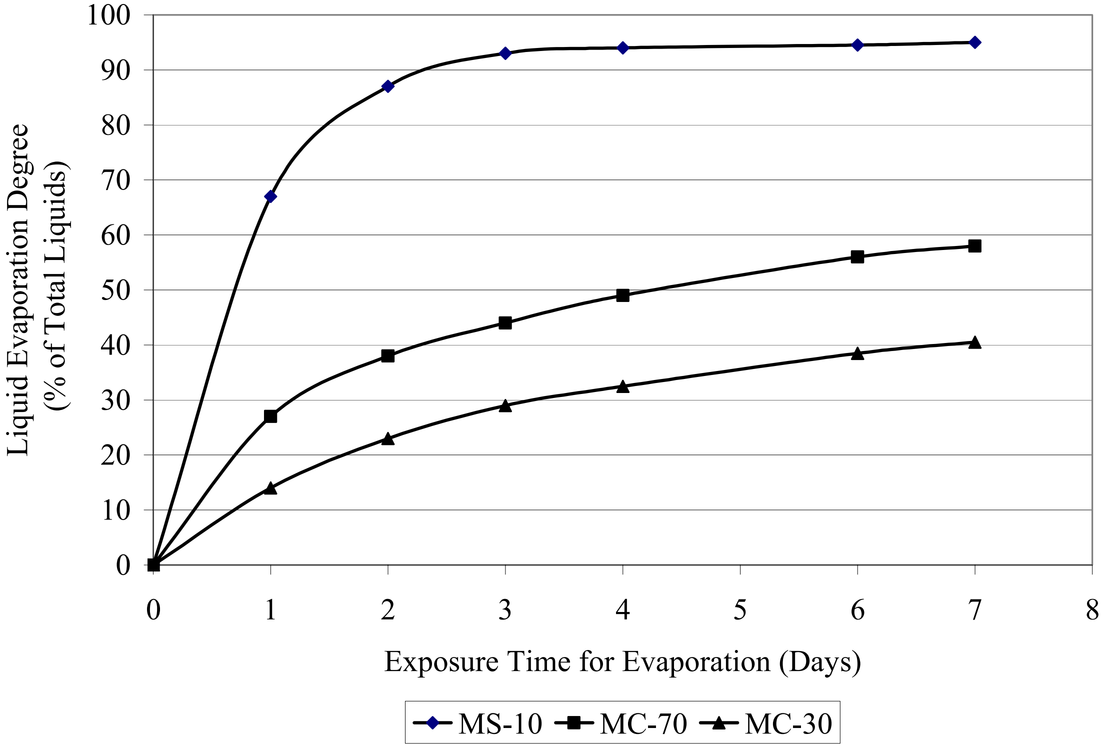

Figure 7. Graph. Liquid evaporation with exposure period at 1.0 kg/m^2 application rate.

Penetration

Mantilla and Button [11] evaluated the penetration depth of various prime materials. The authors compared the penetration of two MC-30 cutbacks, two asphalt emulsion primes (AE-P), penetrating emulsion prime (PEP) and emulsified petroleum resin (EPR-1) in base material compacted at different moisture contents. The maximum penetration obtained 24 hours after application for some of the materials tested are reproduced in Figure 8 [11]. A minimum penetration depth of 5 mm (0.2 in) was considered necessary for adequate performance. As shown in Figure 8, all materials met the minimum 5 mm (0.2 in) penetration depth except the EPR-1. None of the materials evaluated penetrated as deep as the two MC-30 cutbacks. The authors reported that conventional emulsified asphalts did not adequately penetrate most compacted bases. Dilution with water helped penetration but did not provide acceptable penetration [11].

Ishai and Livneh evaluated penetration in their study as well. Their results are reproduced in graphical form in Figure 9 [25]. The authors reported that higher values of penetration were obtained with cutbacks than asphalt emulsions but that the penetration depths with the asphalt emulsion were satisfactory and were of a similar order of magnitude [25].

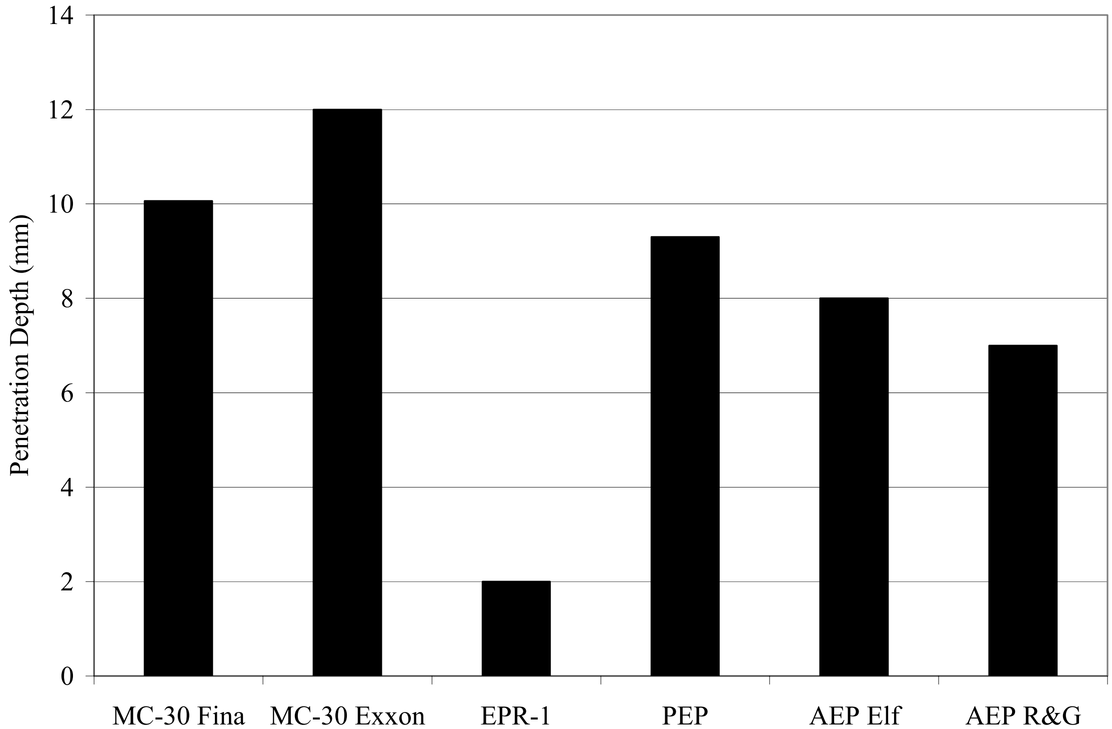

Figure 8. Graph. Penetration depth achieved by various primes after 24-hour cure.

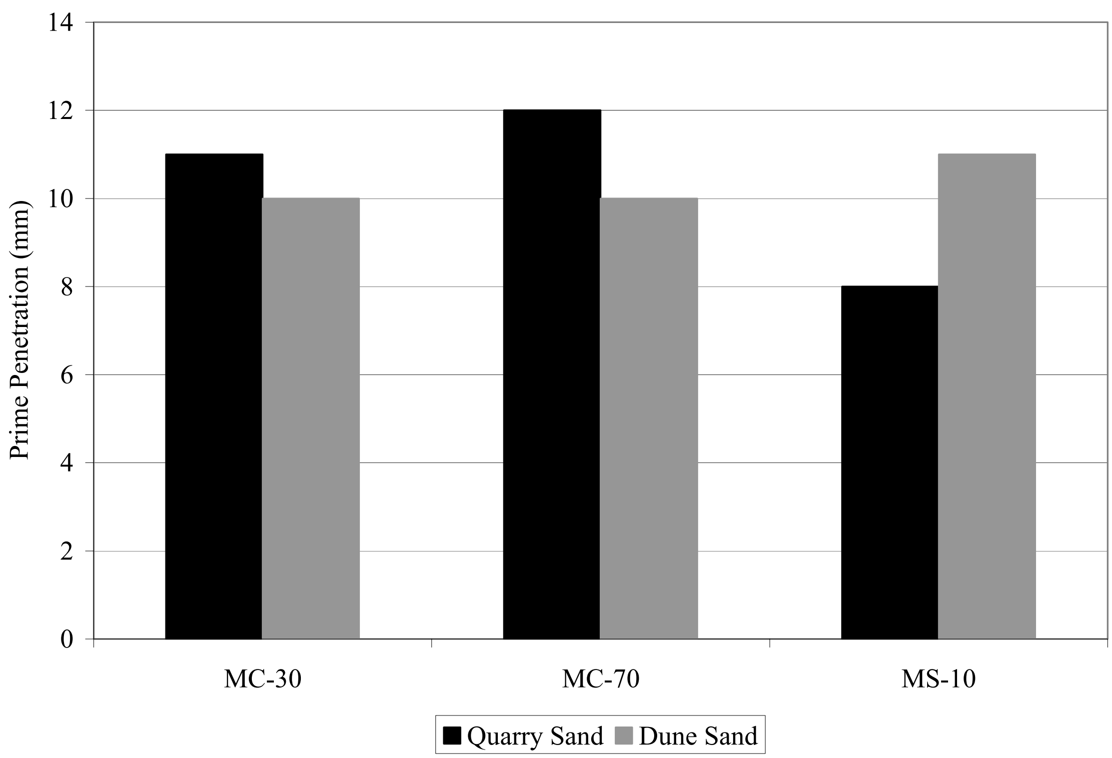

Figure 9. Graph. Average prime penetration into compacted sand samples.

To further evaluate penetration and curing, Ishai and Livneh [25] evaluated the penetration resistance of samples of primed, compacted dune sand for unconfined compressive strength using a pocket penetrometer. Their results are shown in Figure 10. The authors reported that the MC-70 cutback did not gain any significant strength during the first 10 days of curing and only minor strength gain during the next 10 days. Significant early strengthening and accelerated strength gain with time were reported in the asphalt emulsion samples. The results were reported to be in good agreement with their curing data [25].

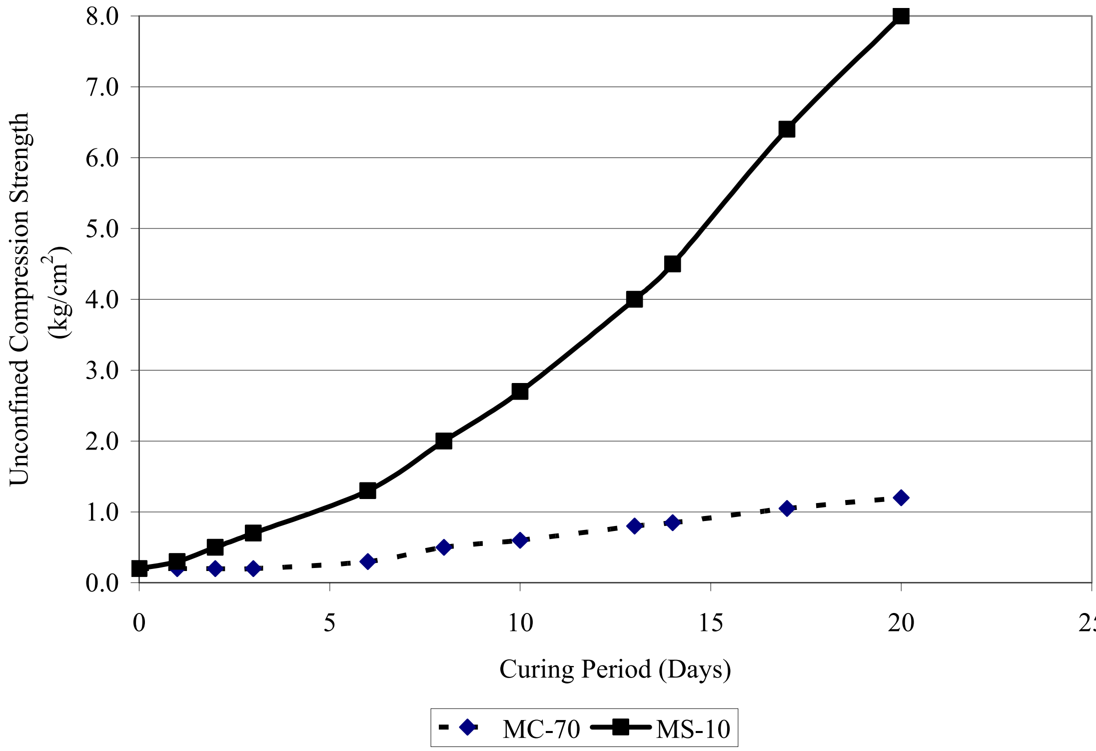

Figure 10. Graph. Relationship between unconfined compression strength of primed, compacted dune sand and curing period [25].

Interface Shear Strength

Direct Shear

Both Ishai and Livneh [25] and Mantilla and Button [11] reported on the direct shear strength of the interface of primed aggregate base and an HMA surface. The results from Ishai and Livneh's study [25] are shown in Figure 11. The authors reported that the results clearly demonstrate the superiority of asphalt emulsion prime, with respect to interfacial adhesion, over cutback primed and unprimed surfaces and of the significant role of an adequately specified prime coat [25].

Mantilla and Button [11] performed direct shear tests on primed samples of aggregate base. Application rates were reported as 1.1 L/m^2 (0.25 gal/yd^2) and a chip seal was placed between the primed base and HMA layer. The prime was allowed to cure for 24 hours at 40^{o}C (104^{o}F) prior to placement of the seal coat. The seal coat was cured for 24 hours at ambient temperatures prior to placing the HMA layer. The results are reproduced in graphical form in Figure 12 (11). The authors reported that MC-30 cutback and AEP samples performed better than unprimed samples and that PEP and low volatile organic compound (LVOC-1) prime performed similarly to the unprimed samples (11).

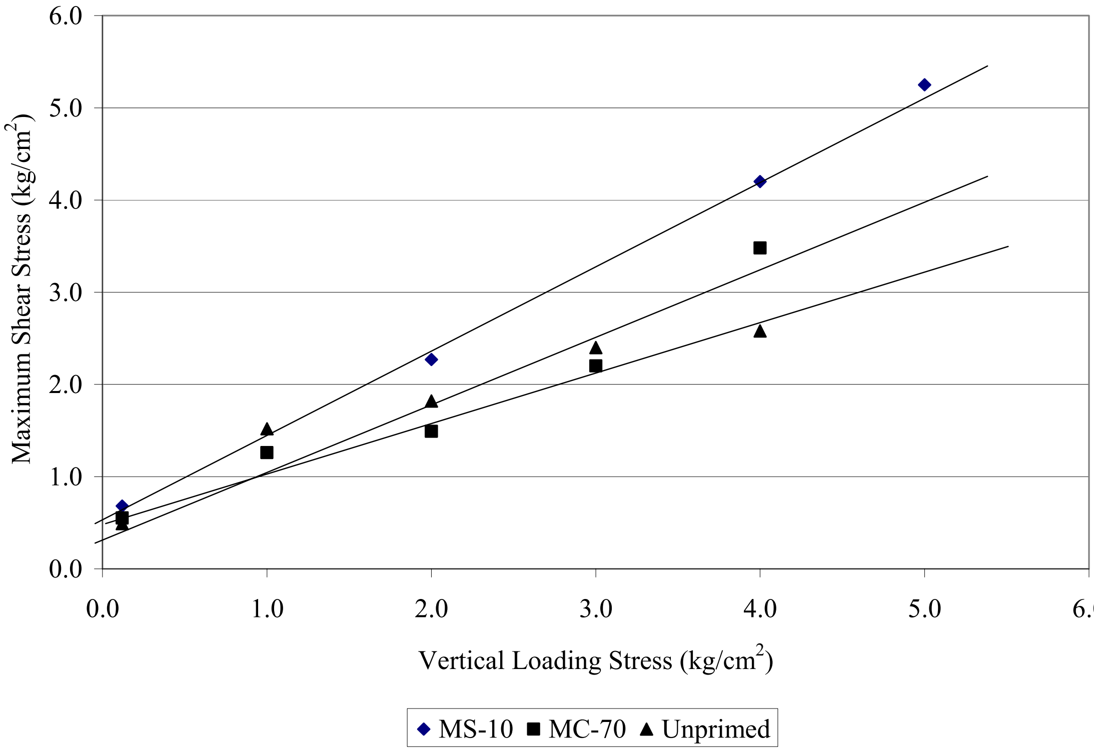

Figure 11. Graph. Maximum shear stress vs. vertical loading stress for compacted crushed-gravel base courses as tested in direct shear test (25).

The authors repeated the testing with dust placed between the prime and the seal coat. Some difficulty was reported with the test procedures and limited results were available. However, the authors reported that primed samples had higher shear strengths than unprimed samples when the primed surface was not adequately cleaned (11).

Torsional Shear

Mantilla and Button (11) determined the torsional shear strength of the primed base interface. The results are reproduced in Figure 13. Although the torsional shear strengths for the different primes evaluated were reported as not being statistically significant, the authors reported that at high normal static stresses, there was little difference between prime coat materials. At lower levels, unprimed samples yielded the lowest torsion shear strength and MC-30, AEP and EPR-1 yielded the highest values (11).

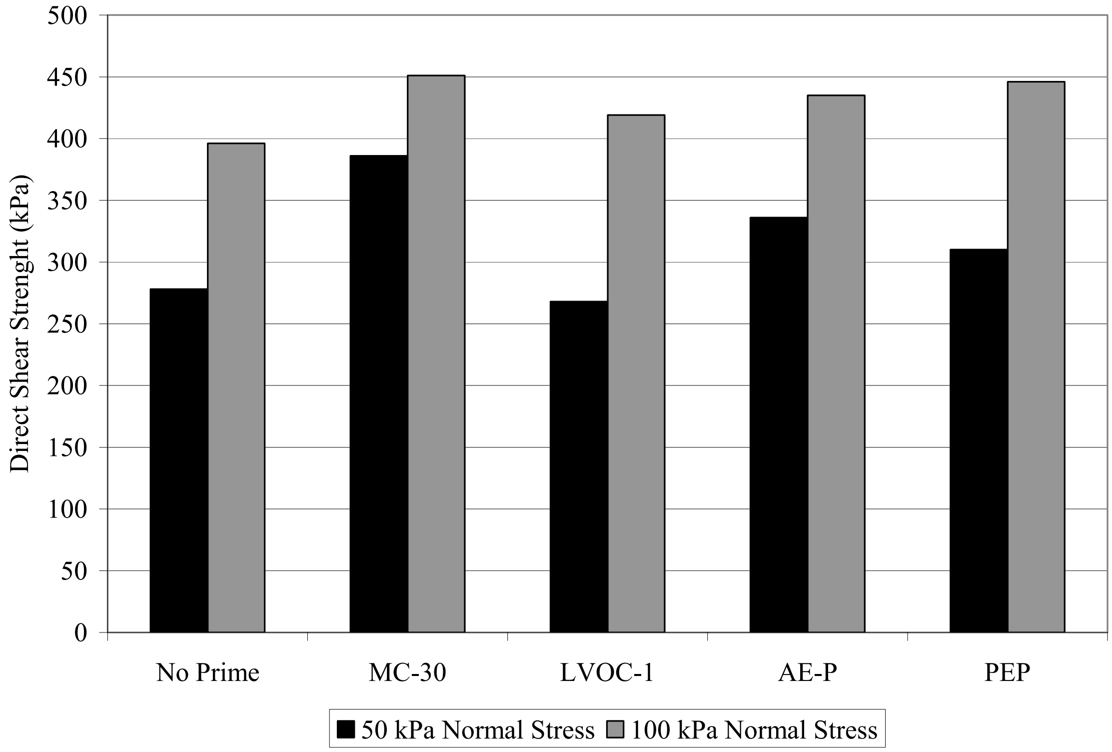

Figure 12. Graph. Direct shear strength for various prime coat materials.

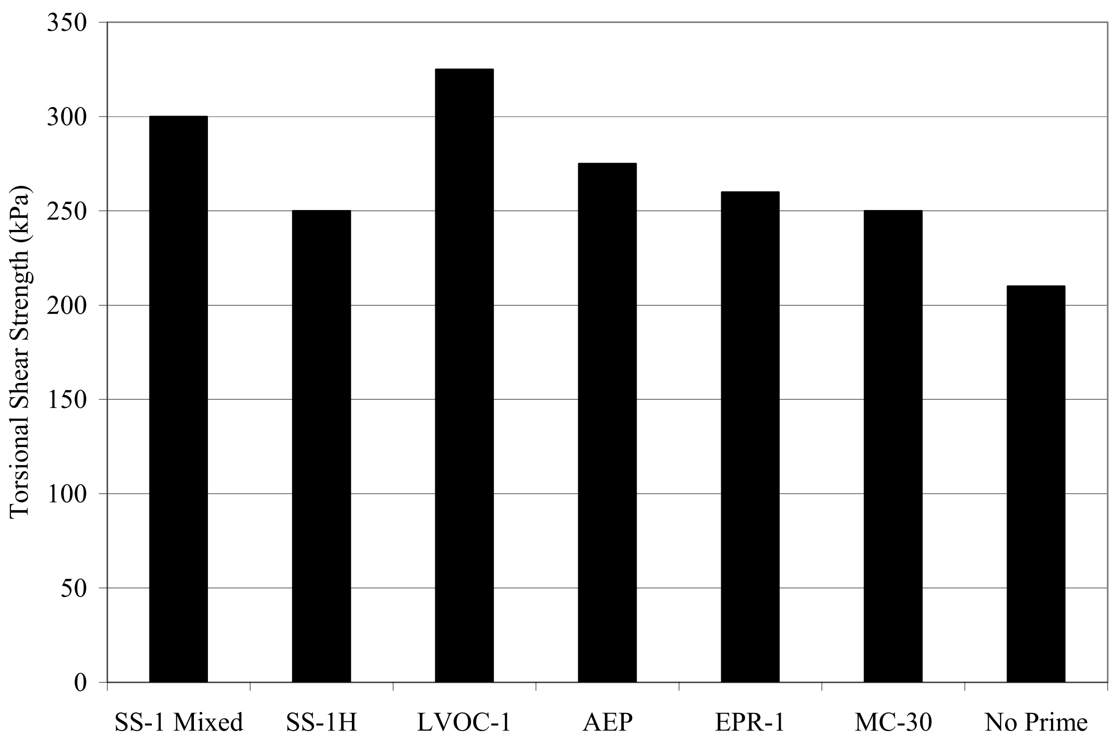

Figure 13. Graph. Torsional shear strength of the interface between the base and the bituminous layer at a normal stress of 410 kPa for different prime materials on limestone base [11].

