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16. Abstract

Prime coats have long been used to seal the surface pores in the base, thus reducing the migration of moisture and absorption of the first application of surface treatment binder, strengthen the granular base near its surface by binding the finer particles of aggregate, help protect the base from inclement weather and limited vehicular traffic before the next pavement layer is constructed, and promote adhesion between a granular base and a subsequently applied bituminous surface by precoating the surface of the base and by penetrating the voids near the surface.

The main objective of this research project was to evaluate the effectiveness of prime coats and determine which combinations of methods and materials provide the most benefit to TxDOT. Testing methods and equipment were developed to measure the penetration of the prime coat into the base course and to determine the increase in adhesion and cohesion at the surface of the base course provided by the prime coat.

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# EFFECTIVE PRIME COATS
# FOR
# COMPACTED PAVEMENT BASES

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The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the objectives of this report.

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# CHAPTER 1.
# INTRODUCTION

The main objective of this research project was to evaluate the effectiveness of prime coats and determine which combinations of methods and materials provide the most benefit to TxDOT. The use of prime coats are described, and their construction requirements are discussed in Item 310 of the Texas Department of Transportation (TxDOT) Standard Specifications.

For this research project, a prime coat is defined as the application of a binder material onto the surface, or mixed into the uppermost portion of a compacted granular base, as a preliminary treatment before the subsequent application of a bituminous surface treatment. The bituminous surface treatment may be the final pavement surface, or it may be a bituminous underseal placed before construction of a hot mix asphalt (HMA) concrete pavement surface. It is because of the availability of new non-asphalt prime materials that primes are not defined as bituminous materials.

Prime coats typically:

- help seal the surface pores in the base, thus reducing the migration of moisture (into and out of the base) and absorption of the first application of surface treatment binder;
- strengthen the granular base near its surface by binding the finer particles of aggregate;
- help protect the base from inclement weather and limited vehicular traffic before the next pavement layer is constructed; and
- promote adhesion between a granular base and a subsequently applied bituminous surface by precoating the surface of the base and by penetrating the voids near the surface.

The following chapters and appendices explain the results of the study.

- Chapter 2. Review of Worldwide Literature on Prime Coats
- Chapter 3. Findings from a Survey of TxDOT Districts
- Chapter 4. Development of Field Experiment Designs
- Chapter 5. Conclusions and Recommendations
- References
- Appendix A–Questionnaire Used in Conducting Phone Survey
- Appendix B–Priming Using Conventional Emulsified Asphalt
- Appendix C–Guidelines for Selection, Application, and Evaluation of Prime Coats
- Appendix D–Presentation Materials for Guidelines for Selection, Application, and Evaluation of Prime Coats
- Appendix E–Results of Field Testing

# CHAPTER 2.
# REVIEW OF WORLDWIDE LITERATURE ON PRIME COATS

## INTRODUCTION

A comprehensive literature review determined that there is not a large volume of published information on prime coats for pavements. The authors found very little information on the selection of appropriate prime coat materials, test methods for evaluating prime coats in the laboratory and the field, optimum application techniques, appropriate curing methods for various products under different conditions, and relative performance of prime coat materials. Only one source specifically addressed prime coats applied prior to application of a surface treatment, which was the main thrust of this study.

For this project, a prime coat is defined as the application of a binder material onto the surface or binder material mixed into the uppermost portion of a compacted granular base as a preliminary treatment before the subsequent application of a bituminous surface treatment (or underseal). A prime coat is designed to perform several interrelated functions (NITRR, 1986; Mantilla and Button, 1994; and Senadheera and Vignarajah, 2007) including:

- act as an intermediary between the surface treatment binder and the base;
- promote adhesion between a granular base and subsequently applied bituminous surface by precoating the surface of the base and by penetrating the voids near the surface;
- help seal the surface pores in the base, thus reducing the migration of moisture and preventing absorption of the subsequent application of surface treatment binder;
- waterproof the base;
- help strengthen the base near its surface by permeating the surface and cohesively binding the finer particles of aggregate; and
- provide the base with temporary protection against the detrimental effects of weather and light traffic until the surface can be constructed.

A prime coat is *not* designed to bind loose dust left on the surface of a compacted and cured base. Prior to priming, TxDOT Specification Item 310 requires sweeping so that all dust would be removed from the surface of the base.

Engineers have often speculated whether prime coats are a cost-effective element of pavement construction, because some pavements constructed without a prime coat have provided satisfactory performance (Cross et al., 2005). However, there have also been failures due to the omission of the prime coat. Undoubtedly, the application of a prime coat reduces the risk of premature failure resulting from imperfections that may occur in the base, which are very costly to repair (NITRR, 1986).