Need For Prime Coat

Mantilla and Button [11] reported that granular bases should always be primed before application of surface treatments or an asphalt pavement of less than 76 mm (3 in) and that granular base should be primed if construction delays of subsequent layers allow damaged due to weather and/or traffic. Prime is not necessary if the base is asphalt stabilized or if the asphalt pavement is 100 mm (4 in) thick [11]. Ishai and Livneh [25] concluded that the cost/benefit ratio of prime coat is positive when properly formulated asphalt emulsion prime is applied and the benefit/cost ratio of cutback priming should be negative since no functional or structural improvement of the base and adjacent HMA were observed in their study.

TACK COAT

A comprehensive review of literature regarding tack coat was performed. There were 13 papers found, excluding the handbooks reviewed in Chapter 2, which were directly related to tack coat application and performance.

Mechanics of Layer Slippage

Van Dam et al. [26], in a report for the Federal Aviation Administration, and Shahin et al., in two separate journal articles [27,28], reported on the effects of layer slippage on pavement behavior using various mechanistic models. The authors reported that even a slight slippage of an overlay causes a redistribution of stresses and strains within a pavement. Layer slippage of the overlay was reported to cause large tensile strains to occur at the bottom of the overlay rather than at the bottom of the bound layer. The HMA at either side of the slipped surface distorts in different directions, propagating the slipped layer and further destroying the bond between the layers. If slippage has occurred, horizontal loads could only be supported by the slipped layer and the fatigue life of the pavement could become a function of the fatigue life of the overlay only, greatly reducing the fatigue life of the entire pavement [26,27,28].

Uzan et al. [29] used mathematical analysis to show that stress distributions at layer interfaces are affected by interface conditions and that a weak interface bond between pavement layers could result in crescent-shaped cracks in the surface. Hachiya and Sato [30] demonstrated through mechanistic analysis that layer slippage or separation can occur if shear stresses at the interface exceed their shear strength.

Consequences of Layer Slippage

Van Dam et al. [26] reported that a lack of bond between layers in an asphalt pavement shortens the pavement life so drastically that adequate steps should be taken during construction to ensure bonding. Shahin et al. [27,28] has reported that a pavement with a slipped overlay would require removal and replacement rather than a second overlay due to the excessive thickness of additional overlay required to keep the tensile strains below acceptable levels. Dunston et al. [31] reported that inadequate tack coat, perhaps through removal by construction traffic, contributed to tearing of an HMA mat during compaction.

Interface Shear Strength

Factors That Affect Laboratory Test Results

Several papers were found through the literature search where researchers evaluated the influence of tack coat on interface shear strength of HMA layers. The results from these studies provide conflicting conclusions as to the effect of tack coat on interface shear strength. The majority of the testing reported was performed using either custom fabricated devices or devices adapted from other test procedures. The effect of the ruggedness or repeatability of many of these custom fabricated devices is unknown. The variability in test methods and testing conditions makes evaluating the influence of tack on interface shear strength problematic.

Several factors were reported in the literature as having an influence on measured interface shear strength. Magnitude of the normal force (29,30,32), rate of shear (29,30,33) and test temperature (29,30,32,33,34,35,36) were all shown to have an effect on interface shear strength.

Normal Force:

The magnitude of the applied normal force in a direct shear test has an effect on the results. Uzan et al. (29) reported that the higher the applied normal force, the higher the shear strength at failure. Figure 14 shows the effect of applied normal force on interface shear strength for samples with various tack coat application rates tested at 25^{o}C (77^{o}F).

Romanoschi and Metcalf (32) reported that normal force did not have a significant effect on shear strength for tacked interfaces but did have a significant effect on untacked surfaces. The researchers reported that an increase in normal stress would increase the contact area of the interface, thus increasing the interface shear strength. With a tack coat, the researchers reported that interface voids are filled with the tack coat so the increase in normal stress does not increase the contact surface (32).

Rate of Shear:

The rate of shear has an effect on shear strength with increased rate of shear resulting in increased shear strength (29,30,33). A typical relationship between rate of shear and shear strength is shown in Figure 15 (30).

Test Temperature:

The temperature of the test sample at failure had an effect on shear strength. Shear strength results are also a function of joint construction type or interface condition. For similar interface condition, increased test temperature resulted in reduced interface shear strength (29,30,32,33,34,35,36). Crispino et al. (36) evaluated a new dynamic test apparatus to test layer strength. They reported that test temperature had a considerable effect on shear strength, affecting the viscous-elastic properties of the tack coat binder and of the asphalt concrete. Figure 16 shows the typical effect of test temperature on interface shear strength.

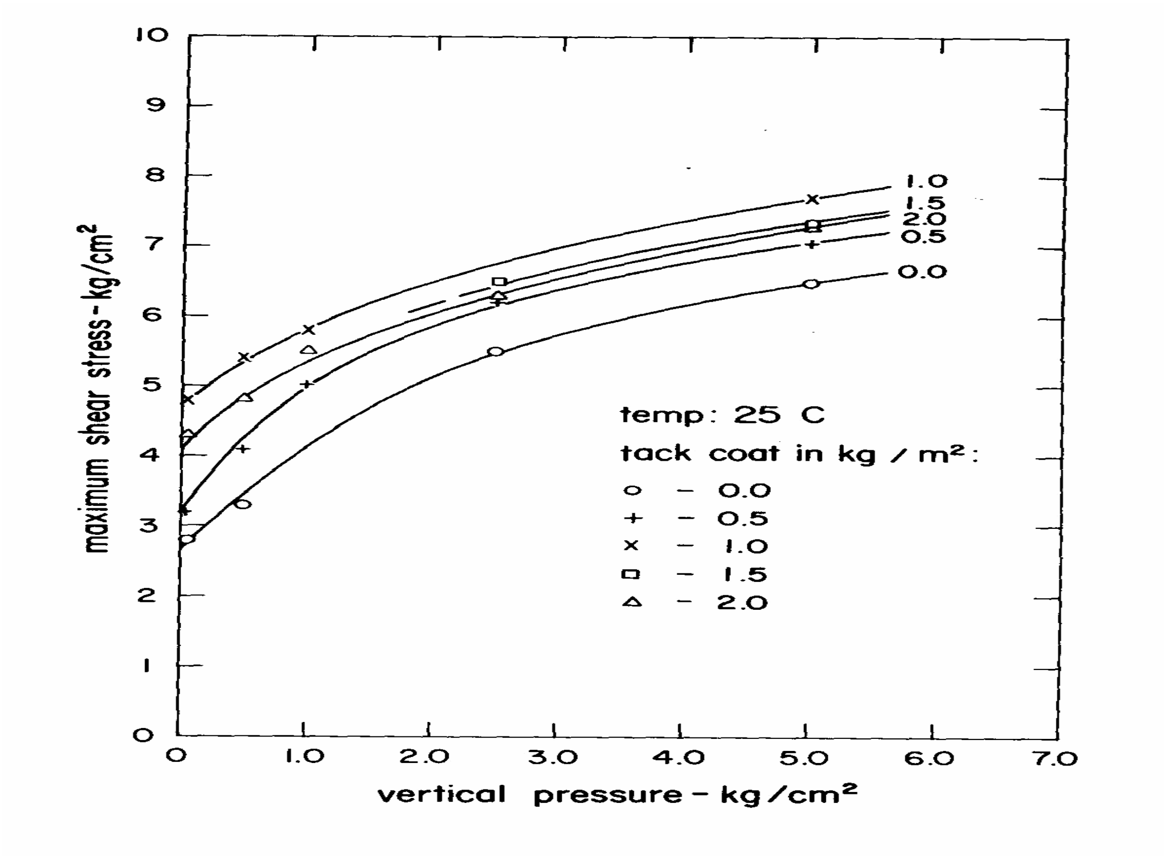

Figure 14. Graph. Maximum shear stress vs. vertical pressure at 25° C (29).

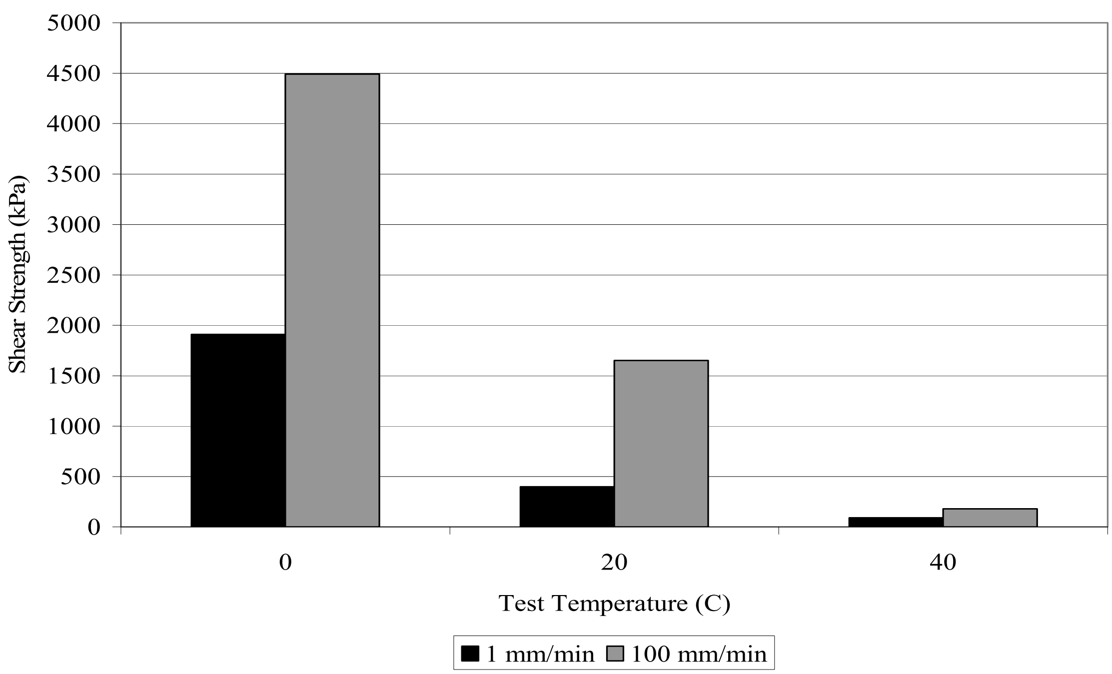

Figure 15. Graph. Rate of shear vs. direct shear strength.

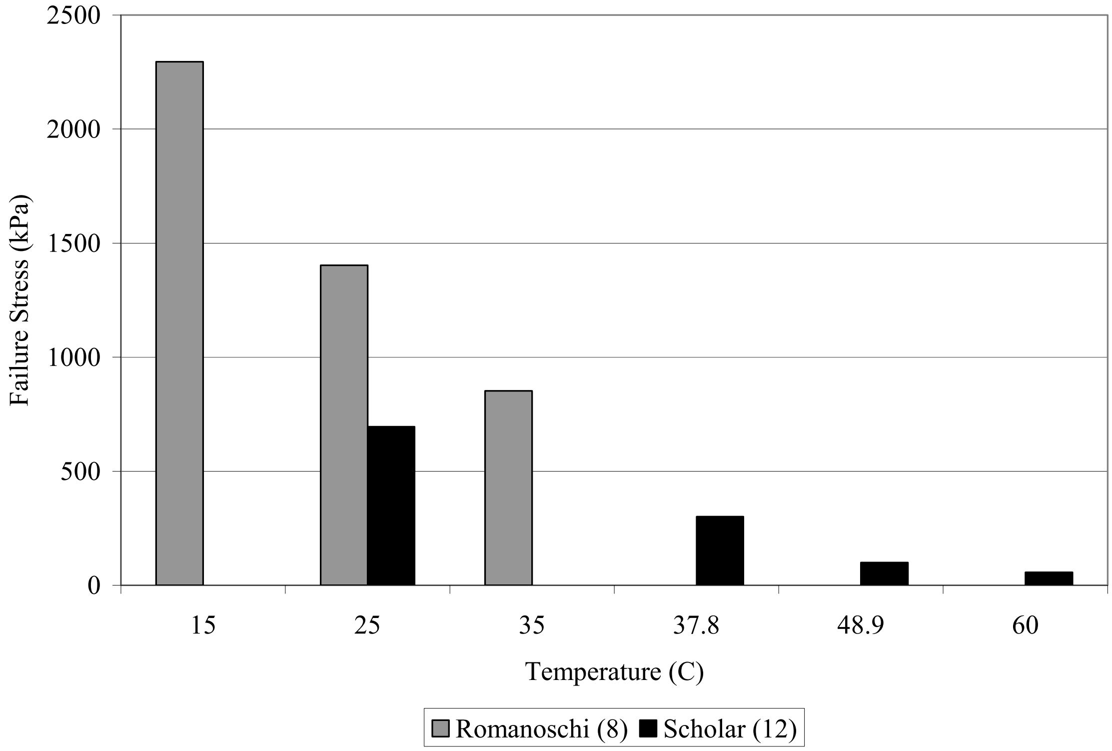

Figure 16. Graph. Effect of test temperature on interface shear strength.

Hachiya and Sato [(30)] evaluated the effect of joint construction method and test temperature on interface shear strength. The researchers evaluated four different joint conditions; hot joint, cold joint, tacked joint and monolithic joint construction. For the hot joint, the upper layer was compacted when the temperature of the lower layer dropped to 60°C (140°F). The results, shown in Figure 17, indicate that increased test temperature results in decreased interface shear strength. The effect was most dramatic for the cold joint samples [(30)].

Type of Joint Construction

The results of shear strength tests found in the literature were a function of joint construction and surface condition. Paul and Scherocman [(37)] reported that almost all state DOTs used tack coat before laying a new asphalt layer over an old existing asphalt layer. However, the review of the handbooks and results from the phone survey indicated that some agencies were deleting tack between new lifts of HMA.

One of the more comprehensive studies performed on tack coat was by Hachiya and Sato [(30)] where they evaluated the effect of tack coat on bonding characteristics at the interface between HMA layers. The researchers used emulsified asphalt for tack coat to provide the bond between two asphalt layers and evaluated the bond strength using tension and flexural tests. The researchers compared four joint construction types, monolithic, hot joint, tacked and cold joint.

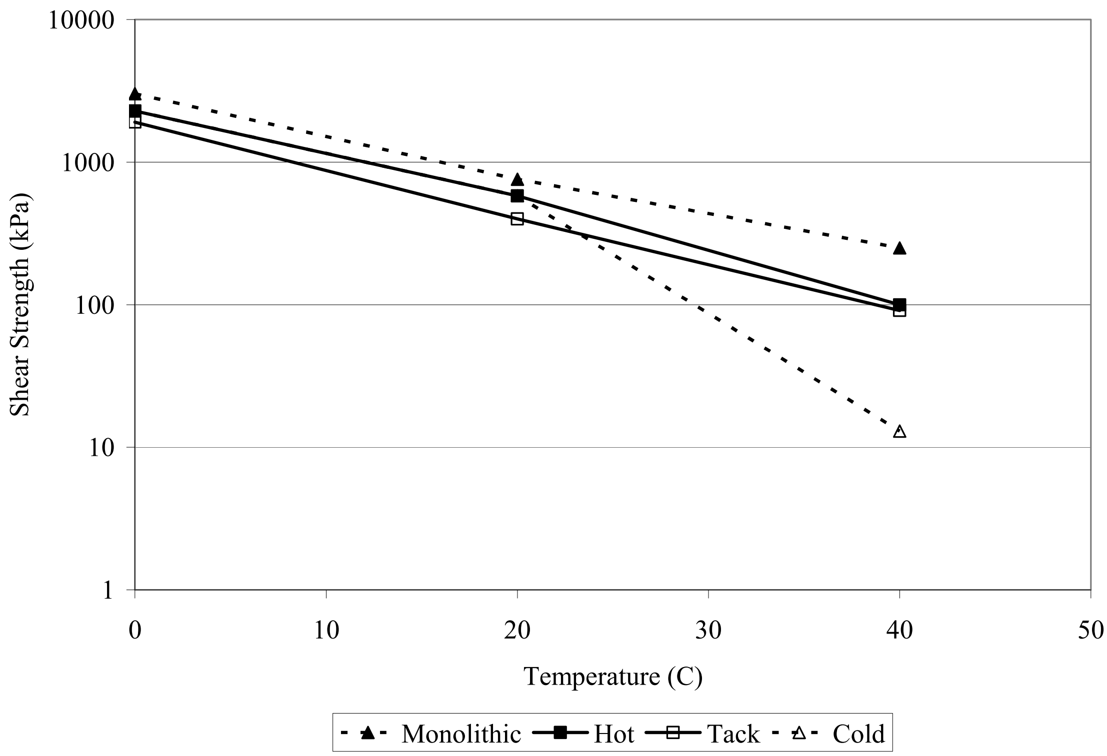

Figure 17. Graph. Shear strength at 1 mm/min vs. various joint construction procedures [30].

For monolithic construction, a 100-mm (4 in) thick layer was constructed in one lift. In hot joint construction, the upper layer was constructed when the lower layer temperature dropped to 60° C (140°F) while the cold joint construction was constructed at ambient temperature. In tack coat construction, 0.4 L/m^2 (0.09 gal/yd^2) of tack coat was spread over the lower layer and the upper layer was constructed after curing the tack for 24 hours. The tests were conducted at 0° C, 20° C and 40° C (32°F, 68°F and 104°F), at a loading rate of 1 and 100 mm/min (0.04 and 4 in/min) [30].

The shear strength results for these four construction joints, at a rate of shear of 1 mm/min (0.04 in/min), were shown in Figure 17. The test results for 100 mm/min (4 in/min) rate of shear are shown in Figure 18. From the plots, it can be seen that monolithic construction has the highest shear strength at any temperature range, followed by hot joint. The shear strength of tacked construction joints was lower than cold joints during low and intermediate temperatures. As the temperature increased above 20°C (68°F), the shear strength of the cold joint decreased rapidly. At 40° C (104°F) shear strength of the tack coated joint, at a loading rate of both 1 mm/min (0.04 in/min) and 100 mm/min (4 in/min), was 8 and 3 times greater than that of cold joint, respectively [30]. Mohammad et al. [35] also reported that flexible pavements constructed in multiple layers using optimum application of CRS 2P as the tack coat produce only 83% of the monolithic mixture shear strength. Other joint construction methods were not reported.

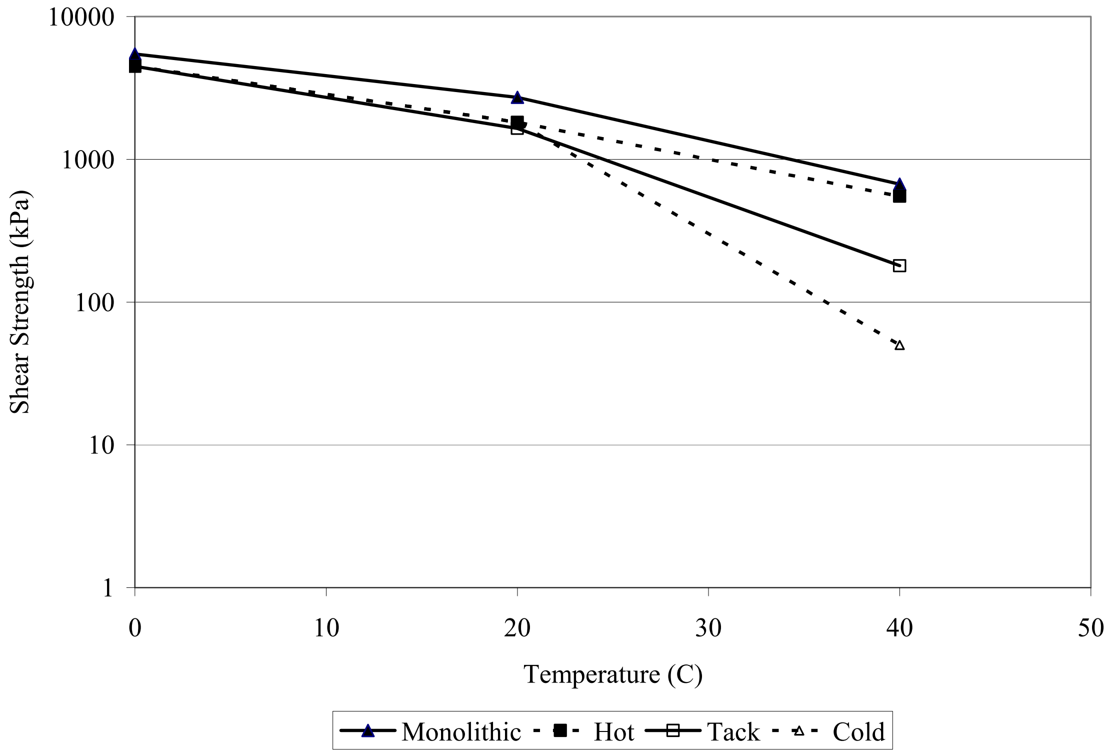

Figure 18. Graph. Shear strength at 100 mm/min vs. various joint construction procedures [30].

Romanoschi and Metcalf [32] conducted research to analyze the characteristics of HMA layer interfaces. Three parameters were identified by the researcher to describe interface behavior. They were interface reaction modulus (K), shear strength (S_{max}) and friction coefficient after failure (μ). Core samples were obtained from the Louisiana Research Facility site from areas with a 0.1 L/m^2 (0.02 gal/yd^2) tack coat and from areas without tack coat. Results from Romanoschi and Metcalf's direct shear testing at a normal force of 276 kPa (40 psi) are shown in Figure 19 [32]. The researchers reported that shear strength (S_{max}) was higher in samples with tack coat than samples without tack coat. Similarly, shear strength of both samples (with and without tack coat) was affected by temperature [32].

Mrawira and Damude [38] evaluated interface shear strength using a test apparatus adapted from ASTM D 143 for testing shear strength in wood. The shear strength was evaluated using tack versus no tack samples of new HMA compacted on top of existing pavement cores. The tack coat was an SS-1 asphalt emulsion applied at a rate of 0.2 to 0.3 L/m^2 (0.04 to 0.07 gal/yd^2). The results are shown in Figure 20.

Mrawira and Damube reported that non tacked overlays seem to exhibit slightly higher ultimate shear strength compared with tack coated overlays. The difference was reported as not statistically significant. The tests were performed after soaking the samples in a water bath at 22±1^{o}C (71.6±1.8^{o}F) for 30 minutes [38].

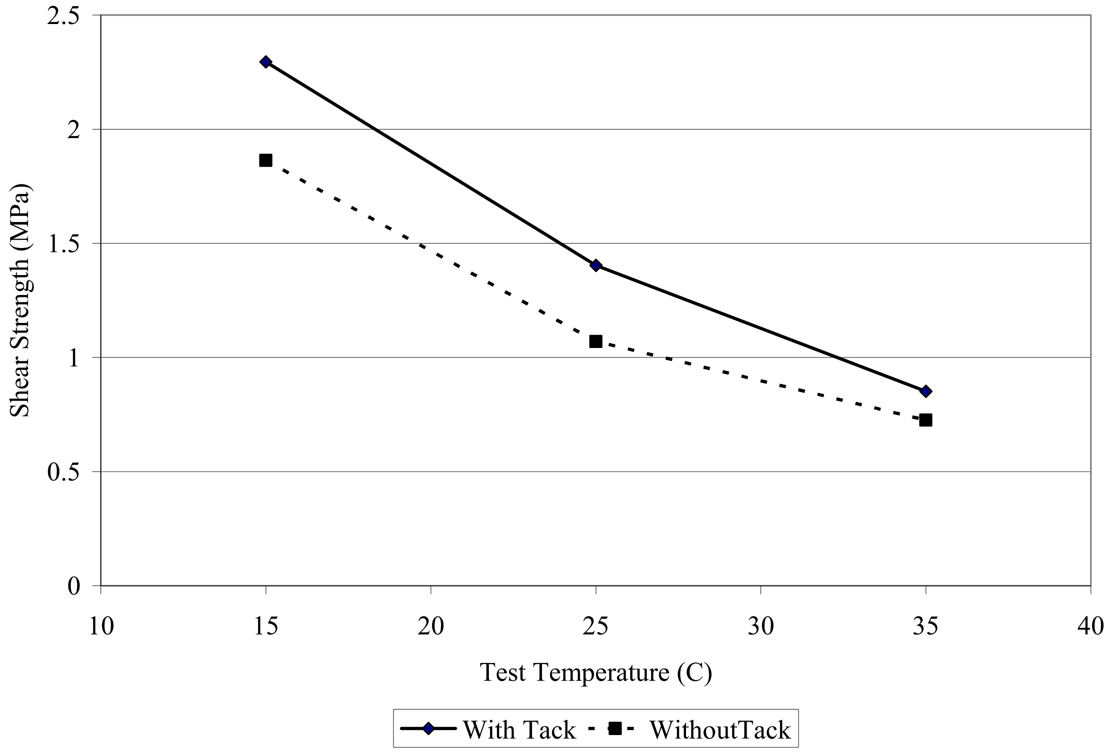

Figure 19. Graph. Effect of tack coat on direct shear strength.

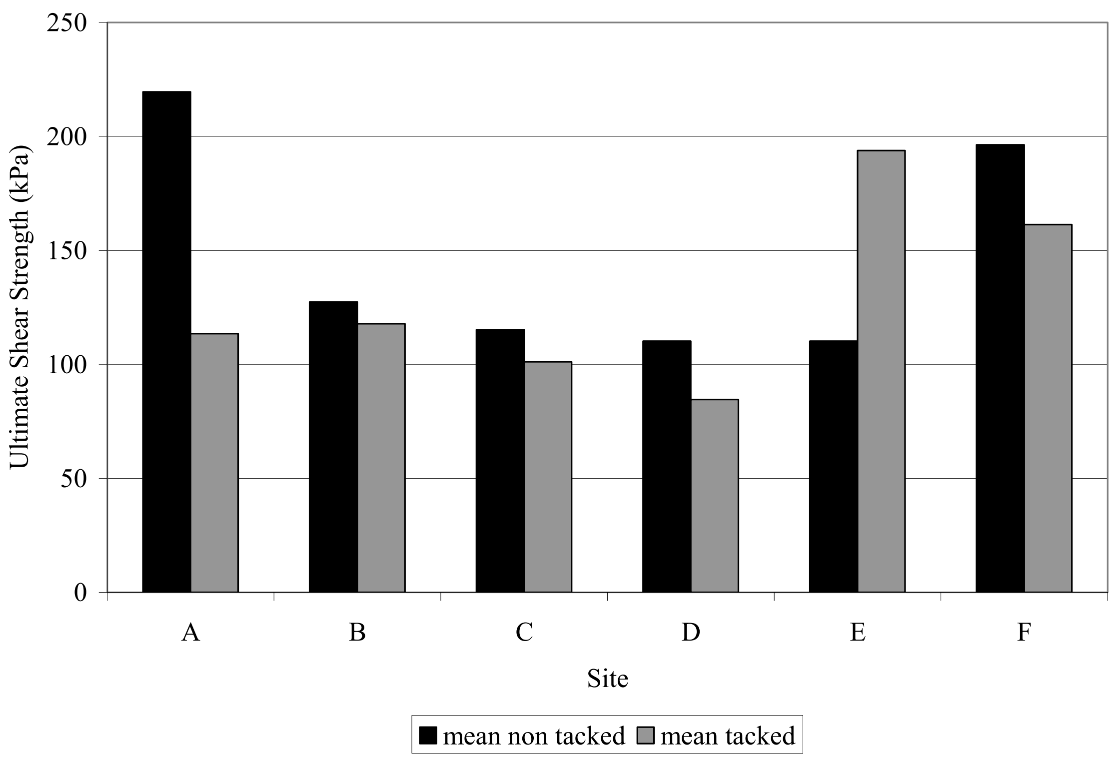

Figure 20. Graph. Comparison of mean ultimate shear strength of tack coated and non tack coated overlays [38].

Uzan et al. [29] performed direct shear tests on samples having a 1.0 kg/m^2 (1.84 lb/yd^2) tack coat of 60-70 penetration asphalt cement. Tests were performed at 25°C (77°F) and 55°C (131°F) at normal stress levels of 0.05, 0.5, 1.0, 2.5 and 5.0 kg/cm^2 (0.7, 7.1, 14.2, 35.5 and 71.1 psi). The results are shown in Figures 21 and 22. Samples with tack coat had higher shear strength than samples without tack, regardless of test temperature or normal stress level [29].

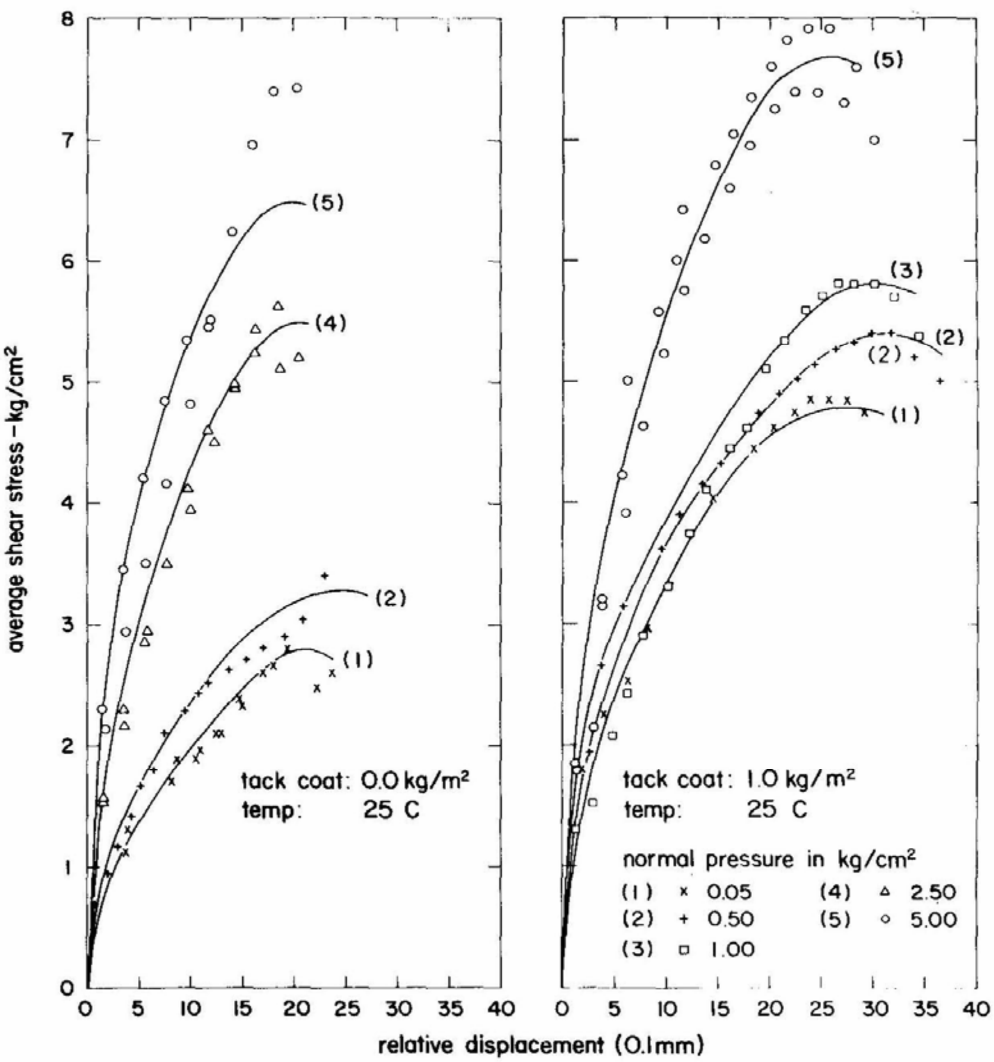

Figure 21. Graph. Shear test results at 25°C [29].

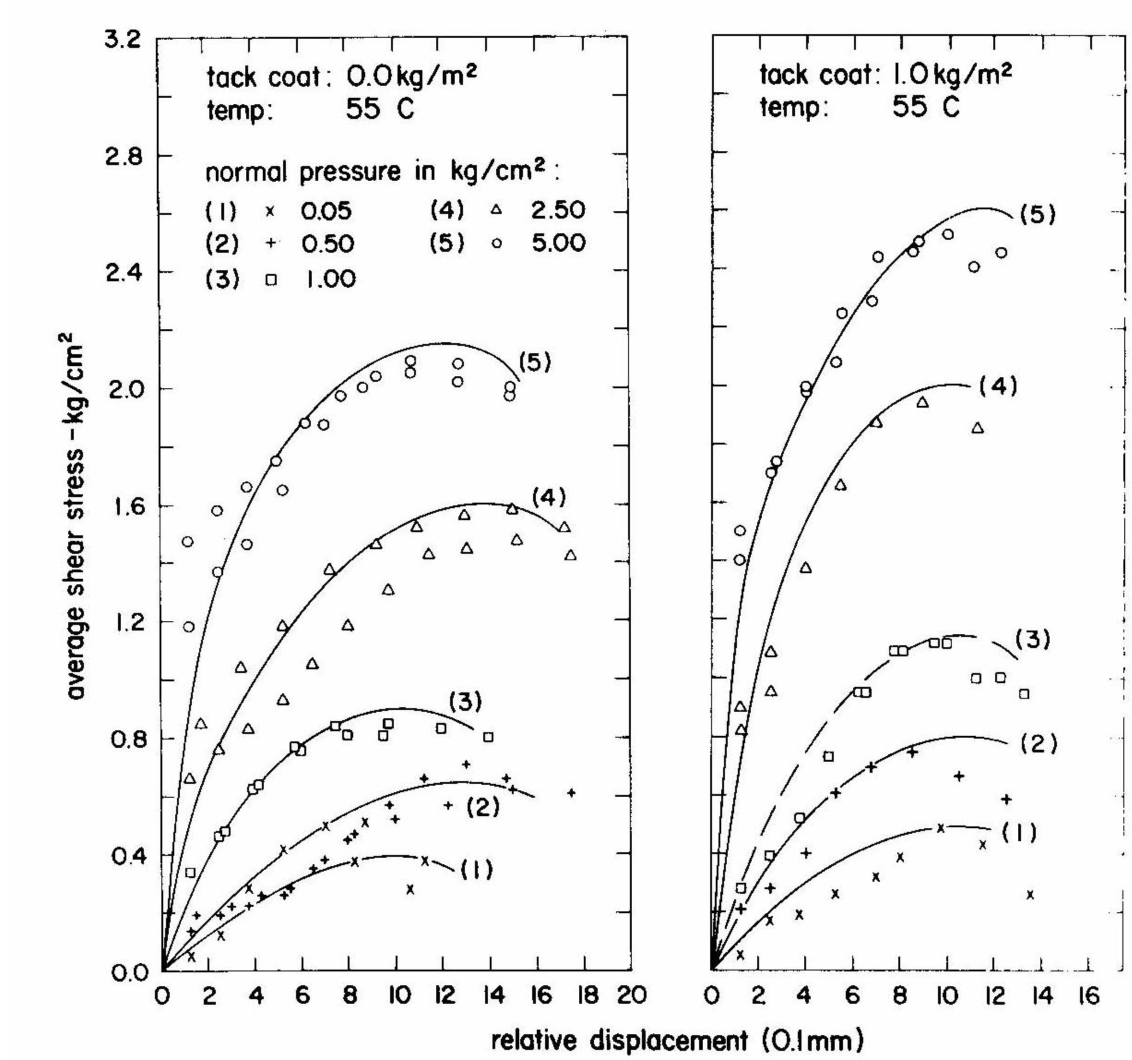

Figure 22. Graph. Shear test results at 55°C (29).

Sholar et al. (33) evaluated direct shear strength of tack coat from field cores. The tests were performed at 25°C (77°F) and at a rate of loading of 50.8 mm/min (2 in/min). The field cores were obtained from test sections with no tack and the minimum, midpoint and maximum Florida DOT specified tack coat application rate. Milled as well as conventional overlay sections were evaluated. The lower application rate of 0.091 L/m^2 (0.02 gal/yd^2) was reported to have slightly higher direct shear strength than the no tack section, for sections with a fine 12.5 mm (0.5 in) Superpave mixture. For test projects consisting of a coarse graded 12.5 mm (0.5 in) Superpave mixture, the benefits of tack were less noticeable. For the milled interface project, tack coat was reported as not being effective in increasing interface shear strength (33).

Materials

Paul and Scherocman (37) surveyed the 50 state DOTs and the District of Columbia about their tack coat practices. Based on 43 survey responses, they reported that almost all states used slow-set asphalt emulsions for tack. Only Georgia was reported to use hot asphalt [37]. Cooley [39] reported on an experimental procedure where millings were used as tack coat material. In a mill and overlay project, the fine millings remaining on the pavement were not swept off the milled surface prior to overlay. The heat from the asphalt overlay was sufficient to melt the fine millings left on the surface and provided sufficient tackiness to bond the overlay to the existing milled surface. Preliminary finding indicated that the procedure was successful [39]. Follow-up reports are not available at this time.

A more comprehensive study of the effectiveness of tack coat materials was performed by Mohammed et al. [35] where they evaluated simple shear strength of two types of performance graded asphalt cements (PG 64-22 and PG 76-22) and four types of emulsified asphalts (CRS-2P, SS-1, CSS-1, and SS-1h). Simple shear strength was determined using the Superpave Shear Test (SST) at a constant rate of shear of 222.5 N/min (50 lb/min). The researchers reported that at a test temperature of 55°C (131°F), there was no significant difference in simple shear strength between the tack materials evaluated. At a test temperature of 25°C (77°F), CRS-2P had significantly higher shear strength than the other tack materials [35]. Typical test results at optimum application rate, which corresponds to maximum shear strength, are shown in Figure 23. The authors reported that test results with the same letter indicate no significant difference in simple shear strength.

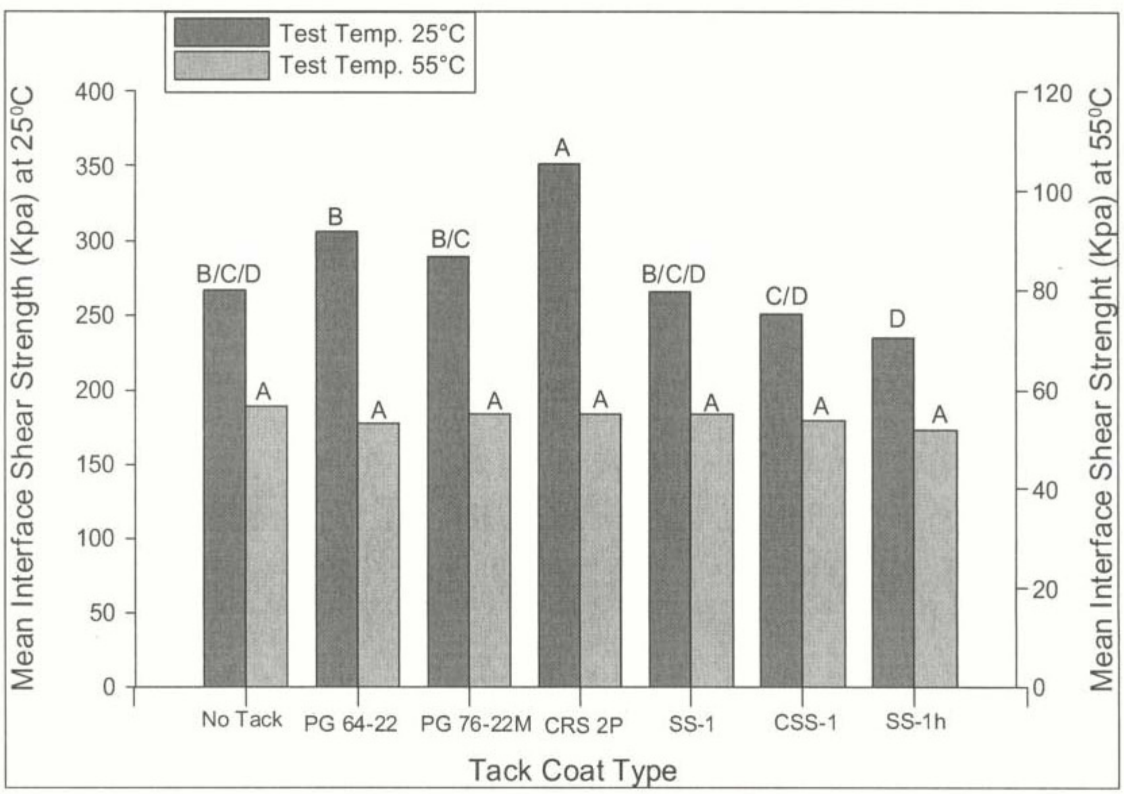

Figure 23. Graph. Mean shear strength vs. tack coat type [35].

Mohammad et al. [35], Crispino et al. [36], and Tschegg et al. [34] all reported on the influence of tack coat binder viscosity on interface shear strength. All reported that the higher the viscosity of the tack coat binder, the higher the interface shear strength.

Application Rate

Paul and Scherocman [37] conducted a survey of tack coat practices. From their survey of state DOT materials engineers, they reported that the residual application rate of tack coat typically varies from 0.06 to 0.26 L/m^2 (0.01 to 0.06 gal/yd^2). Different application rates were used depending on the type of surface.

One of the more comprehensive studies on application rates was by Mohammad et al. [35]. The researchers evaluated the use of tack coats through laboratory simple shear strength testing using the SST at a constant rate of shear of 222.5 N/min (50 lb/min) to determine the optimum application rate. Two types of performance graded asphalt cement and four asphalt emulsions were used. The application rates, based on residual asphalt content, were 0.00, 0.09, 0.23, 0.45 and 0.9 L/m^2 (0.00, 0.02, 0.05, 0.10 and 0.20 gal/yd^2). The tests were conducted at 25°C (77°F) and 55°C (131°F).

Mohammad et al. [35] found that the best tack performer was CRS-2P emulsion with an application rate of 0.09 L/ m^2 (0.02 gal/ yd^2). At the lower test temperature, an increase in tack coat application rate resulted in a decrease in interface shear strength. However, at a higher temperature, shear strength was not sensitive to application rate [35]. Their results for CRS-2P and SS-1h are shown in Figures 24 and 25, respectively.