## RECENT GUIDES FOR PRIME COATS

A few informative guidelines for prime coats have been published recently. The most comprehensive guideline was prepared for the FHWA Central Federal Lands Highway Division (Cross and Shrestha, 2005), while the guidelines most specific for the Texas Department of Transportation were prepared by the Center for Multidisciplinary Research in Transportation (TechMRT) at Texas Tech (Senadheera and Vignarajah, 2007).

### Summary of Guidelines from Cross and Shrestha (2005)

The objective of Cross and Shrestha (2005) was to produce a prime coat and tack coat guide publication for project development and field personnel to provide decision-making guidance on how to use, when to require, and when to eliminate prime and tack coats. The guidelines address:

- the need for a prime coat,
- materials and application rates,
- curing,
- penetration/waterproofing, and
- interface shear strength or structural benefits.

This complete guideline is available on the Internet at:
http://ttap.colostate.edu/Library/FHWA/FHWA-TD-05-002.pdf

Cross and Shrestha (2005) offer the following conclusions:

- 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 base to function properly.
- 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.
- Prime coats must be allowed to cure completely before covering with HMA. Cutbacks generally take longer to cure than asphalt emulsions.
- Excess prime that is not absorbed into the base after 24 hours should be absorbed with blotter sand and removed from the surface.
- Prime is often deleted in cold weather because it is riskier to pave over uncured prime than over unprimed base (NCHRP, 1978).
- 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 4 inches thick.

- 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.
- 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 4 inches (100 mm).
- Use of prime coat is not a substitute for maintaining the specified condition of the base or subgrade.
- Prime should not be applied to stabilized bases or subgrade.
- The main environmental concern with prime coat applications is air pollution associated with the release of volatile organic compounds (VOC) into the air.
- The Environmental Protection Agency (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.
- Deleting prime would lessen the amount of liquid asphalt contractors must handle, lessening the associated liability with handling these products.
- Prime may be omitted if there is a strong possibility of runoff entering a waterway.

Additionally, Cross et al. (2005) produced "Guidelines for Prime Coat Usage on Low-Volume Roads," which is essentially a summary of the prime coat-related findings from Cross and Shrestha (2005).

**Summary of Guidelines from Senadheera and Vignarajah (2007)**

The constructibility review of surface treatments on base courses (Senadheera and Vignarajah, 2007 and Vignarajah and Senadheera, 2007) developed a surface treatment design and construction guide, updates to the TxDOT surface treatment training manual, and updated specifications. They declared that priming the base is one of the most critical elements in surface treatment construction. They identified certain "optimum" conditions that a base should have before a sprayed-on prime coat is applied; these are:

- A Reasonably Smooth Surface – However, it should not be overly smooth as is often achieved using slush rolling, because this can produce a low-porosity surface and inhibit penetration of prime, thus yielding a weakened primed interface with a poor bond to the next pavement layer.
- Reasonable Porosity (permeability) –This is best achieved by simply blading and rolling the base at or slightly above optimum moisture content. The required pore size is governed by the prime coat material and the wettability of the compacted base.
- No Loose Dust on the Surface – Brooming must be done carefully to avoid disturbing larger aggregate particles at the surface of the compacted base. If the base structure is

too fragile for aggressive brooming (as with some sandstones that lack fine binder material), compressed air can be used to cleanse the surface.

- Adequate Structural Strength – The base should be adequately, but only partially, cured such that strength is sufficient to support construction traffic and occasional highway traffic. A treated/stabilized base should be completely cured before application of cutback asphalt that may inhibit the stabilizer curing process. It should be allowed to dry to 2 percentage points below optimum to enhance penetration of the prime material.

### Priming Guidelines Developed by Other Studies

In 2006, the Southern Africa Bitumen Association (SABITA) produced a concise guideline designed to assist road authorities with the selection of proven alternative prime coat products and processes (SABITA, 2006). This guide is titled, "Interim Guidelines for Primes and Stone Precoating Fluids" and is available at http://www.sabita.co.za/documents/MAN26.pdf.

In 2003, the Arizona DOT published a workbook entitled, "Prime, Flush, and Tack Coat Inspection" (Roy Jorgensen Associates, 2003). This is an educational document containing instructions and examinations. It discusses basic procedures for prime coat application, distributor operations, inspection, and documentation. This is of particular value for construction inspectors.

Much earlier, Mantilla and Button (1994) developed for TxDOT two alternative detailed guidelines for incorporating mixing-grade emulsified asphalt into the uppermost layer (about 2 inches) of the base. One process involves mixing diluted emulsion into the base during the normal base construction process. The other process involves complete compaction of the base followed by scarification of the upper 1 or 2 inches, mixing in the emulsion, and then recompaction. An instructional video supplements the written guidelines and aids in the implementation of these processes. For convenience, these mix-in methods are provided in Appendix B. They reported that, based on comments from TxDOT engineers, when this priming process is considered in the total bid price for highway construction, the cost difference when compared to spray-on cutback prime is insignificant.