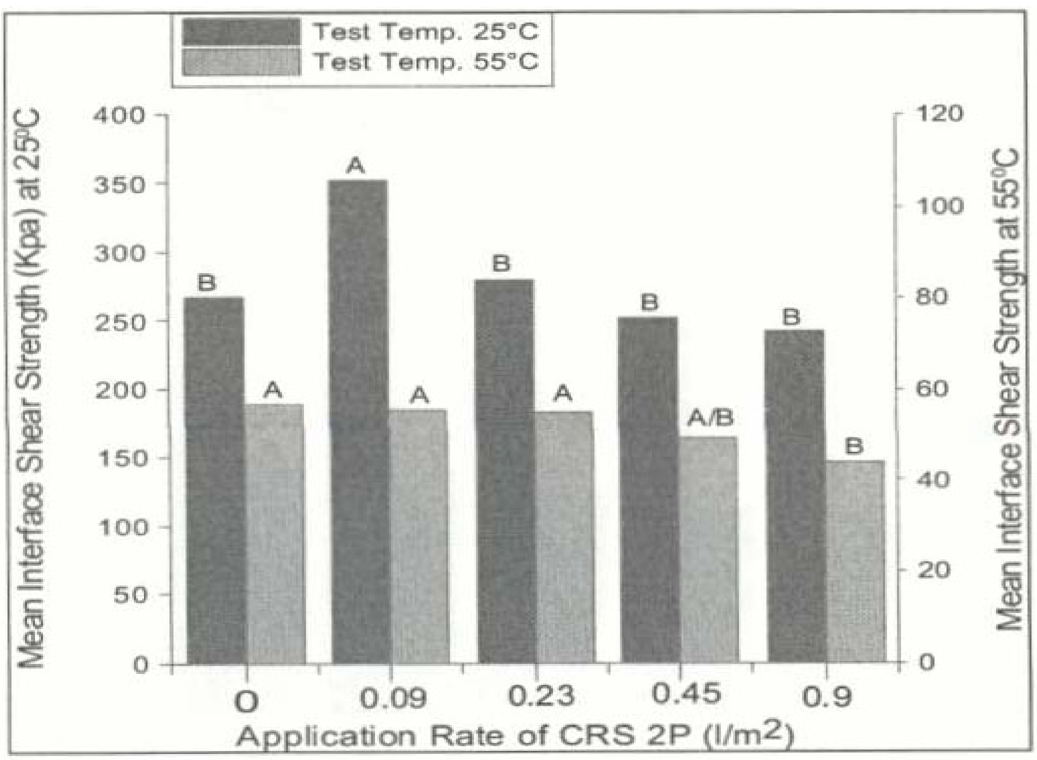

Figure 24. Graph. Interface shear strength with varying application rates of CRS 2P [35].

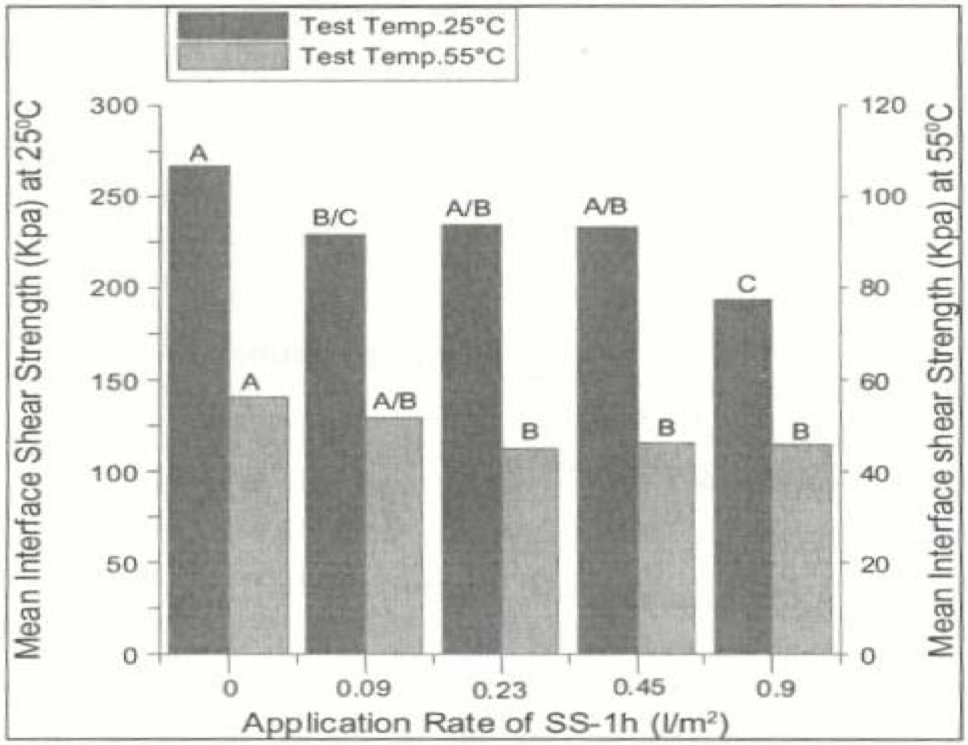

Figure 25. Graph. Interface shear strength with varying application rates of SS-1h (35).

Uzan et al. (29) reported that high application rates of tack results in an increased film thickness of bitumen, resulting in decreased adhesion and interlocking resistance. Results from their study are shown in Figure 26. The researchers concluded there is an optimal amount of tack coat at which the shear resistance is maximum, but the influence of tack coat rate on shear resistance of fresh HMA is slight (29).

Sholar et al. (33) evaluated application rates of tack coat from field cores using direct shear. The tests were performed at 25°C (77°F) at a rate of loading of 50.8 mm/min (2.0 in/min). Three application rates were evaluated; the minimum, midpoint and maximum Florida DOT specified application rates, 0.091, 0.226 and 0.362 L/m^2 (0.02, 0.05 and 0.08 gal/yd^2), respectively. The application rate was reported to have a slight effect on shear strength. Shear strengths were slightly higher at higher application rates. As weeks passed, shear strengths were reported to equalize, regardless of application rate (33).

Weather

Sholar et al. (33) evaluated the effect of rain falling on a cured tack coat prior to application of the HMA overlay. The direct shear strength was determined from field cores tested at 25°C (77°F). Partial test results from the US-90 project are shown in Figure 27. The authors concluded that water applied to the surface of tack coat, to represent rain water, reduced shear strength when compared to equivalent sections without water applied. As weeks passed, shear strength of both sections increased, but the rain water sections never reached the strength of the sections without water. Sections with higher application rates, 0.362 L/m^2 (0.08 gal/yd^2) performed better than sections with lower application rates, 0.091 L/m^2 (0.08 gal/yd^2).

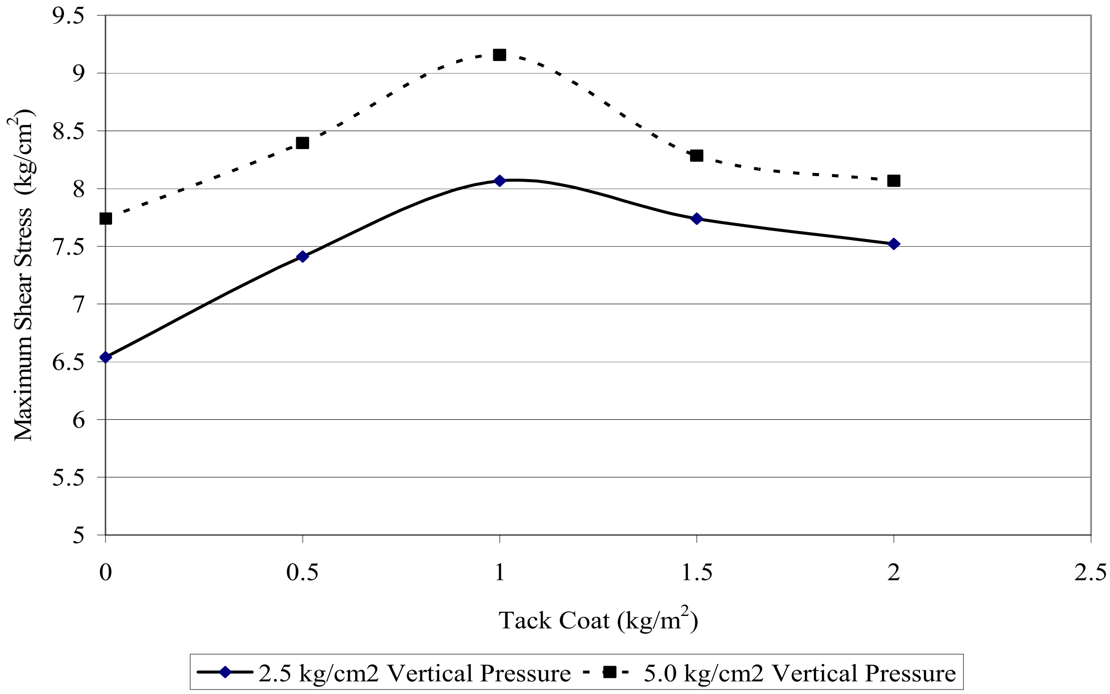

Figure 26. Graph. Tack coat application rate vs. maximum shear stress.

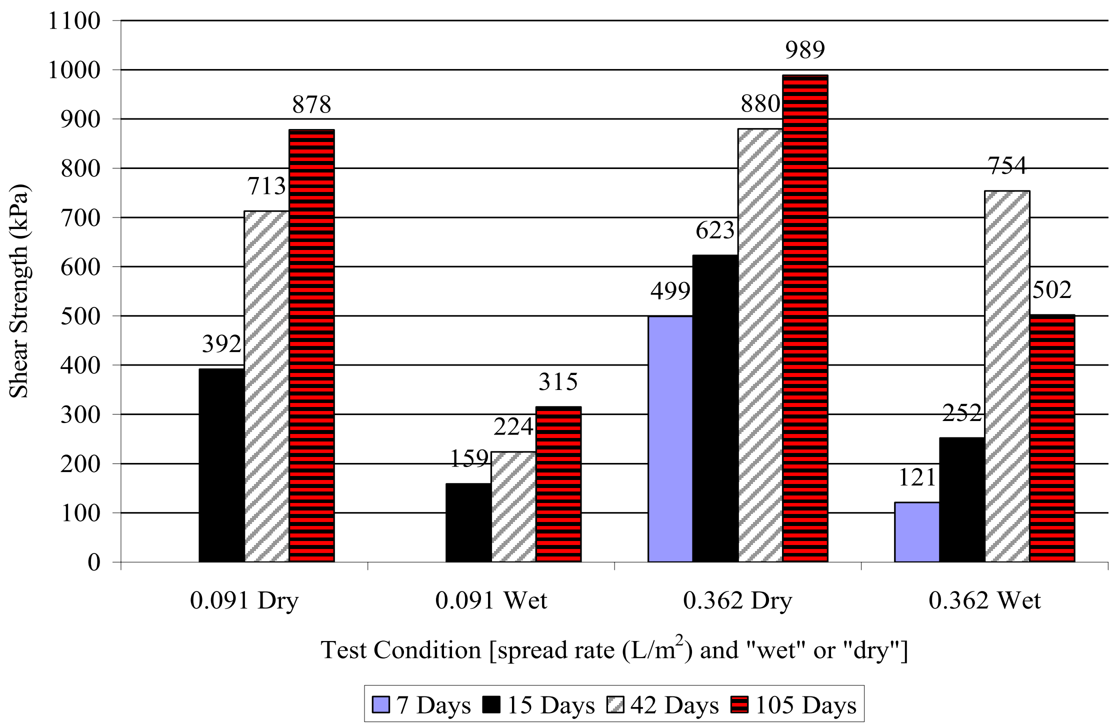

Figure 27. Graph. Shear strength test data for US-90 project [33].

Curing

Paul and Scherocman [37] found from their survey of state DOTs on tack coat practices that cure time between tack coat application and paving was typically after the asphalt emulsion had broken. They also reported that tack coat materials exposed for more than 24 hours were required to be retacked.

Sholar et al. [33] evaluated the effect of cure time on direct shear strength of tack coat from field core samples. The tests were performed at 25°C (77°F) at a rate of loading of 50.8 mm/min (2.0 in/min). Tack coat application rates included no tack and the minimum, midpoint and maximum Florida DOT specified application rates, 0.091, 0.226 and 0.362 L/m^2 (0.02, 0.05 and 0.08 gal/yd^2), respectively. Cure times were up to 100 days. Typical results are shown in Figure 28. The researchers concluded that shear strength increased slightly with time and that shear strength equalized with time, regardless of application rate [33].

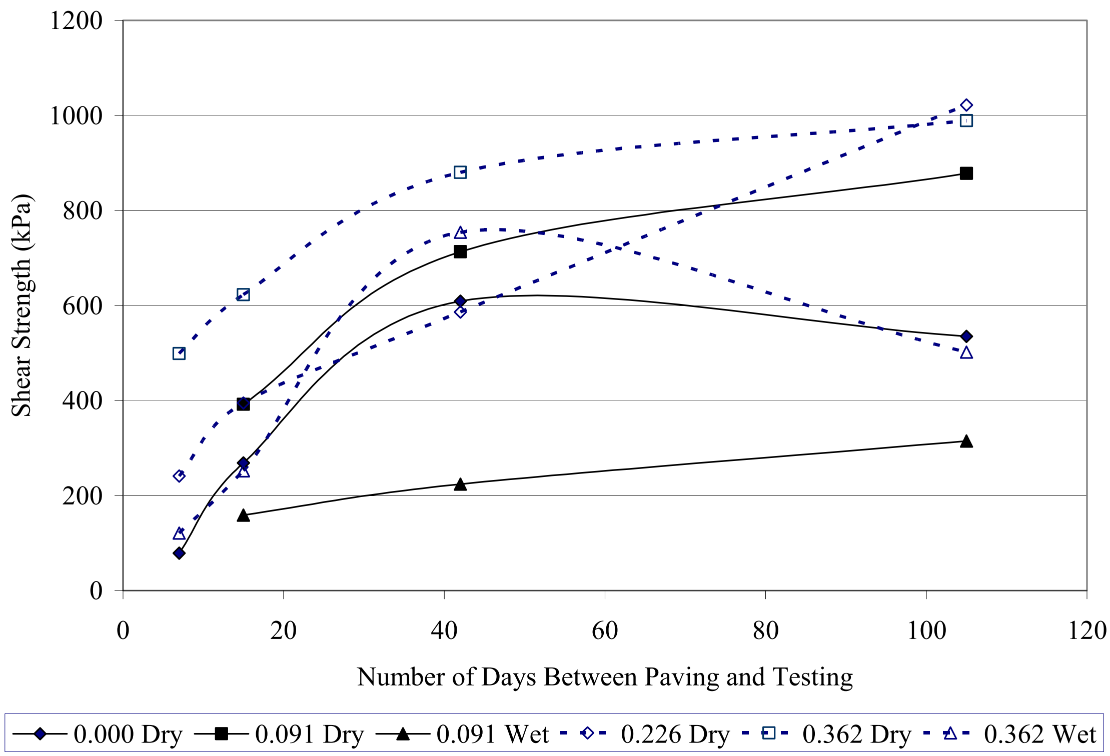

Figure 28. Graph. Shear strength test data vs. time for US-90 project [33].

Hachiya and Sato [30] evaluated the importance of curing tack coat. The researchers measured the change of mass of emulsified asphalt after being exposed to the environment. At an application rate of 0.2 L/m^2 (0.04 gal/yd^2) and laboratory exposure conditions, the mass of an emulsified asphalt tack coat decreased to a nearly constant value after six hours. For an application rate of 0.4 and 0.6 L/m^2 (0.09 and 0.13 gal/yd^2) the mass did not become constant, even after 24 hours of curing. The study also compared the evaporation process between indoor (laboratory) and outdoor conditions at an application rate of 0.4 L/m^2 (0.09 gal/yd^2). When the emulsion was exposed in a natural outdoor environment, the mass of emulsified asphalt became constant after one hour. The difference in weather (fine or cloudy) did not influence the process significantly [30].

Another important finding of Hachiya and Sato's research was the influence of dirt on tack coat strength. The authors reported that dirt did not influence the strength of interface bond if the curing was conducted fully, as there was little reported difference in interface strength [30].

SUMMARY

Prime Coat

Based on the review of research data and reports, the following conclusions are warranted:
1. Prime coat increased the bond strength at the interface between a compacted base and asphalt layer over that of no prime coat. The reported differences were not always statistically significant.
2. At higher static normal stresses, shear strength at the interface is not appreciably affected by the type or even the presence of a prime coat.
3. Medium cure cutback asphalts penetrated deeper than conventional emulsified asphalts. Dilution of emulsified asphalts with water helped penetration but did not provide acceptable penetration.
4. Some emulsified asphalt primes were essentially emulsified asphalt cutbacks and were no less polluting than medium cure cutback asphalts.

Tack Coat

1. A loss of bond between HMA layers can cause crescent shaped slippage cracks or debonding to occur, leading to reduced pavement life.
2. Many factors were shown to affect laboratory interface shear strength, including rate of shear, magnitude of normal force, temperature and joint construction.
3. Monolithic construction provided the highest shear strength followed by hot joint construction. Neither of these construction methods is always feasible.
4. In a few studies, tacked surfaces were shown to have slightly lower interface shear strengths than untacked surfaces. However, in these studies the statistical significance of the difference in interface shear strength was not reported. In reports where the statistical significance of the differences in interface shear strength was evaluated, tacked interfaces were either stronger or not significantly different from untacked interfaces.
5. The higher the viscosity of the bituminous binder in the tack the higher the reported interface shear strength.
6. At typically specified application rates, application rate had little effect on interface shear strength. Higher than typically recommended application rates resulted in slightly lower interface shear strengths.

CHAPTER 4 – ENVIRONMENTAL ISSUES

There are several environmental issues related to the use of prime and tack coat which are not solely related to the use of asphalt emulsions versus cutback asphalts. Numerous references were found stating that asphalt emulsions are replacing cutbacks due to environmental concerns. NCAT lists the following four reasons that asphalt emulsions should be used in lieu of cutbacks [(1)]:

1. Environmental regulations. Emulsions are relatively pollution free. Unlike cutback asphalts there are relatively small amounts of volatiles to evaporate into the atmosphere other than water.
2. Loss of high energy products. When cutback asphalts cure, the diluents which are high energy, high price products are wasted into the atmosphere.
3. Safety. Emulsions are safe to use. There is little danger of fire as compared to cutback asphalts, some of which have very low flash points.
4. Lower application temperature. Emulsions can be applied at relatively low temperatures compared to cutback asphalt, thus saving fuel costs. Emulsions can also be applied effectively to a damp pavement, whereas dry conditions are required for cutback asphalts.

Environmental issues related to the use of prime and tack coat are complex due to the overlapping jurisdiction of several federal agencies and the fact that the regulations are subject to interpretation by the courts. Local, state and federal regulations should be consulted for specific regulations regarding environmental issues with use of cutback and asphalt emulsions.

Environmental issues related to the use of prime and tack coats can be grouped under the concerns of air and water quality issues, worker safety and hazardous materials issues, and contractor liability issues. The following is a discussion of some of the environmental issues relating to prime and tack coat usage and is not meant to be a guideline on procedures, reporting requirements or regulations. Appropriate local, state and federal rules and regulations should be consulted.

AIR QUALITY ISSUES

The primary pollutants of concern from asphalt paving operations are volatile organic compounds (VOC). Cutback asphalts are the major source of VOCs as only minor amounts of VOCs are emitted from emulsified asphalts and asphalt cements. VOC emissions from cutback asphalts result from the evaporation of the petroleum distillate used to liquefy the asphalt cement. VOC emissions can occur at both the job site and the mixing plant; however, the largest source of emissions is from the road [(41)].

A typical prime coat material would be MC cutback with approximately 25 to 45 percent diluent. The Environmental Protection Agency (EPA) reports that approximately 70 percent of the diluent will eventually evaporate from MC cutback with some of the diluent permanently retained in the asphalt cement. The rate of diluent evaporation for MC cutback, based on limited test data, was reported as 20 percent emitted during the first day after application, 50 percent during the first week and 70 percent after 3 to 4 months [(41)].

Rapid cure (RC) cutback is occasionally used for tack coat by some agencies, although it is not allowed in current CFLHD specifications. EPA reports that approximately 95 percent of the diluents eventually evaporate from RC cutback with 75 percent emitted during the first day after application, 90 percent during the first month and 95 percent in 3 to 4 months [(41)].

Asphalt emulsions are typically used in place of cutback asphalts to eliminate VOC emissions. The use of cutback asphalt is regulated in many jurisdictions to help reduce VOC emissions. Prohibitions on the use of cutback, either permanently or during certain times of the year, are common in jurisdictions that have either reached, or are nearing non attainment for ozone requirements of the Clean Air Act.

WATER QUALITY ISSUES

Water quality issues are much more complex than air quality issues because of the overlapping jurisdiction of several federal agencies, the complexity of many of the regulations, and the variability of regulations and jurisdictions on the state and local levels. Local, state and federal regulations should be consulted for specific reporting and remediation requirements and for regulations regarding water quality issues with use of cutback and asphalt emulsions.

HMA has been successfully used as a liner for drinking water reservoirs. The Asphalt Institute reported that the Metropolitan Water District of Southern California has been using asphalt-lined water reservoirs for over 50 years [(42)] and that Washington and Oregon operate fish hatchery ponds that are lined with HMA with an emulsified asphalt seal coat [(43)].

Oil Spills into Waterways

The EPA has interpreted asphalt emulsions and cutback as oil as defined in Section 311(a)[(1)] of the Clean Water Act [(44)]. Therefore, according to the Clean Water Act, there is no differentiation between spills of cutback or asphalt emulsion. The Clean Water Act, in part, requires that any spill of oil that could enter a waterway, as defined by The Clean Water Act, and violates applicable water quality standards or causes a film or sheen on the water, would require reporting to the National Response Center and local authorities [(45)]. The EPA states that “a sheen” refers to an iridescent appearance on the surface of the water [(44)]. Both cutback and asphalt emulsion would most probably leave a sheen on any body of water they entered.

A direct spill into a waterway is not the only way prime and tack coat materials can enter a waterway. Entry is available through a spill that enters storm water and waste water sewers, drainage ditches, etc. to name but a few sources. There is even a possibility that rain water could wash a freshly applied uncured prime or tack coat into a waterway in sufficient quantity to cause a sheen to form on the water way. Figure 29 shows the effect of rain on a freshly applied prime coat. The Storm Water Pollution Prevention Plans (SWP3), required by the storm water permit process for construction sites, further addresses requirements for pollution prevention from storm water runoff of waterways and environmentally sensitive areas. The Asphalt Institute [(2)] recommends that prime coat be omitted if there is a strong possibility of runoff.

Figure 29. Photo. Effect of rain on a freshly applied prime coat.

Oil Spills on Ground

The reporting requirements for a spill of oil on the ground that does not enter a waterway, for oil as defined by the clean water act, is more complicated due to the various agencies that could have jurisdiction. Under Spill Prevention, Control and Countermeasure (SPCC) regulations [44], a spill of oil must be reported to the National Response Center and local authorities if, in part, the spill is greater than 3,785 L (1,000 gal) or a spill of over 160 L (42 gal) of oil in each of two spills occurs within a 12 month period. Local requirements could be more stringent.

According to the Resource Conservation and Recovery Act (RCRA) [46], hazardous chemicals have an associated reportable quantity (RQ) that is contained in an EPA list. If a spill or release of more than a RQ of a material occurs at a site, the spill must be reported to the National Response Center and local authorities. There can be RCRA regulated materials in cutback and occasionally in some asphalt emulsions. However, these RCRA hazardous materials are usually present in such low concentrations that those RQs would rarely be reached in normal paving operations. State and local jurisdictions can have lower RQ requirements and suppliers and local agencies should be contacted if there is a question concerning a reportable spill.

ACCIDENTAL SPILL PROCEDURES

The following procedures to be taken in case of a spill or release of cutback or asphalt emulsion were obtained from supplier's material safety data sheets (MSDS) [47,48,49,50].

A spill or accidental release should be contained immediately by diking or impounding. Do not allow spill to enter sewers or watercourse. Remove all sources of ignition. Absorb with appropriate inert materials such as sand, clay, etc. Notify appropriate authorities of spill. The spill may be a regulated waste. If regulated solvents are used to clean up the spilled material, the resulting waste mixture may be a regulated waste. Assure conformity with local state and federal governmental regulations for disposal.

Disposal of recovered spill material must be in accordance with applicable local, state and federal regulations. Disposal methods could include recycling of the waste, incineration of the waste at an approved facility, landfilling at an approved facility or a special waste or industrial landfill.

WORKER SAFETY AND HAZARDOUS MATERIALS ISSUES

Under RCRA, asphalt cement is not considered a hazardous material (46). However, occasionally RCRA defined hazardous materials are contained in diluents used to make cutback asphalts or in additives added to emulsifying agents or performance enhancing agents in asphalt emulsions. The concentrations of these RCRA defined hazardous materials in MC cutbacks and asphalt emulsions are usually in such small quantities that a major release, much larger than would be likely to occur on a typical CFLHD paving project, would be required to meet or exceed RCRA reportable quantity (RQ) limits.

Other worker safety issues concern health risks to workers from exposure to the product, fire danger and stability or reactivity of the product. Table 3 shows the Hazardous Materials Information Resource System (HMIRS) or National Fire Protection Association (NFPA) hazard identification ratings for materials typically used in prime and tack coat applications.

Table 3. Hazard identification rating and volatility.

Material / Source	HMIRS / NFPA Hazard Rating[1]			% Volatility
	Health	Fire	Reactivity	
LVOC-1 / Prime Materials[2]	0	0	0	0
AE-P / Prime Materials[2]	0	2	0	10
AE-P / Koch Materials[3]	3	1	0	ND
EAP&T / Prime Materials[2]	1	0	0	NL
SS-1 / Prime Materials[2]	1	0	0	0
CSS-1 / Prime Materials[2]	1	0	0	0
CSS-1H / Citgo[4]	1	1	0	Negligible
MC-70 / Jebro[5]	1	2	0	15-35
Unmodified Asphalt / Citgo[4]	2	1	0	Negligible
Citcoflex SP / Citgo[4]	2	1	0	Negligible

[1] 0-least, 1-slight, 2-moderate, 3-high, 4-extreme, *-may present chronic health effects
[2] Reference (47)
[3] Reference (48)
[4] Reference (49)
[5] Reference (51)
ND = not determined, NL = not listed.

Unmodified and modified asphalt cements are shown for comparison purposes. The information was obtained from supplier MSDS.

As shown in Table 3, none of the materials typically used for prime or tack is reactive or pose more than a slight health risk, with the exception of Koch Material's AE-P, and they are less reactive and pose less of a health risk than unmodified or modified asphalt cement. There is a health risk associated with worker exposure to fumes from heated asphalt products, mainly in confined spaces. This is not usually an issue when applying prime or tack coat if workers stay a reasonable distance away from the spray bar during application.

The two materials with a diluent, MC 70 and AE-P, contain VOCs and have a moderate fire risk. Fire can be a concern when using MC for prime coat or RC for tack coat. Application of MC and RC often involves heating the material above its flash point. A fire that is initiated at the spray bar may spread through accumulated asphalt deposits and destroy the vehicle. Therefore, the Asphalt Institute recommends asphalt distributors should be kept clean and free of asphalt accumulations and the burner should be shut off prior to application. Dry chemical or carbon dioxide extinguishers should be used to extinguish such a fire [(52)].

There is also a possibility of fire during application of cutbacks, such as by a cigarette or match. This would be more likely with RC, with gasoline or naptha as the diluent, rather than MC cutback with kerosene as the diluent [(52)]. This should not be a serious issue for CFLHD as they do not specify RC cutback for prime or tack.

CONTRACTOR LIABILITY ISSUES

The above discussion dealt with statutory regulations concerning environmental issues associated with the use of prime and tack coats. There is also the possibility of civil liability and public relations/public perception issues associated with accidental spills or releases of oils. Deleting prime coat would not remove this liability completely, as there are many other products that contractors routinely handle, including fuel and lubricating oils, which are as much an environmental concern as prime and tack coats. However, prime coat has been successfully deleted with few documented cases of failure directly attributed to deletion of the prime coat. Furthermore, prime is generally applied at higher application rates than tack and can take longer to cure before being covered, increasing the possibility that it would be washed into a waterway. Many local jurisdictions, including cities and counties, are routinely deleting prime coat, often at the request of the contractor. The rational for deleting prime coat appears to be that the benefits of prime do not outweigh the increased liability associated with handling liquid asphalts.

CHAPTER 5 – REVIEW OF CFLHD SPECIFICATIONS

One of the objectives of this study was to review CFLHD specifications for prime and tack coat and compare them with best practices. To assist in determining best practice, the construction specifications from the 13 DOTs that make up the CFLHD region were reviewed and compared to CFLHD's *Standard Specifications* (53), *Construction Manual* (54) and *Field Materials Manual* (55). In addition, each DOT in the CFLHD region was contacted by phone and surveyed for their typical materials, methods and procedures for using prime and tack coat.

PRIME COAT

Phone Survey

In order to determine typical agency practices regarding prime coat application, a representative from each state DOT was contacted by phone. The agency contact was either a member of the Construction Division or Materials Division. The results from the phone survey for prime coat are shown in Table 4. The responses are general in nature and would represent the normal agency procedures regarding prime coat usage. For the purpose of this study, agency responses of "rarely" or "occasionally" were interpreted as meaning the procedure/material was not used. The purpose of the survey was to determine when prime was used, what material was typically used, if cutbacks were allowed and if there were written guidelines for field personnel regarding deletion of prime coat. The CFLHD responses to the phone survey are included for comparison purposes only and are not included in the summary analysis.

Use of Prime Coat

Aggregate Base:

Two DOTs reported not using prime coats at all. The other 11 DOTs reported using prime coat over aggregate base. Of the 11 DOTs that reported using prime coat over aggregate base, two reported deleting the prime 95 percent of the time, two reported deleting prime coat 75 percent of the time, one reported deleting prime 50 percent of the time, one reported deleting prime 15-20 percent of the time and the remaining five agencies reported deleting prime less than 10 percent of the time. To summarize, 31 percent of the DOTs (4 of 13) reported deleting prime at least 95 percent of the time. Forty-six percent of the DOTs (6 of 13) reported deleting prime at least 75 percent of the time and 46 percent of the DOTs (6 of 13) reported deleting prime less than 25 percent of the time.

Stabilized Base:

Only one DOT reported using prime over asphalt stabilized base, such as a CIR or FDR base, and one DOT reported using prime over other stabilized bases.

Table 4. Results of prime coat practice phone survey.

Survey Questions	Arizona	California	Colorado	Kansas	Nebraska	Nevada	New Mexico
1. Is prime coat typically specified for use over:							
a. aggregate base?	Yes	No	Yes	No	Yes	Yes	Yes
b. cold recycled asphalt base?	No	No	No	No	No	No	No
c. other stabilized bases?	No	No	No	No	No	No	No
d. subgrade?	No	No	Varies	No	No	Yes	No
2. Is prime ever deleted by field personnel?	Yes	N/A	Yes	No	N/A	No	Yes
3. If deleted by field personnel, approximately what percentage of the time is it deleted?	>95%	N/A	50%	N/A	>95%	<1%	< 10%
4. Under what circumstances is prime deleted?	Note 1	N/A	Note 2	N/A	Note 3	Note 4	Note 4
5. Are there formal guidelines for deletion of prime?	Yes	N/A	No	N/A	N/A	No	No
6. Any pavement failures attributed to prime coat?	No	No	No	N/A	No	No	No
7. Material typically specified.	MC-70	N/A	MC-70 PEP AE-P	N/A	AE-P	MC & SC 70,250,800 CRS-1,2 SS-1h, CMS-2	AE-P PE-P
8. Other materials occasionally used.	None	N/A	None	N/A	PE-P	None	MC-70
9. Other comments		Cutbacks not used	Note 5		Cutbacks not used		Cutbacks rarely used

Note 1. If HMA thickness is 100 mm (4 in) or more, prime can be deleted without additional review.
If HMA thickness less 100 mm (4 in), additional review required.
Note 2. Deleted if full depth HMA or if base will be covered within a short period of time.
Note 3. Contractor has the option to delete prime if the base is maintained to the specified condition until placement of HMA.
Note 4. Deleted if base will be covered within a short period of time and contractor maintains specified condition of base.
Note 5. Cutbacks not used in ozone non-attainment areas.

Table 4 (Con't.). Results of prime coat practice phone survey.

Survey Questions	North Dakota	Oklahoma	South Dakota	Texas	Utah	Wyoming	CFLHD
1. Is prime coat typically specified for use over:							
a. aggregate base?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
b. cold recycled asphalt base?	N/A	No	Yes	N/A	No	No	No
c. other stabilized bases?	No	No	No	Yes	No	No	Varies
d. subgrade?	No	Yes	No	No	No	No	No
2. Is prime ever deleted by field personnel?	Yes	Yes	Yes	No	Yes	No	Yes
3. If deleted by field personnel, approximately what percentage of the time is it deleted?	Occasionally	>75%	15-20%	Rarely	>75%	0%	30%
4. Under what circumstances is prime deleted?	Note 4	Note 4	Notes 1 & 4	Note 4	Note 1	N/A	Notes 2 & 5
5. Are there formal guidelines for deletion of prime?	No	No	No	No	No	N/A	No
6. Any pavement failures attributed to prime coat?	No	No	No	No	No	No	No
7. Typical material specified.	MC-70 MC-250	MC-70	MC-70	MC-30	MC-70 MC-250	MC-70	MC-70
8. Other materials occasionally used.	None	SS-1	None	AE-P	SS-1	MC-30	CSS-1, SS-1, MC-30, MC-250
9. Other comments					Cutbacks not available		

Note 1. If HMA thickness is 100 mm (4 in) or more, prime can be deleted without additional review.
If HMA thickness less 100 mm (4 in), additional review required.
Note 2. Deleted if full depth HMA or if base will be covered within a short period of time.
Note 3. Contractor has the option to delete prime if the base is maintained to the specified condition until placement of HMA.
Note 4. Deleted if base will be covered within a short period of time and contractor maintains specified condition of base.
Note 5. Cutbacks not used in ozone non-attainment areas.

Subgrade:

Only three DOTs reported applying prime to subgrade, Colorado, Oklahoma and Nevada. Oklahoma reported that prime was used over subgrade less than 25 percent of the time and was used to ensure that the contractor maintained the specified moisture and density requirements of the subgrade. Colorado reported that the practice varied throughout the state.

Justification

Utah reported that prime coat could be deleted without additional agency review if the total thickness of HMA would exceed 100 mm (4 in). Colorado reported that prime was not used on full depth HMA pavements. Nebraska reported that the contractor is responsible for maintaining the base course within specification tolerances until the HMA is placed and that the use of prime coat is up to the contractor. Nebraska reported that contractors opt to use prime coat less than 5 percent of the time. Seven DOTs reported that prime can be deleted if the base will be covered with HMA within a short period of time and inclement weather is not expected.

Only one DOT, Arizona, has a written procedure for deletion of prime coat. The Arizona DOT Construction Manual states that [56]:

> Prime coats may be eliminated from the work in those cases where the aggregate base surface is tightly bound and will not displace under the laydown machine and hauling equipment. Except, never eliminate the prime coat on a secondary road project that has a chip seal, or an asphaltic concrete friction course applied directly on top of the prime coat.

Materials

Nine DOTs reported using cutbacks for prime coat with MC-70 being the most common followed by MC-250. Only three states, Nebraska, New Mexico and California, reported that cutback asphalts were no longer used by the agency. New Mexico reported using AE-P or PEP. Utah reported that many contractors have had difficulty obtaining either MC-70 or MC-250, and on projects that required prime, diluted SS-1 was reported as being substituted most frequently.

Pavement Failures

None of the DOTs could recall a pavement failure associated with prime coat. One or two DOTs reported hearing of slippage being reported on county roads where prime was deleted. It was generally thought that steep grades and thin pavement sections were involved but this information cannot be verified.

Agency Specifications

The standard construction specifications for the 13 state DOTs in the CFLHD region were reviewed for prime coat practices and specification requirements [57,58,59,60,61,62,63,64,65,66,67,68,69]. Because many CFLHD projects are for the U.S. Forest Service, their specifications were reviewed along with the Unified Facilities Criteria [4] of the military. The specifications were reviewed to determine placement requirements, weather limitations, materials and application rates. There were several instances found where the specifications allowed materials, such as cutbacks, where the phone survey indicated they were not used by the agency. A summary of agency specifications for prime coat is shown in Table 5. The CFLHD specifications are included for comparison purposes only and are not included in the summary analysis.

Materials

Most agencies were not specific in their specifications with regard to prime coat materials and allow a wide range of materials. Of the 15 agency specifications reviewed, four agencies allowed cutbacks, asphalt emulsions and asphalt cement. Seven agencies allowed either cutback or asphalt emulsion. One agency apiece specified only cutback or asphalt emulsion. Three agencies had material specifications for AE-P or PEP. New Mexico requires the use of AE-P or PEP. California does not allow the use of cutbacks. All agencies indicated that the prime coat material would be indicated on the plans.

Weather Limitations and Curing

All agencies had a statement in their specifications concerning weather conditions. The majority stated that the surface should be dry, although nine agencies specifically mentioned that the surface could be moistened to enhance penetration. Temperature restrictions were found for all but three agencies. The temperature requirements ranged from a low of 4°C (40°F) to a high of 20°C (70°F). One agency required the temperature be above 4°C (40°F), eight required the ambient temperature be above 10°C (50°F), two required the temperature be above 15°C (60°F) and one required the temperature be above 20°C (70°F). Four agencies had requirements on both the ambient and surface temperature.

All agencies required the prime coat be fully cured before allowing traffic on the base or paving over the base with HMA. Cured appeared to be defined as being either not tacky to the touch or no pickup of the prime by traffic. Three agencies required a minimum 48-hour cure and one agency reported placement of HMA was "as directed by the engineer." One agency had separate cure requirements for cutback and asphalt emulsion prime, requiring a minimum five-day cure for cutback and 24 hours for asphalt emulsion. All agencies reported that any excess prime not absorbed into the base within 24 hours be removed with blotter material.

Application Rates

Five of the 15 agency specifications reviewed contained either maximum application rates or an application range. Eight agency specifications indicated that the application range would be found in the plans or special provisions and two agencies reported that the engineer or project monitor would provide the application rate. Application rates would vary depending on the material used and the permeability or openness of the base.

Table 5. Summary of agency prime coat specifications.

Agency	Material	Application Rates (L/m^2)	Temperature Limitations	Cure Requirements	Moisten Surface
Arizona (*57*)	CB & Emulsions	Shown in Special Provisions	Ambient > 20 C (70 F)	N/M	Yes
California (*58*)	No CB	1.15 (0.25 gal/yd^2)	N/M	N/M	N/M
Colorado (*59*)	AE-P PEP	Shown on Plans	N/M	N/M	N/M
Kansas (*60*)	CB & Emulsions	Shown on Plans	Ambient > 15 C (60 F)	48 hrs	Yes
Nebraska (*61*)	CB	1.35 (0.30 gal/yd^2)	Ambient >10 C (50 F)	N/M	N/M
Nevada (*62*)	CB & Emulsions	Shown on Plans	Ambient >10 C (50 F)	Cured	N/M
New Mexico (*63*)	AE-P PEP	By Project Manager	Ambient > 10 C (50 F)	N/M	Yes
North Dakota (*64*)	All	Shown on Plans	Ambient or Surface > 4 C (40 F)	48 hrs	N/M
Oklahoma (*65*)	CB & Emulsions	0.45 - 1.8 (0.1 - 0.4 gal/yd^2)	Ambient >10 C (50 F)	Cured	Yes
South Dakota (*66*)	CB & Emulsions	Shown on Plans	Ambient and Surface > 15 C (60 F)	As Directed by the Engineer	Yes
Texas (*67*)	All & AE-P PEP	By Engineer	Ambient >10 C (50 F)	N/M	Yes
Utah (*68*)	All	Shown on Plans	Ambient >10 C (50 F)	N/M	N/M
Wyoming (*69*)	All	Shown on Plans	Ambient or Surface > 10 C (50 F)	N/M	Yes
USFS (*70*)	CB & Emulsions	MC: 0.45 - 2.25 (0.10 - 0.50 gal/yd^2) EAC: 0.45 - 1.35 (0.10 - 0.30 gal/yd^2)	Ambient and Surface > 10 C (50 F)	Cutback 5 days EAC 24 hrs	Yes
UFC (*4*)	CB & Slow Set Emulsions	0.45 - 1.13 (0.10 - 0.25 gal/yd^2)	N/M	48 hours	Yes
CFLHD (*53*)	CB & Emulsions	MC: 0.45 - 2.25 (0.10 - 0.50 gal/yd^2) EAC: 0.45 - 1.35 (0.10 - 0.30 gal/yd^2)	Ambient and Surface > 10 C (50 F)	MC: 3 days EAC: 24 hrs	Yes

N/M = Not mentioned in specifications. CB = Cutback asphalt. EAC = Emulsified asphalt cement.

Application rates ranged from a low of 0.45 L/m^2 (0.10 gal/yd^2) to a maximum of 2.25 L/m^2 (0.50 gal/yd^2). All agencies indicated that the exact application rate would require approval by the engineer.

TACK COAT

Phone Survey

The results from the phone survey for tack coat practices are shown in Table 6. The responses are general in nature and would represent the normal agency procedure or procedures regarding tack coat usage. For the purpose of this study, an agency response of "rarely" was interpreted as meaning the procedure/material was not performed. The purpose of the survey was to determine when tack was used, what material was typically used, and if there were written guidelines for field personnel regarding deletion of tack coat. The CFLHD responses to the phone survey are included for comparison purposes only and are not included in the summary analysis.

Use of Tack Coat

All 13 DOTs reported using tack coat on a routine basis. All DOTs reported applying tack to existing HMA surfaces and between lifts of new HMA. Four DOTs indicated that they apply tack coat to an aggregate base or primed aggregate base. Six of the 10 DOTs that reported placing cold recycled asphalt pavements indicated they would use a tack coat on the recycled mix. Only one DOT reported not tacking a concrete surface prior to overlay with HMA prior to placing the HMA surface. All agencies reported that vertical surfaces, such as longitudinal joints, construction joints, curbs, gutters, etc. should be tacked.

Tack coat was rarely deleted by field personnel although nine of 13 DOTs reported that field personnel have deleted tack coat and only four agencies reported that tack was not deleted. Sixty-nine percent of the DOTs (9 of 13) reported that tack coats are not deleted or rarely deleted (< 5%) by field personnel. Three additional DOTs, or 92 percent of the DOTs (12 of 13), reported that tack is deleted less than ten percent of the time. One DOT reported that tack was deleted 25 percent of the time.

Justification

No DOT had written guidelines for deletion of tack coat. Seven of the respondents stated that tack is occasionally deleted if the existing surface is a new or recently placed HMA and the surface is clean, not tracked up and the surface is tacky. Three DOTs indicated the same conditions for deletion of tack as stated above and added that both lifts needed to be placed in the same day. One DOT added that the project must be small. Two DOTs, Texas and California, reported increased emphasis on using tack coat.

Table 6. Results of tack coat practice phone survey.

Survey Questions	Arizona	California	Colorado	Kansas	Nebraska	Nevada	New Mexico
1. Is tack coat typically specified over:							
a. new HMA surface?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
b. Old or existing HMA surface?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
c. aggregate base?	No	No	Yes	No	N/A	No	Yes
d. cold recycled asphalt base?	No	No	Yes	Yes	No	Yes	Yes
e. concrete surface?	Yes	Yes	Yes	Yes	Yes	No	Yes
2. Is tack ever deleted by field personnel?	Yes	No	No	Yes	No	Yes	Yes
3. If deleted by field personnel, approximately what percentage of the time is tack deleted?	Rarely	Rarely	Rarely	Rarely	<1%	25%	Rarely
4. Under what circumstances is tack deleted?	Note 1		Note 2	Note 1		Note 3	Note 3
5. Are there formal guidelines for deletion of tack?	No	Yes	No	No		No	No
6. Any pavement failures attributed to tack coat?	No	No	Yes	Yes	No	No	Yes
7. What was typical defect?	N/A	Debonding	Debonding / slippage	Debonding	N/A	N/A	Slippage
8. Material typically specified.	SS-1	AR-4000	CSS-1, 1h SS-1, 1h	SS-1h CSS-1h	SS-1h CSS-1h	SS-1h	CSS-1, 1h SS-1, 1h
9. Other material occasionally used?	PG-binder	CSS-1, SS-1	None	RC-70	None	SS-1, CSS-1, 1h	PG binder
10. Other comments		Note 3		Note 4			

Note 1. Deleted if existing surface is clean, tacky and will be covered in same day.
Note 2. Deleted if project is small and existing surface is clean and tacky.
Note 3. Deleted if existing surface is clean, tacky and will be covered within a short period of time.
Note 4. Full scale load testing showed debonding if tack inadequate. New guidelines published in March 2003.
Note 5. Failures attributed to too little tack coat.
Note 6. Do not allow dilution of tack. Ongoing research has shown dilution adversely affects bond strength.

Table 6 (Con't.). Results of tack coat practice phone survey.

Survey Questions	North Dakota	Oklahoma	South Dakota	Texas	Utah	Wyoming	CFLHD
1. Is tack coat typically specified over:							
d. new HMA surface?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
c. Old or existing HMA surface?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
a. aggregate base?	Yes	No	Yes	No	No	No	No
b. cold recycled asphalt base?	N/A	N/A	Yes	Yes	No	N/A	Yes
e. concrete surface?	Yes	Yes	Yes	Yes	Yes	N/A	Yes
2. Is tack ever deleted by field personnel?	Yes	Yes	No	Yes	Yes	Yes	Yes
3. If deleted by field personnel, approximately what percentage of the time is tack deleted?	10%	<5%	<1%	<10%	<10%	<5%	Rarely
4. Under what circumstances is tack deleted?	Note 3	Note 3	Note 3	Note 3	Note 3	Note 1	Notes 1 & 3
5. Are there formal guidelines for deletion of tack?	No	No	No	Yes	No	No	No
6. Any pavement failures attributed to tack coat?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
7. What was typical defect?	Slippage	Slippage	Debonding	Debonding	Debonding	Slippage	Slippage
8. Typical material specified.	SS-1h CSS-1h	SS-1	SS-1h CSS-1h	SS-1h CSS-1h	SS-1h	SS-1, 1h	CSS-1, 1h SS-1, 1h
9. Other material occasionally used?	MS-1	None	None	PG binder	None	None	None
10. Other comments				Note 6	Note 5		

Note 1. Deleted if existing surface is clean, tacky and will be covered in same day.
Note 2. Deleted if project is small and existing surface is clean and tacky.
Note 3. Deleted if existing surface is clean, tacky and will be covered within a short period of time.
Note 4. Full scale load testing showed debonding if tack inadequate. New guidelines published in March 2003.
Note 5. Failures attributed to too little tack coat.
Note 6. Do not allow dilution of tack. Ongoing research has shown dilution adversely affects bond strength.

Materials

Kansas DOT was the only agency that reported occasionally using cutback asphalts as tack coat. Kansas reported that cutback was occasionally used in cool weather and over concrete pavements to improve bond. Twelve of the 13 DOTs reported using slow set emulsified asphalts as the primary material for tack coat, either an SS-1 or SS-1h or a CSS-1 or CSS-1h. California reported that a paving grade asphalt, AR-4000, was the most common tack coat material followed by either SS-1 or CSS-1 emulsified asphalt. New Mexico and Texas reported that PG binders were occasionally used as tack.

Pavement Failures

None of the DOTs could recall a specific pavement failure associated with tack coat; however, none of the 13 DOTs could recall a pavement failure, either slippage or debonding, that was possibly caused by tack coat. Insufficient tack was mentioned as a cause of debonding, but in no instance was too much tack listed as the cause of slippage. California and Texas recently released new guidelines for tack coat application. California's tack coat application rates were increased [71] to prevent debonding that was reported in pavements tested at an accelerated loading facility [72] and Texas revised their application rates to address debonding as well [22]. The Texas DOT reported no longer allowing dilution of emulsions for tack coat to improve bond strength.

Agency Specifications

The standard construction specifications for the 13 state DOTs in the CFLHD region, the US Forest Service [70] and the UFC [4] specifications were reviewed to determine placement requirements, weather limitations, materials and application rates for tack coat. There were several instances found where the specifications allowed materials, such as cutbacks, where the phone survey indicated they were not used by the agency. A summary of agency specifications for tack coat is shown in Table 7. The CFLHD specifications are included for comparison purposes only and are not included in the summary analysis.

Materials

Most agencies allow a wide range of materials for use as tack coat in their specifications. All agency specifications allowed emulsified asphalts and a few agencies indicated that asphalt cements could be used. The Kansas DOT was the only agency that specified cutbacks. Ten agencies reported diluting asphalt emulsions with water to achieve more uniform coverage. Five agencies required a 1 to 1 dilution with water, one agency used 40% water, two agencies indicated the dilution rate would be stated in the plans or determined by the engineer, and two agencies did not specify a dilution rate.

Table 7. Summary of agency tack coat specifications.

Agency	Application Rates (L/m^2)	Temperature Limitations	Require Dry Surface	Tack Vertical Surfaces	Require Dilution	Limits on Application
Arizona (*57*)	Target rate of 0.3 - 0.5 (0.06 - 0.12 gal/yd^2)	NF	Yes	NF	NS	Same Day Coverage
California (*58*)	See table 8	A & B mix >10 C (50 F) Base mix > 5 C (40 F)	Yes	Yes	NS	Same Day Coverage
Colorado (*59*)	Shown in Plans and Specifications	Surface or Ambient > 5 C (40 F)	Yes	Yes	NS	NF
Kansas (*60*)	Shown in Plans and Specifications	Air > 4C (40 F) Surface > 7 C (45	Yes	Yes	50%	NF
Nebraska (*61*)	0.2 - 0.45 (0.05 - 0.10 gal/yd^2)	Surface > 3 C (37 F)	Yes	NF	50%	NF
Nevada (*62*)	Shown in Plans and Specifications	Ambient & Aggregate > 4 C (40 F)	Yes	Yes	40% Water	Same Shift Coverage
New Mexico (*63*)	Provided by Project Manager	Ambient > 7 C (40 F)	Yes	Yes	NS	NF
North Dakota (*64*)	Shown in Plans and Specifications	Surface or Ambient > 5 C (40 F)	Yes	NF	50%	NF
Oklahoma (*65*)	< 0.45 (0.10 gal/yd^2)	NF	Yes	Yes	Yes	Same Day Coverage
South Dakota (*66*)	Shown in Plans and Specifications	Surface or Ambient > 2 C (35 F)	Yes	Yes	As Per Engineer	Same Day Coverage
Texas (*67*)	0.2 - 0.45 (0.04 - 0.10 gal/yd^2)	Surface > 15 C (60 F)	Yes	Yes	Not Allowed	NF
Utah (*68*)	Shown in Plans and Specifications	Surface > 10 C (50 F)	Yes	Yes	In Plans	Same Day Coverage
Wyoming (*69*)	Shown in Plans and Specifications	Surface & Air > 5 C (40 F)	NF	Yes	50%	Same Day Coverage
USFS (*70*)	0.15 - 0.70 (0.03 - 0.15 gal/yd^2)	Surface > 5 C (40 F)	Yes	NF	50%	Cover Within 4 hrs
UFC (*4*)	0.23 - 0.68 (0.05 - 0.15 gal/yd^2)	NF	Yes	NF	Yes	Same Day Coverage
CFLHD (*53*)	0.15 - 0.70 (0.03 - 0.15 gal/yd^2)	Surface > 2 C (35 F)	Yes	NF	Yes	Cover Within 4 hrs

NF = Not found in specifications. NS = Not specified.

Weather Limitations and Curing

Weather limitations for tack coat application were generally the same as for HMA paving and were often found under paving specifications rather than tack coat specifications. Twelve agencies required a minimum ambient and/or surface temperature before placing tack. Minimum temperatures for tack application ranged from a low of 2°C (35°F) to a high of 15°C (60°F).

All agencies required the surface to be clean and dry during tack application. Six agencies specifically required the tack be cured (allowed to break) before paving. No mention of breaking or curing prior to overlay was found in the remaining agency specifications. Seven agencies required tack to be covered the same day it was placed, one agency required coverage in the same shift and one agency required coverage within 4 hours. All agencies indicated that no more tack should be placed than could be covered in the same day and tack that was not covered would require re-tacking prior to paving. The Texas DOT has a test to evaluate tackiness of the tack coat (73). The current test method, TEX 243-F, is subjective; however, an objective test method is under development (73).

Ten agency specifications made reference to applying tack coat to all vertical surfaces, including longitudinal and transverse joints, curbs and gutters, and other structures. It appeared from the review of the specifications that if tack were deleted, longitudinal and transverse joints would not be tacked either.

Application Rates

Seven of the 15 agency specifications reviewed contained either a maximum recommended application rate or an application rate range for tack coat. Seven agency specifications indicated that the application range would be found in the plans and one agency reported that the engineer would provide the application rate. Application rates vary depending on the material used, the condition of the existing surface and how application rates are reported. Application rates can be reported as residual asphalt content, undiluted liquid asphalt content or as a diluted quantity for diluted asphalt emulsions. Application rates ranged from a low of 0.15 L/m^2 (0.03 gal/yd^2) to a maximum of 0.70 L/m^2 (0.15 gal/yd^2). All agencies indicated that the exact application rate would require approval by the engineer. Recommended application rates recently released by the California DOT (71), based on results from full scale load tests (72), are shown in Table 8. Recommended tack coat application rates from the Texas DOT (22), based on OCAPE recommendations (21), were shown in Table 2.

CFLHD SPECIFICATIONS

The CFLHD *Standard Specifications* (53)*, Construction Manual* (54)*,* and *Field Materials Manual* (55) were reviewed to obtain information on prime and tack coat requirements for comparison to local agency practice. The information from CFLHD *Standard Specifications* (53), *Construction Manual* (54) and *Field Materials Manual* (55) are shown in Tables 5 and 7 to aid in comparison of CFLHD's practice to local agency practices.

Table 8. Recommended tack coat application rates [71].

Asphalt Concrete overlay (except Open Graded) Liters per square meter			
Type of Surface to be Tack Coated	Slow-Setting Asphaltic Emulsion	Rapid-Setting Asphaltic Emulsion	Paving Asphalt
Dense, Tight Surface (e.g., between lifts)	0.20 – 0.35 [A]	0.10 – 0.20 [B]	0.05 – 0.10
Open Textured or Dry, Aged Surface (e.g., milled surface)	0.35 – 0.90 [A]	0.20 – 0.40 [B]	0.10 – 0.25
Open-Graded Asphalt Concrete overlay Liters per square meter			
Type of Surface to be Tack Coated	Slow-Setting Asphaltic Emulsion	Rapid-Setting Asphaltic Emulsion	Paving Asphalt
Dense, Tight Surface (e.g., between lifts)	0.25 – 0.50 [A]	0.10 – 0.25 [B]	0.05 – 0.15
Open Textured or Dry, Aged Surface (e.g., milled surface)	0.50 – 1.10 [A]	0.25 – 0.55 [B]	0.15 – 0.30

[A] Asphaltic emulsion diluted with additional water. The water shall be added and mixed with the asphaltic emulsion (which contains up to 43 percent water) so that the resulting mixture will contain one part asphaltic emulsion and not more than one part added water. The water shall be added by the emulsion producer or at a facility that has the capability to mix or agitate the combined blend.
[B] Undiluted Asphaltic Emulsion.

Prime Coat

As shown in Table 5, the CFLHD specifications and practices for prime coat compare well with agency specifications within the CFLHD jurisdiction. The CFLHD specifications were one of several specifications that required scarification of the base to improve penetration when priming with emulsified asphalts. CFLHD did not have a materials specification for AE-P and PEP. With air pollution requirements limiting the usage of cutback asphalts in some locations, a materials specification for AE-P and PEP would be a beneficial addition.

Tack Coat

As shown in Table 7, the CFLHD specifications and practices for tack coat compare well with agency specifications within the CFLHD jurisdiction. The CFLHD specifications are more restrictive in materials allowed and curing conditions than most agencies reviewed. CFLHD could consider including paving grade asphalt cements for use as tack coat. A specific reference to tacking vertical surfaces of longitudinal and transverse joints, and the surface of angled longitudinal joints could remove some confusion among CFLHD field personnel and contractors, and result in standard practice for tacking joints. Finally, inclusion of application rates similar to those recommended by OCAPE [21] and published by Texas DOT [22], as shown in Table 2, or those published by the California DOT [71], as shown in Table 8, could provide additional guidance in selecting initial tack coat application rates.

CHAPTER 6 – CONCLUSIONS

Based on the literature reviewed and information supplied through the phone survey, interviews with knowledgeable experts, bituminous materials suppliers, industry organizations, state DOTs, and other agencies, the following conclusions for prime and tack coat usage are warranted.

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 must adequately penetrate the base to function properly.
4. Medium cure cutbacks are normally used for prime. Medium cure cutback asphalts penetrate deeper than conventional emulsified asphalts. Dilution of emulsified asphalts with water helps penetration but emulsified asphalts generally require mixing into the base to function properly.
5. Prime coats need to be allowed to cure completely before covering with HMA. Cutbacks generally take longer to cure than asphalt emulsions.
6. Excess prime not absorbed into the base after 24 hours should be absorbed with blotter sand and removed from the surface.
7. Prime is often deleted in cold weather because it is riskier to pave over uncured prime than over unprimed base.
8. 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 is greater than 100 mm (4 in) thick.
9. Prime coat increased the bond strength at the interface between a compacted base and asphalt layer over that of no prime coat. The reported differences were not always statistically significant.
10. At higher static normal stresses, shear strength at the interface is not appreciably affected by the type or even the presence of a prime coat. This supports the practice of deleting prime at a minimum HMA thickness, typically 100 mm (4 in).
11. Use of prime coat is not a substitute for maintaining the specified condition of the base or subgrade.
12. Prime should not be applied to stabilized bases or subgrade.
13. The main environmental concern with prime coat applications is air pollution associated with the release of VOCs into the air.
14. The EPA treats spills of cutbacks and emulsified asphalts the same; therefore, priming with emulsified asphalts or specially formulated penetrating asphalt emulsions does not result in reduced oil spill reporting regulations or requirements.
15. Deleting prime would lessen the amount of liquid asphalt contractors must handle, lessening the associated liability with handling these products.
16. Prime may be omitted if there is a strong possibility of runoff entering a waterway.

TACK COAT

1. The purpose of tack coat is to ensure bond between the existing pavement surface and a new pavement surface.
2. A loss of bond between HMA layers can cause crescent-shaped slippage cracks or debonding to occur, leading to reduced pavement life.
3. Prior to tack application the surface should be clean, dry and free from loose material.
4. Applying tack is not a substitute for properly cleaning the existing HMA surface.
5. 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.
6. If possible, all traffic should be kept of tacked surfaces.
7. Tack should be applied to old existing HMA surfaces and PCC surfaces.
8. Tack has been successfully deleted between new lifts of HMA when the existing surface is still clean and tacky.
9. There is not complete agreement regarding the requirement that tack coat be allowed to break and set before placing the HMA layer.
10. Many factors were shown to affect laboratory interface shear strength, including rate of shear, magnitude of normal force, temperature and joint construction.
11. In a few studies, tacked surfaces were shown to have slightly lower interface shear strengths than untacked surfaces. However, in these studies the statistical significance of the difference in interface shear strength was not reported. In reports where the statistical significance of the differences in interface shear strength was evaluated, tacked interfaces were either stronger or not significantly different from untacked interfaces.
12. The higher the viscosity of the bituminous binder in the tack, the higher the reported interface shear strength.
13. At typically specified application rates, application rate had little effect on interface shear strength. Higher than recommended application rates resulted in slightly lower interface shear strengths.
14. Diluted slow set emulsions are typically used for tack coat.

CHAPTER 7 – RECOMMENDATIONS

CFLHD SPECIFICATIONS

Based on the literature review and information supplied through the phone survey, interviews with knowledgeable experts, bituminous materials suppliers, industry organizations, state DOTs, and other agencies, the following changes to CFLHD's *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects, FP-03,* are proposed.

1. Specifications for AE-P and PEP should be added to *Section 702. – ASPHALT MATERIAL* under subsection *702.03 Emulsified Asphalt*.
2. In *Section 412. – ASPHALT TACK COAT*, asphalt binder, meeting the requirements of subsection *702.01 Asphalt Cement*, could be added to subsection *412.02*. This would allow contractors the option of tacking with the paving grade asphalt cement.
3. A reference to the requirements for tacking longitudinal and transverse joints, placed in the *Construction Manual* or *Field Materials Manual*, would remove questions regarding the necessity of tacking joints. This could be most helpful with longitudinal joints.
4. A table placed in the either the *Construction Manual* or *Field Materials Manual* with recommended application rates for different surface conditions, similar to those shown in Tables 2 and 8, could assist CFLHD field personnel with initial tack coat application rates.

GUIDELINES FOR PRIME COAT USAGE

Before any action is taken regarding the use of prime coat, it is strongly recommended that Project Engineers consult with the Construction Operations Engineer (COE).

The following decision tree is proposed for use over aggregate bases as described in *Section 301. - UNTREATED AGGREGATE COURSES, Section 308. – MINOR CRUSHED AGGREGATE* and subsection *303.06 Aggregate Surface Reconditioning*. The decision tree is meant to provide CFLHD project development and field personnel decision-making guidance on how to use, when to keep, and when to eliminate prime coat.

The decision tree, in flow chart form, is shown in Figure 30. Bituminous stabilized bases, as described in sections *309. – EMULSIFIED ASPHALT-TREATED BASE COURSE, 408. – COLD RECYCLED ASPHALT BASE COURSE* and *416. – CONTINUOUS COLD RECYCLED ASPHALT BASE COURSE*; and treated or stabilized aggregate courses, as described in sections *302. – TREATED AGGREGATE COURSES* and *304. – AGGREGATE STABILIZATION*, should not be primed.

1. Untreated aggregate base course will be exposed to wet weather for more than 7 days prior to paving.
   Yes: Go to question #10.
   No: Go to question #2.

2. Untreated aggregate base course will carry local and/or construction traffic more than 7 days prior to paving.
   Yes: Go to question #3.
   No: Go to question #8.

3. Construction traffic/haul trucks cause instability resulting in major surface deformation and reduced load-carrying capacity.
   Yes: Prime coat will not help; consider stabilization (sec 302, 304 or 309).
   No: Go to question #4.

4. Local traffic causes instability resulting in major surface deformation and reduced load-carrying capacity.
   Yes: Prime coat will not help; consider stabilization (sec 302, 304 or 309).
   No: Go to question #5.

5. Construction traffic/haul trucks cause minor surface raveling.
   Yes: Prime coat would be beneficial – (surface scarification in accordance with sec 411.06 might be necessary). Go to question #10.
   No: Go to question #6.

6. Local traffic causes minor surface raveling.
   Yes: Prime coat would be beneficial – (surface scarification in accordance with sec 411.06 might be necessary). Go to question #10.
   No: Go to question #7.

7. Dust control is necessary.
   Yes: Prime coat would help (go to question #10) or consider a dust palliative (sec 306).
   No: Go to question #8.

8. Pavement has steep grades and/or switchbacks.
   Yes: Prime coat would be beneficial. Go to question #10.
   No: Go to question #9.

9. Total HMA thickness is greater than 100 mm (4 in).
   Yes: Go to question #13.
   No: Prime coat would be beneficial. Go to question #10.

10. Adequate time and weather conditions prior to paving for prime coat to completely cure (minimum 72 hours cutback asphalts and 24 hours emulsified asphalts)?
  Yes: Go to question #11.
  No: Reschedule priming operations or delete prime coat and pave within 7 days. Do not pave over uncured prime coat.

11. Strong possibility of rainstorm washing uncured prime coat material into environmentally sensitive area (stream, wetland, waterway, etc.)?
  Yes: Schedule priming operations to limit exposure to significant rainfall or delete prime coat and pave within 7 days.
  No: Go to question #12.

12. Air pollution concerns with VOCs in solvents or other environmental concerns with liquid asphalt products?
  Yes: a. Consider asphalt emulsions (AE) such as SS-1 diluted 50 percent with water applied in accordance with sec 411.06. Scarification (sec 411.06) will be necessary to obtain adequate penetration.
  b. Consider using asphalt emulsion prime (AE-P) or penetrating emulsion prime (PEP); however, these products can contain VOCs and could still cause air pollution concerns.
  c. Delete prime coat and pave within 7 days.
  No: Prime using cutback asphalt (sec 702.02) or emulsified asphalt (sec 702.03) applied in accordance with section 411.

13. Application of prime coat is optional. Is there is any doubt about performance if prime coat is deleted?
  Yes: Go to question #10.
  No: Go to question #14.

14. Prime coat can be deleted without compromising quality and/or performance of project if paved within 7 days and before significant wet weather. Apply dust palliative (sec 306) if necessary.

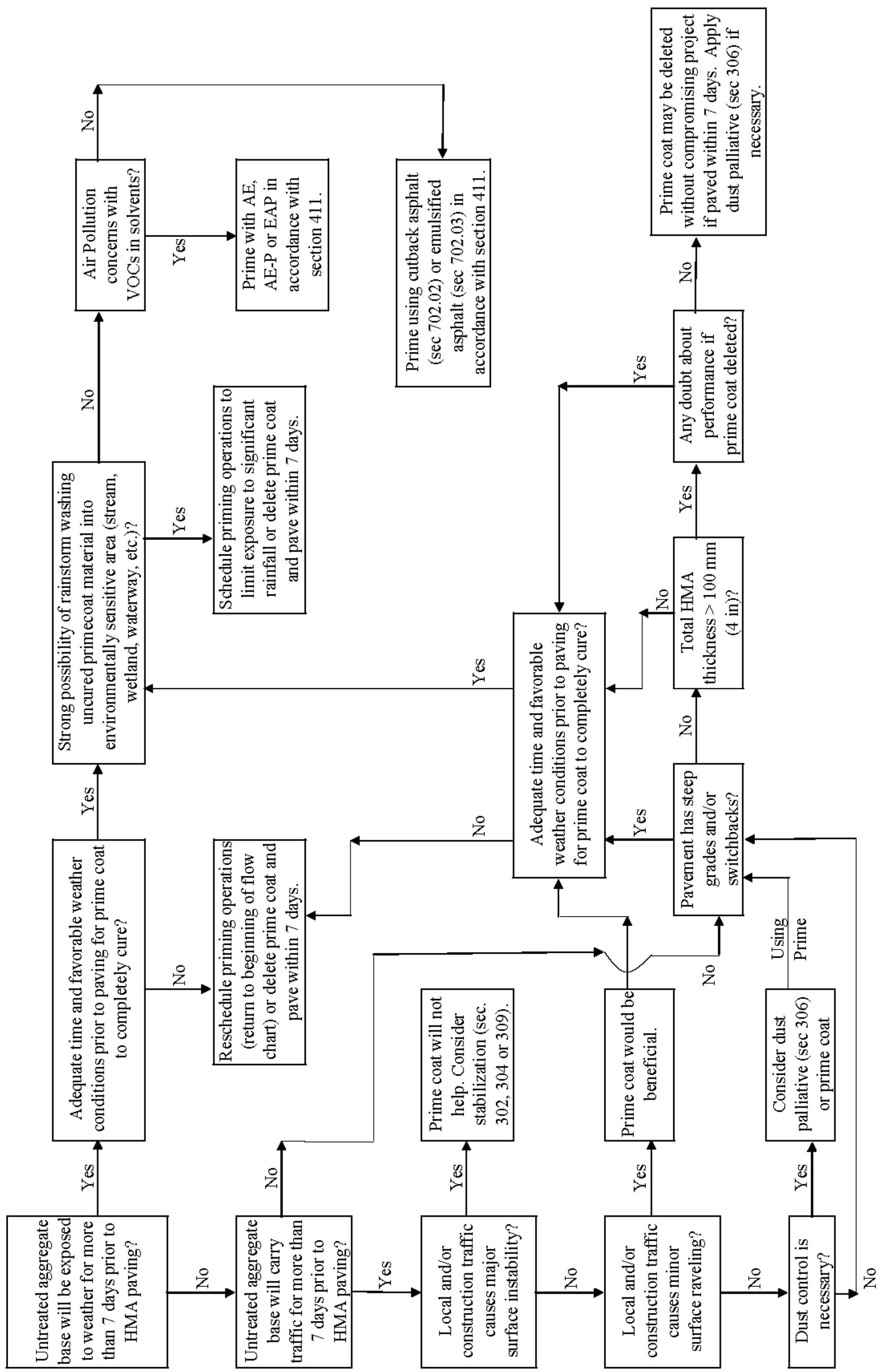

Figure 30. Flowchart. Guideline for prime coat usage flow chart.

GUIDELINES FOR TACK COAT USAGE

Before any action is taken regarding the use of tack coat, it is strongly recommended that Project Engineers consult with the Construction Operations Engineer (COE).

The following decision tree is proposed for use with tack coat as described in *Section 412. - ASPHALT TACK COAT*. The decision tree is meant to provide CFLHD project development and field personnel decision-making guidance on how to use, when to keep, and when to eliminate tack coat. The decision tree, in flow chart form, is shown in Figure 31.

Note: If tack coat is placed, all vertical surfaces, including curb and gutters, inlets, longitudinal joints and transverse (construction) joints should be tacked prior to placing the HMA lift.

1. Is this the first HMA layer?
   Yes: Go to question #2.
   No: Go to question #12.

2. Is the underlying layer an existing HMA or PCC pavement?
   Yes: Go to question #3.
   No: Go to question #5.

3. Has the existing pavement been milled?
   Yes: Go to question #4.
   No: Go to question #16.

4. Apply tack coat using higher range of application rate due to rough surface. Alternately, if the HMA layer is placed shortly after milling, the fine millings can be left on the surface by not sweeping the milled pavement. The fine millings will be heated by the placement of the HMA course and can act as a tack coat. This process should be considered as experimental and is not recommended for routine use. See question #17.

5. Is the existing surface a bituminous stabilized surface (sec 309, 408 or 416)?
   Yes: Go to question #6.
   No: Go to question #7.

6. Is the existing bituminous surface clean, tacky and intact?
   Yes: Go to question #15.
   No: Go to question #16.

7. Is the base course a treated/stabilized base (sec 302 or 304)?
   Yes: Go to question #8.
   No: Go to question #10.

8. Did the treated/stabilized base receive a bituminous curing seal (sec 302.08 or 304.09)?
   Yes: Go to question #9.
   No: Go to question #14.

9. Is the existing bituminous curing seal (sec 302.08 or 304.09) clean, tacky and bonded to the existing base?
   - Yes: Go to question #15.
   - No: Sweep surface to remove seal and go to question #14.

10. The base course is an aggregate base (sec 301, 308 or 303.06). Has the aggregate base course received a prime coat (sec 411) or bituminous dust palliative (sec 306)?
   - Yes: Go to question #11.
   - No: Go to question #15.

11. Is the prime coat or bituminous dust palliative still clean, tacky, intact and bonded to the existing base?
   - Yes: Go to question #15.
   - No: Go to question #14.

12. Is the surface of the newly placed HMA layer still clean, warm (> 60^{o}C or 140^{o}F) and tacky?
   - Yes: A hot bond should be stronger than a tacked bond. A tack coat should not be used.
   - No: Go to question #13.

13. Is the surface of the newly placed HMA layer still clean and tacky?
   - Yes: Go to question #15.
   - No: Go to question #16.

14. Does pavement have steep grades and/or switchbacks or a total HMA thickness of less than 100 mm (4 in)?
   - Yes: Go to question #16.
   - No: Go to question #15.

15. Application of tack coat is optional. Is there is any doubt about performance if tack is deleted?
   - Yes: Go to question #16.
   - No: Delete tack coat.

16. Apply tack coat. Use higher range of application rate for rough or absorptive surface and the lower range for non absorptive and or flush surfaces. See question #17.

17. Strong possibility of rainstorm washing uncured tack coat material into environmentally sensitive area (stream, wetland, waterway, etc.)?
   - Yes: Monitor weather conditions (precipitation) and coordinate paving operations to minimize unnecessary exposure of uncured tack to significant rainfall.
   - No: Apply tack coat in accordance with sec. 412.

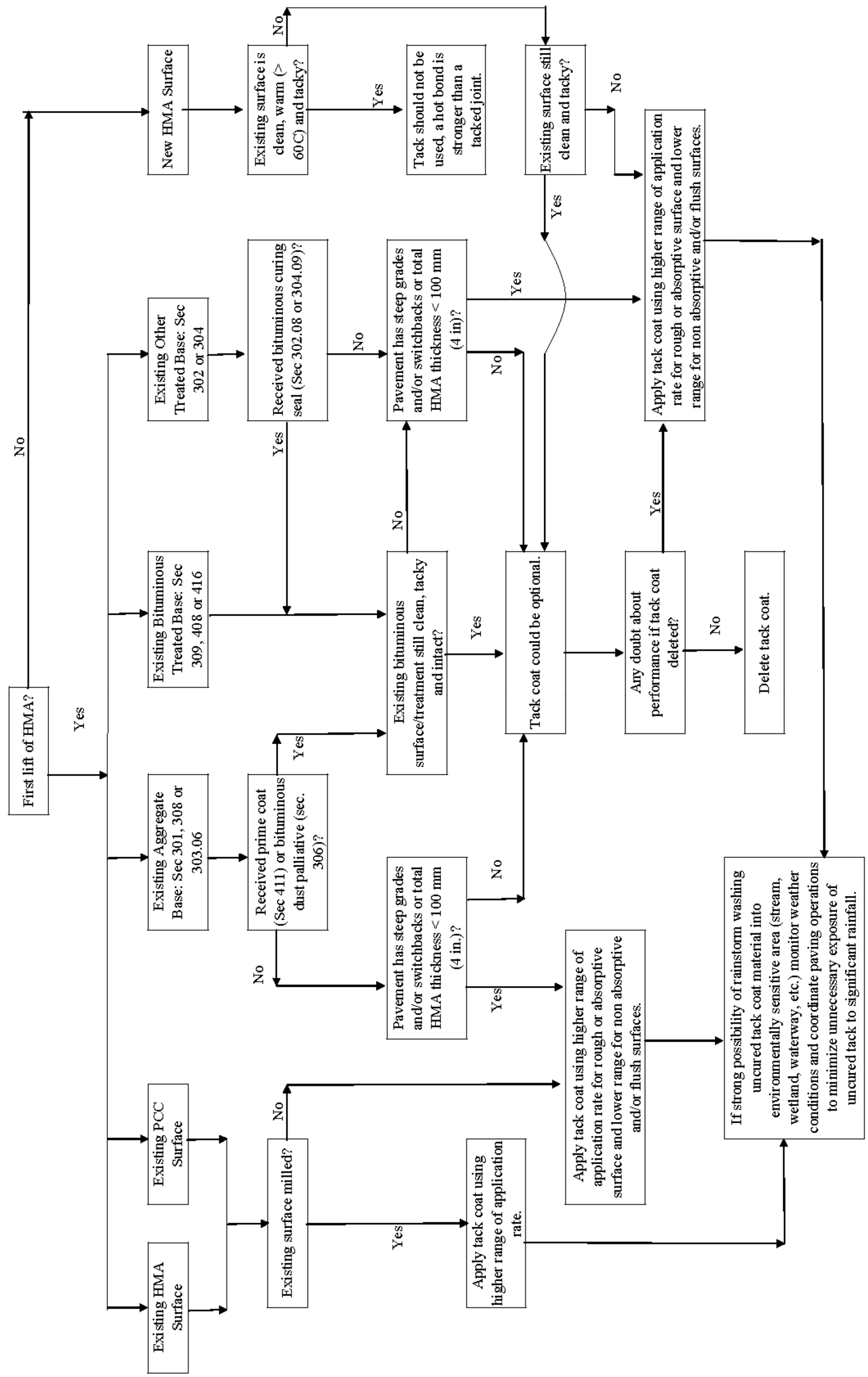

Figure 31. Flowchart. Guideline for tack coat usage flow chart.

APPENDIX A – ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
AEMA	Asphalt Emulsion Manufacturers Association
AE-P	asphalt emulsion prime
AR	application rate
ASTM	American Society for Testing and Materials
BARM	Basic Asphalt Recycling Manual
CFLHD	Central Federal Lands Highway Division
CIR	cold in-place recycling
CRS	cationic rapid set
CSS	cationic slow set
DOT	Departments of Transportation
EAC	emulsified asphalt cement
EAP&T	emulsified asphalt prime & tack
EPA	Environmental Protection Agency
EPR	emulsified petroleum resin
FDR	full depth reclamation
FHWA	Federal Highway Administration
HMA	hot mix asphalt
HMIRS	Hazardous Materials Information Resource System
ICONDA	International Construction Database
LVOC	low volatile organic compound
MC	medium cure
MS	medium set
MSDS	material safety data sheets
NCAT	National Center for Asphalt Technology
NCHRP	National Cooperative Highway Research Program
NFPA	National Fire Protection Association
NTIS	Nation Technical Information Services
OCAPE	Ohio Center for Asphalt Pavement Education
PCC	Portland cement concrete
PEP	penetrating emulsion prime
PG	performance grade
RAC	residual asphalt content
RAR	residual application rate
RC	rapid cure
RCRA	Resource Conservation and Recovery Act
RQ	reportable quantity
SPCC	Spill Prevention, Control and Countermeasure
SS	slow set
SST	Superpave shear test
SWP3	Storm Water Pollution Prevention Plans
TRB	Transportation Research Board
TRIS	Transportation Research Information Services

UFC	Unified Facilities Criteria
USACE	U.S. Army Corps of Engineers
VOC	volatile organic compounds

APPENDIX B – PRIME AND TACK COAT INSPECTION BULLETS

PRIME COAT

- Prior to priming, assure placement of the aggregate base course is in accordance with the plans and specifications. A prime coat is not a substitution for maintaining the specified condition of the aggregate base course prior to paving.
  - Assure grade tolerances are met.
  - Assure proper crown exists.
  - Assure no raveling or segregated areas exist.
  - Assure specified moisture and density requirements are maintained.
- Complete a 300 m (1000 ft) test strip to determine proper application rate.
  - Follow proper asphalt distributor construction procedures to prevent streaking and allow proper application rate and uniform coverage.
    - The spray bar nozzles should be set at an angle of 15 to 30 degrees to the horizontal axis of the spray bar to prevent the spray of liquid asphalt from interfering with adjacent spray nozzles. Most nozzles are set at 30 degrees as shown in Figure 32.

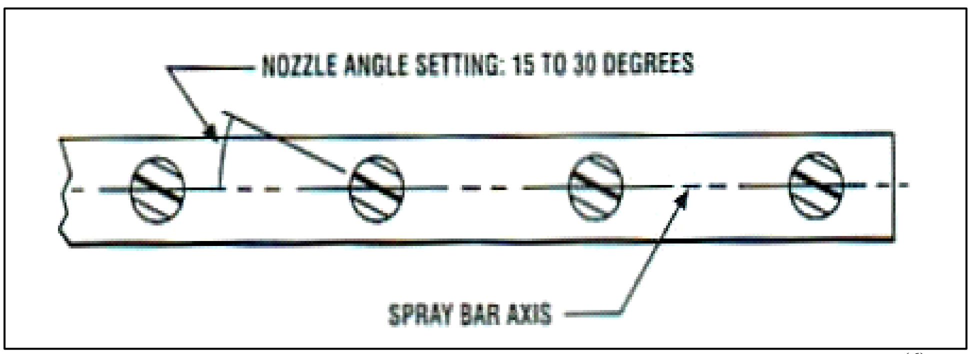

Figure 32. Schematic. Recommended spray bar nozzle settings [6].

    - The height of the spray bar should be set to allow for an exact single, double or triple overlap as shown in Figure 33. Other than an exact single, double or triple overlap will result in streaking and non-uniform application rates as shown in Figure 34. A double overlap is recommended for most prime applications.
    - 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.
  - Select an appropriate initial application rate for the type of aggregate base course present.
    - Application rates are a function of the openness of the aggregate base and can vary slightly with the absorption of the aggregate. Open graded bases will require more prime than dense graded bases.

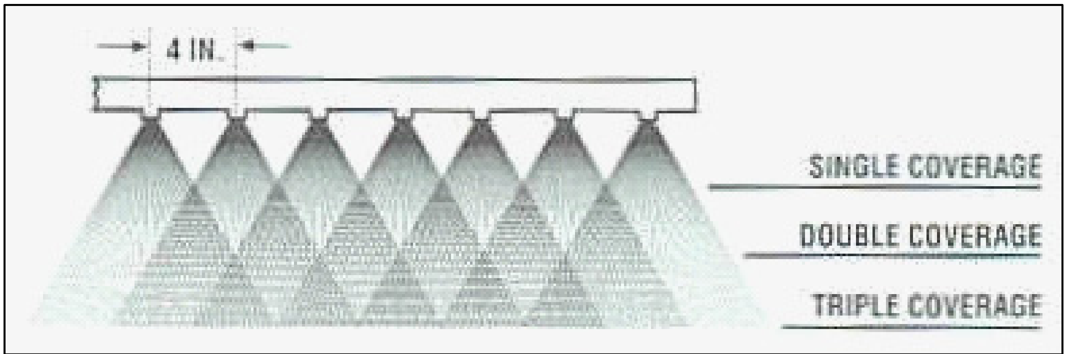

Figure 33. Schematic. Recommended spray bar heights (6).

Figure 34. Photo. Streaking in spray application caused by improper pump pressure and/or spray bar height.

- Good practice is to start at 0.90 L/m^2 (0.20 gal/yd^2) and adjust as necessary.
- Apply asphalt cutback prime and specially formulated penetrating asphalt emulsion prime at an application rate of 0.45 to 2.25 L/m^2 (0.10 to 0.50 gal/yd^2) for optimum penetration.
- Apply non special formulated emulsified asphalt for prime at an application rate of 0.45 to 1.35 L/m^2 (0.10 to 0.30 gal/yd^2) for optimum penetration.

o No more prime should be applied than can be absorbed by the aggregate base in 24 hours.
  - Prime oil that balls up may be an indication of too little prime. Increase the application rate in 0.20 L/m^2 (0.05 gal/yd^2) increments.
  - Fat spots or puddling is an indication of too much prime. Decrease the application rate in 0.20 L/m^2 (0.05 gal/yd^2) increments.

- The major purpose of prime coat is to protect the underlying layers from wet weather by providing a temporary waterproofing layer. Additional benefits of prime coat are stabilizing or binding the surface fines together and promoting bond to the HMA layer.
  - Prime must adequately penetrate the aggregate base course to perform the above functions.
  - Adequate penetration to be effective has been reported as a minimum of 5 to 10 mm (0.25 to 0.5 in). Figure 35 shows typical penetration of an MC prime into a dense graded crushed stone base.

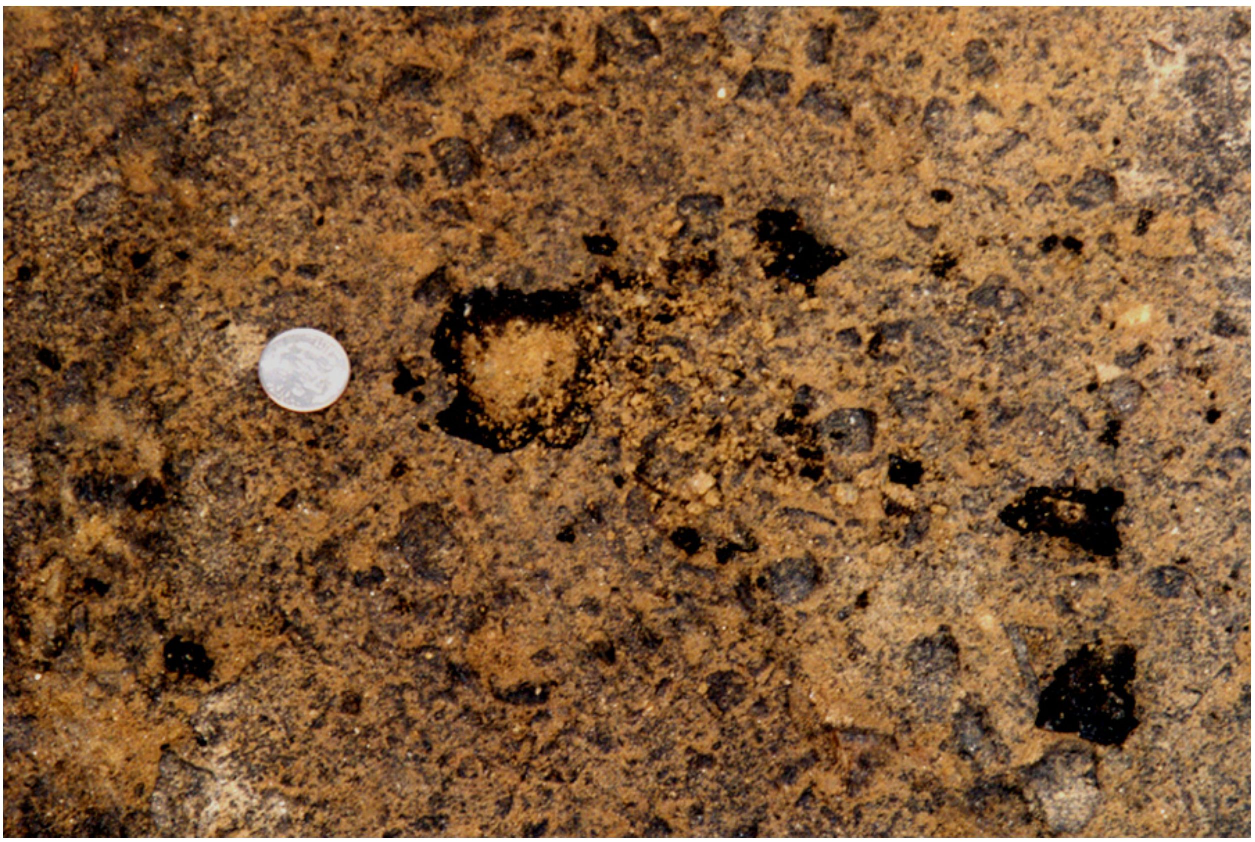

Figure 35. Photo. Typical penetration of MC-70 prime into a dense graded aggregate base.

  - Regular asphalt emulsions are not usually suitable for use as prime coat because they will not penetrate the surface unless diluted with water. Bases with a high percentage of fine grained materials, passing 0.075 mm (#200) sieve, act as a filter and will not let emulsified asphalt particles penetrate. Mechanical mixing or scarification of the surface to a depth of 25 to 50 mm (1 to 2 in) is recommended to produce an acceptable prime when asphalt emulsions are used. Figure 36 shows the lack of penetration of prime onto a base which was caused by too high a viscosity of the prime when applied and the high fines content of the base.

Figure 36. Photo. Poor penetration of prime caused by the high fines content of the base.

- The surface of the aggregate base course should be slightly damp prior to application of prime materials.
  - Water may be added to the surface of the aggregate base course to achieve a slightly damp condition.
  - A damp surface lowers application rates by preventing excess absorption of the prime by the aggregates.
  - A damp surface helps prevent balling of the prime with dust particles on the surface and aids in penetration.
- For uniform application the proper viscosity of the prime coat material must be maintained.
  - This is achieved by heating MC cutbacks.
  - This is achieved by occasionally heating asphalt emulsions or diluting them with water.
  - Figure 37 shows the results of applying prime when the viscosity of the material was too high.
  - Table 9 provides recommended spray temperatures for prime coat application.

Figure 37. Photo. Results of applying prime at too high viscosity.

Table 9. Recommended spray temperature range for prime coat.

Type and Grade of Asphalt	Temperature Range	
	°C	°F
SS-1, SS-1h, CSS-1, CSS-1h[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)

- Any excess prime that is not absorbed into the aggregate base course after 24 hours should be removed with blotter sand to prevent wash off into waterways and tracking and pickup of the material by traffic.
  - Recommended blotter sand application rates are 2.2 to 4.4 kg/m^2 (4 to 8 lbs/yd^2).
  - Blotter sand should be applied using a mechanical devise such as a salt or chip spreader. Dumping blotter sand with a loader and spreading with a shovel should be avoided.
  - Excess blotter sand should be broomed from the surface before HMA placement to ensure a proper bond.

- Prime coat must cure completely to function properly.
  Prime coats generally take several days to properly cure so they can withstand construction traffic.
    - The curing of prime coat depends upon the weather. If the weather is hot the prime coat will cure quickly but if the weather is cool and damp the prime coat will cure slowly.
    - Emulsified products generally cure faster than cutback asphalts.
        - Asphalt emulsions require a minimum of 24 hours to fully cure.
        - Cutbacks require a minimum of 72 hours to fully cure.
    - It is riskier to place an 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. Excessive prime remaining on the surface can be absorbed into overlying asphalt layers and the solvents in the prime used to liquefy the asphalt, typically kerosene or diesel fuel, can damage the asphalt layer quickly, contributing to pavement slippage or rutting and lateral movement of the asphalt concrete during rolling operations.
    - At a minimum, construction traffic should be kept off a fresh prime coat until cured sufficiently to prevent tracking and rutting of the prime.
- Weather and temperature limitations.
    - The curing of prime coat depends upon the weather.
    - Prime coat may be omitted in cold weather because prime materials cure slowly at low temperatures.
    - Prime should not be applied unless the air temperature in the shade and the pavement temperature are 10^{o}C (50^{o}F) and rising and when the weather is not foggy or rainy.
- Existing structures should be protected from application of prime coat materials.
    - Curbs, gutters, manhole inlets, etc. should not be primed. The vertical edges of these structures receive a tack coat.
    - All structures, including existing retaining walls, sidewalks, curbs, gutters, manhole inlets, etc. should be protected from accidental spray of prime coat materials.
    - Structures can be protected from overspray, wind drift and splatter by using a shield, such as plywood, or by covering the structure with plastic sheeting or other suitable material.
- The inspector should keep track of the yield and quantities of prime coat material, blotter sand and dilution water.

TACK COAT

- Prior to tacking, assure the condition of the existing surface is in accordance with the plans and specifications. A tack coat is not a substitution for properly cleaning the existing surface.
- Complete a 300 m (1000 ft) test strip to determine proper application rate.
    - Follow proper asphalt distributor construction procedures to prevent streaking and allow proper application rates and uniform coverage.
        - The spray bar nozzles should be set at an angle of 15 to 30 degrees to the horizontal axis of the spray bar to prevent the spray of liquid asphalt from interfering with adjacent spray nozzles. Most nozzles are set at 30 degrees, as shown in Figure 32.
        - The height of the spray bar should be set to allow for an exact single, double or triple overlap, as shown in Figure 33. Other than an exact single, double or triple overlap will result streaking and non uniform application rates. A double overlap is recommended for most tack applications. Figure 38 shows streaky application caused

by improper spray bar height or pump pressure. Note that the distributor is traveling in the wrong direction, driving over the freshly applied tack.

- 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.
- A streaked tack coat can be rolled with a pneumatic roller prior to the asphalt emulsion breaking to improve uniformity of application.

Figure 38. Photo. Streaking in tack coat caused by improper spray bar height and/or pump pressure.

- o Select an appropriate initial application rate for the type of surface. Table 10 provides recommended tack coat application rates.
  - Application rates typically vary from 0.15 to 0.70 L/m^2 (0.03 to 0.15 gal/yd^2).
  - Good practice is to start at 0.20 L/m^2 (0.05 gal/yd^2) and adjust as necessary.

➢ For uniform application, the proper viscosity of the tack coat material must be maintained.
- o This is achieved by heating asphalt emulsions or diluting them with water.
- o Application of tack at too high a viscosity will result in non uniform application.
- o Table 11 provides recommended application temperatures for tack coat materials.

Table 10. Recommended tack coat application rates [(21)].

Existing Pavement Condition	Application Rate			
	Undiluted[1]		Diluted (1:1)[2]	
	(L/m^2)	(gal/yd^2)	(L/m^2)	(gal/yd^2)
New Asphalt	0.20 to 0.30	0.05 to 0.07	0.40 to 0.60	0.10 to 0.13
Oxidized Asphalt	0.30 to 0.45	0.07 to 0.10	0.60 to 0.90	0.13 to 0.20
Milled Surface (asphalt)	0.45 to 0.60	0.10 to 0.13	0.90 to 1.20	0.20 to 0.27
Milled Surface (PCC)	0.45 to 0.60	0.10 to 0.13	0.90 to 1.20	0.20 to 0.27
Portland Cement Concrete	0.30 to 0.45	0.07 to 0.10	0.60 to 0.90	0.13 to 0.20
Vertical Face[3]				

[1] Asphalt emulsion meeting requirements of AASHTO M 140, Table 1.
[2] Asphalt emulsion meeting requirements of AASHTO M 140, Table 1, diluted with equal parts water and asphalt emulsion.
[3] Longitudinal construction joints should be treated using a rate that will thoroughly coat the vertical face without running off.

Table 11. Recommended application temperatures for tack coat materials.

Type and Grade of Asphalt	Temperature Range	
	°C	°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

[1] Reference [(6)]

- Traffic, both construction and local, should be kept off fresh tack.
  - A freshly applied tack coat surface is too slick for safe driving, particularly before the asphalt emulsion has broken.
  - Traffic should be kept off the tack coat until no hazardous conditions exist.
  - Drivers should be warned of the probability of the asphalt emulsion splattering when traffic is permitted on a tack coat.
  - To limit disruption of traffic and to keep traffic off the fresh tack, minimize the length ahead of the asphalt laydown operation that the tack is applied.
- Weather and temperature limitations.
  - The curing rate of tack depends upon the weather.
  - Apply asphalt tack coat on a dry, unfrozen surface when the air temperature in the shade is above 2°C (35°F) and rising.
- The vertical surfaces of transverse joints, longitudinal joints, curbs, gutters, manhole inlets, etc. should receive a tack coat.
  - Tack should be applied uniformly and completely by fogging with a hand spray attachment or by another approved method.
  - If excess asphalt material is applied, squeegee the excess from the surface.
- Existing structures should be protected from application of tack coat materials.
  - All structures, including existing retaining walls, sidewalks, curbs, gutters, manhole inlets, etc. should be protected from accidental spray of tack coat materials.
  - Structures can be protected from overspray, wind drift and splatter by using a shield, such as plywood, or by covering the structure with plastic sheeting or other suitable material
- The inspector should keep track of the yield and quantities of tack coat material.

APPLICATION RATES

- The following formulas can be used to determine the volume of prime or undiluted tack coat, at the delivered temperature, required to cover a test section at the specified application rate, when the specified application rate is for undiluted material.
  - In SI units:

    Volume of material at delivered temperature = (AR * A) / M

    Where:

    AR = application rate at 15.6^{o}C in L/m^2 of material (cutback or asphalt emulsion)

    A = area of test section (length * spray bar length) in m^2

    M = multiplier for correcting volumes to the basis of 15.6^{o}C as shown in Tables 12 for cutbacks and 13 for asphalt emulsions.

    - Example:

      Desired application rate (AR) = 0.90 L/m^2 of MC-70
      Test section length = 300 m
      Spray bar length = 4.0 m
      Temperature of prime as delivered = 60^{o}C
      Multiplier (M) = 0.9686 from Table 12
      Area (A) = 300 m * 4.0 m = 1,200 m^2

      Volume of prime required = (AR * A) / M
      = (0.90 L/m^2 * 1,200 m^2) / 0.9686 = 1,115 L

  - In English units:

    Volume of material at delivered temperature = (AR * A) / (9 ft^2/yd^2 * M)

    Where:

    AR = application rate at 60^{o}F in gal/yd^2 of material (cutback or asphalt emulsion)

    A = area of test section (length * spray bar length) in ft^2

    M = multiplier for correcting volumes to the basis of 60^{o}F as shown in Tables 12 for cutbacks and 13 for asphalt emulsions.

    - Example:

      Desired application rate (AR) = 0.20 gal/yd^2 MC-70
      Test section length = 1000 ft
      Spray bar length = 13 ft
      Temperature of prime as delivered = 140^{o}F
      Multiplier (M) = 0.9686 from Table 12
      Area (A) = 1000 ft * 13 ft = 13,000 ft^2

      Volume of prime required = (AR * A) / (9 ft^2/yd^2 * M)
      = (0.20 gal/yd^2 * 13,000 ft^2) / (9 ft^2/yd^2 * 0.9686) = 298 gal

- The following formulas can be used to determine the volume of diluted prime or tack coat, at the delivered temperature, required to cover a test section at the specified application rate, when the specified application rate is for undiluted material.
  - In SI units:
    Volume of material at delivered temperature = [(AR / (D/100)) * A] / M
    Where:
    AR = application rate at 15.6°C in L/m² of diluted asphalt emulsion
    D = percent dilution
    A = area of test section (length * spray bar length) in m²
    M = multiplier for correcting volumes to the basis of 15.6°C as shown in Table 13 for asphalt emulsions.
  - Example:
    Desired application rate (AR) = 0.20 L/m² of 1:1 diluted CSS-1
    Test section length = 300 m
    Spray bar length = 3.66 m
    Temperature of tack as delivered = 50°C
    Multiplier (M) = 0.98450 from Table 13
    Area (A) = 300 m * 3.66 m = 1,098 m²
    D = 50 percent dilution

    Volume of tack required = [(AR / (D/100)) * A] / M
    = [(0.20 L/m² / (50/100))* 1,098 m²] / 0.98450 = <u>446 L</u>

  - In English units:
    Volume of material at delivered temperature = [(AR / (D/100)) * A] / (9 ft²/yd² * M)
    Where:
    AR = application rate at 60°F in gal/yd² of undiluted asphalt emulsion.
    D = percent dilution.
    A = area of test section (length * spray bar length) in ft²
    M = multiplier for correcting volumes to the basis of 60°F as shown in Table 13 for asphalt emulsions.
  - Example:
    Desired application rate (AR) = 0.05 gal/yd² of 1:1 diluted CSS-1
    Test section length = 1000 ft
    Spray bar length = 12 ft
    Temperature of tack as delivered = 122°F
    Multiplier (M) = 0.98450 from Table 13
    Area (A) = 1000 ft * 12 ft = 12,000 ft²

    Volume of tack required = [(AR / (D/100)) * A] / (9 ft²/yd² * M)
    = [(0.05 gal/yd² / (50/100)) * 12,000 ft²) / (9 ft²/yd² * 0.98450) = <u>135 gal</u>

ENVIRONMENTAL ISSUES

- The primary pollutants of concern from asphalt paving operations are volatile organic compounds (VOC). Cutback asphalts are the major source of VOCs as only minor amounts of VOCs are emitted from emulsified asphalts and asphalt cements.
  - The use of cutback asphalt is regulated in many jurisdictions to help reduce VOC emissions. Prohibitions on the use of cutback, either permanently or during certain times of the year, are common in jurisdictions that have either reached, or are nearing non-attainment for ozone requirements of the Clean Air Act.
  - Asphalt emulsions are typically used in place of cutback asphalts to eliminate VOC emissions.
  - Local, state and federal regulations should be consulted for specific requirements and regulations regarding use of cutback asphalts.
- Liquid asphalt products, including prime and tack coats, must be kept out of waterways.
  - Water quality issues are complex because of the overlapping jurisdiction of several federal agencies, the complexity of many of the regulations, and the variability of regulations and jurisdictions on the state and local levels.
  - Local, state and federal regulations should be consulted for specific reporting and remediation requirements and for regulations regarding water quality issues with use of cutback and asphalt emulsions.
  - A direct spill into a waterway is not the only way prime or tack coat materials can enter a waterway. Entry is available through a spill that enters storm water and waste water sewers, drainage ditches, etc., to name but a few sources. Additionally, rain water could wash a freshly applied uncured prime coat into a waterway as shown in Figure 39.
  - Prime should not be placed if there is a high probability of rain within 24 hours of application or before the prime can be fully absorbed into the base and any excess removed with blotter sand.
  - Prime coat should be omitted if there is a strong possibility of runoff entering a waterway.
  - The requirements of the contractors Storm Water Pollution Prevention Plans (SWP3), required by the storm water permit process for construction sites, should be in place and in working order prior to application of prime or tack.
  - A spill or accidental release should be contained immediately by diking or impounding. Do not allow spills to enter sewers or watercourse. Remove all sources of ignition. Absorb with appropriate inert materials such as sand, clay, etc. Notify appropriate authorities of spill. The spill may be a regulated waste. If regulated solvents are used to clean up the spilled material, the resulting waste mixture may be a regulated waste. Assure conformity with local, state and federal governmental regulations for disposal.

Figure 39. Photo. Prime runoff caused by rain shower on freshly applied prime.

Table 12. Temperature - volume corrections for cutback asphlats [74].

°C	°F	M	°C	°F	M	°C	°F	M
21.1	70	0.9960	46.1	115	0.9783	71.1	160	0.9609
21.7	71	0.9956	46.7	116	0.9779	71.7	161	0.9605
22.2	72	0.9952	47.2	117	0.9775	72.2	162	0.9601
22.8	73	0.9948	47.8	118	0.9771	72.8	163	0.9597
23.3	74	0.9944	48.3	119	0.9767	73.3	164	0.9593
23.9	75	0.9940	48.9	120	0.9763	73.9	165	0.9589
24.4	76	0.9936	49.4	121	0.9760	74.4	166	0.9585
25.0	77	0.9932	50.0	122	0.9756	75.0	167	0.9582
25.6	78	0.9929	50.6	123	0.9752	75.6	168	0.9578
26.1	79	0.9925	51.1	124	0.9748	76.1	169	0.9574
26.7	80	0.9921	51.7	125	0.9744	76.7	170	0.9570
27.2	81	0.9917	52.2	126	0.9740	77.2	171	0.9566
27.8	82	0.9913	52.8	127	0.9736	77.8	172	0.9562
28.3	83	0.9909	53.3	128	0.9732	78.3	173	0.9559
28.9	84	0.9905	53.9	129	0.9728	78.9	174	0.9555
29.4	85	0.9901	54.4	130	0.9725	79.4	175	0.9551
30.0	86	0.9897	55.0	131	0.9721	80.0	176	0.9547
30.6	87	0.9893	55.6	132	0.9717	80.6	177	0.9543
31.1	88	0.9889	56.1	133	0.9713	81.1	178	0.9539
31.7	89	0.9885	56.7	134	0.9709	81.7	179	0.9536
32.2	90	0.9881	57.2	135	0.9705	82.2	180	0.9532
32.8	91	0.9877	57.8	136	0.9701	82.8	181	0.9528
33.3	92	0.9873	58.3	137	0.9697	83.3	182	0.9524
33.9	93	0.9869	58.9	138	0.9693	83.9	183	0.9520
34.4	94	0.9865	59.4	139	0.9690	84.4	184	0.9517
35.0	95	0.9861	60.0	140	0.9686	85.0	185	0.9513
35.6	96	0.9857	60.6	141	0.9682	85.6	186	0.9509
36.1	97	0.9854	61.1	142	0.9678	86.1	187	0.9505
36.7	98	0.9850	61.7	143	0.9674	86.7	188	0.9501
37.2	99	0.9846	62.2	144	0.9670	87.2	189	0.9498
37.8	100	0.9842	62.8	145	0.9666	87.8	190	0.9494
38.3	101	0.9838	63.3	146	0.9662	88.3	191	0.9490
38.9	102	0.9834	63.9	147	0.9659	88.9	192	0.9486
39.4	103	0.9830	64.4	148	0.9655	89.4	193	0.9482
40.0	104	0.9826	65.0	149	0.9651	90.0	194	0.9478
40.6	105	0.9822	65.6	150	0.9647	90.6	195	0.9475
41.1	106	0.9818	66.1	151	0.9643	91.1	196	0.9471
41.7	107	0.9814	66.7	152	0.9639	91.7	197	0.9467
42.2	108	0.9810	67.2	153	0.9635	92.2	198	0.9463
42.8	109	0.9806	67.8	154	0.9632	92.8	199	0.9460
43.3	110	0.9803	68.3	155	0.9628	93.3	200	0.9456
43.9	111	0.9799	68.9	156	0.9624	93.9	201	0.9452
44.4	112	0.9795	69.4	157	0.9620	94.4	202	0.9448
45.0	113	0.9791	70.0	158	0.9616	95.0	203	0.9444
45.6	114	0.9787	70.6	159	0.9612	95.6	204	0.9441
						96.1	205	0.9437

M = multiplier for converting oil volumes to the basis of 15.6 °C (60 °F)

Table 13. Temperature - volume corrections for asphalt emulsions [(6)].

°C	°F	M	°C	°F	M	°C	°F	M
10.0	50	1.0025	35.0	95	0.9912	60.0	140	0.9800
10.6	51	1.0022	35.6	96	0.9910	60.6	141	0.9797
11.1	52	1.0020	36.1	97	0.9907	61.1	142	0.9795
11.7	53	1.0017	36.7	98	0.9905	61.7	143	0.9792
12.2	54	1.0015	37.2	99	0.9902	62.2	144	0.9790
12.8	55	1.0012	37.8	100	0.9900	62.8	145	0.9787
13.3	56	1.0010	38.3	101	0.9897	63.3	146	0.9785
13.9	57	1.0007	38.9	102	0.9895	63.9	147	0.9782
14.4	58	1.0005	39.4	103	0.9892	64.4	148	0.9780
15.0	59	1.0002	40.0	104	0.9890	65.0	149	0.9777
15.6	60	1.0000	40.6	105	0.9887	65.6	150	0.9775
16.1	61	0.9997	41.1	106	0.9885	66.1	151	0.9772
16.7	62	0.9995	41.7	107	0.9882	66.7	152	0.9770
17.2	63	0.9992	42.2	108	0.9880	67.2	153	0.9767
17.8	64	0.9990	42.8	109	0.9877	67.8	154	0.9765
18.3	65	0.9987	43.3	110	0.9875	68.3	155	0.9762
18.9	66	0.9985	43.9	111	0.9872	68.9	156	0.9760
19.4	67	0.9982	44.4	112	0.9870	69.4	157	0.9757
20.0	68	0.9980	45.0	113	0.9867	70.0	158	0.9755
20.6	69	0.9977	45.6	114	0.9865	70.6	159	0.9752
21.1	70	0.9975	46.1	115	0.9862	71.1	160	0.9750
21.7	71	0.9972	46.7	116	0.9860	71.7	161	0.9747
22.2	72	0.9970	47.2	117	0.9857	72.2	162	0.9745
22.8	73	0.9967	47.8	118	0.9855	72.8	163	0.9742
23.3	74	0.9965	48.3	119	0.9852	73.3	164	0.9740
23.9	75	0.9962	48.9	120	0.9850	73.9	165	0.9737
24.4	76	0.9960	49.4	121	0.9847	74.4	166	0.9735
25.0	77	0.9957	50.0	122	0.9845	75.0	167	0.9732
25.6	78	0.9955	50.6	123	0.9842	75.6	168	0.9730
26.1	79	0.9952	51.1	124	0.9840	76.1	169	0.9727
26.7	80	0.9950	51.7	125	0.9837	76.7	170	0.9725
27.2	81	0.9947	52.2	126	0.9835	77.2	171	0.9722
27.8	82	0.9945	52.8	127	0.9832	77.8	172	0.9720
28.3	83	0.9942	53.3	128	0.9830	78.3	173	0.9717
28.9	84	0.9940	53.9	129	0.9827	78.9	174	0.9715
29.4	85	0.9937	54.4	130	0.9825	79.4	175	0.9712
30.0	86	0.9935	55.0	131	0.9822	80.0	176	0.9710
30.6	87	0.9932	55.6	132	0.9820	80.6	177	0.9707
31.1	88	0.9930	56.1	133	0.9817	81.1	178	0.9705
31.7	89	0.9927	56.7	134	0.9815	81.7	179	0.9702
32.2	90	0.9925	57.2	135	0.9812	82.2	180	0.9700
32.8	91	0.9922	57.8	136	0.9810	82.8	181	0.9697
33.3	92	0.9920	58.3	137	0.9807	83.3	182	0.9695
33.9	93	0.9917	58.9	138	0.9805	83.9	183	0.9692
34.4	94	0.9915	59.4	139	0.9802	84.4	184	0.9690
						85.0	185	0.9687

M = multiplier for converting oil volumes to the °C (60°F)

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