A set of guidelines for selection, application, and evaluation of prime coats was developed as part of this study and is included in Appendix C, along with a proposed revision to Specification Item 310.

## TYPES OF PRIME COAT MATERIALS

The most utilized and successful prime materials have traditionally been cutback asphalts, but some newer emulsified asphalt specialty primes have been successfully used. Mixing grade emulsified asphalts can be used for priming; however, they must be mechanically mixed into the base as they do not adequately penetrate into a most compacted base. If the primed surface must carry significant traffic or carry traffic for an extended period, then a thin surface treatment, sometimes called an inverted prime or covered prime, typically using cutback asphalt to promote penetration into the base may be in order.

According to TxDOT (2004), typical prime coat materials include cutback asphalt (e.g., MC-30) as well as emulsified cutback asphalts (e.g., asphalt emulsion prime [AEP], emulsified asphalt prime and tack [EAP&T], and prime, cure, emulsion control [PCE]; respectively). Other materials (e.g., RC-250 and slow setting emulsions) can be and have been successfully used in Texas (These will be discussed later.). Other agencies (e.g., CalTrans, Illinois DOT, South Africa, Australia) list additional prime materials, such as MC-70 (cutback), penetrating emulsion prime (PEP), and invert emulsion prime (IEP).

Specialty non-asphalt prime coat products that are being or have been marketed include coal tar emulsion primes, polymer-modified coal tar emulsion (e.g., Tar-Prime and PolyTar), emulsified wood pitch (e.g., TP-1), emulsified naphthenic oils (e.g., LVOC-1 [low volatile organic compounds]), and EcoPrime (an aqueous suspension of dry powder that melts upon application of a hot asphalt mat).

For unstabilized bases, probably, the most historically utilized prime material, worldwide, has been MC-30 (Ishai and Livneh, 1984). MC-30 offers reasonably good penetration into most bases; however, complete curing may require a few days, depending on the weather, application rate, permeability of the base, and other factors.

For cement-stabilized bases and subbases, deep penetration of prime is not necessary to bind the fine aggregates in the uppermost stratum nor is it desirable. A smaller quantity of prime is typically used on stabilized bases since the prime material will not normally penetrate the stabilized layer anyway; in fact, prime is often eliminated on stabilized bases (Cross and Shrestha, 2005). Although the authors could find nothing in the literature on this subject, it appears that significant penetration of cutback (containing kerosene or diesel) into an uncured cement-stabilized base might interrupt the cement hydration process and, thus, yield a weakened interlayer at the surface and create a potential slippage plane.

When a cement-stabilized base is used, the prime coat, typically PCE in Texas, acts more as a curing membrane. If a prime coat is not placed, the layer should be moistened frequently during the first few days after construction to ensure that the cement continues to hydrate. Further, caution should particularly be exercised regarding application of excess water during finish rolling. Excess water applied to the surface of a cement-stabilized base material, in effect, increases the water/cement ratio near the surface causing a weak interface in the cured layer.

According to PCA (1995), when a prime is used on soil cement, common primers might include RC-250, MC-250, RT-5, or SS-1. Application rates vary from 0.15 to 0.30 gallons per square yard. In most cases, a light application of water should immediately precede the bituminous prime coat.

## TYPES OF PRIME COAT APPLICATIONS

Senadheera and Vignarajah (2007) described four types of prime coat. These include:

1. Spray Prime with or without Blotting Material – This is typically MC-30 or AEP cutback sprayed onto a compacted base using an asphalt distributor at an application rate of about 0.20 gallons per square yard depending on conditions. If the project is constructed under traffic, a blotting material such as sand or small crushed stone is often applied to eliminate splash onto vehicles and then removed.

2. Worked-in (or cut-in) Prime – Diluted emulsified asphalt (e.g., SS-1, CSS-1h, or MS-2) is sprayed on the finished base, which is then covered with a thin coating of base material fines, working the windrow from side to side using a motor grader. This process is usually repeated two to three times to obtain an asphalt-sand layer that is approximately 1/8 inch thick with a residual emulsion application rate of about 0.2 gallons per square yard.
3. Inverted Prime or Covered Prime – This is similar to a one-course surface treatment where 0.17 to 0.20 gal/yd$^2$ of RC-250 is applied onto the finished base and then covered by spreading Grade 5 stone. This technique is particularly useful when the primed surface must accommodate significant traffic or must carry traffic for a prolonged period (e.g., through the winter months).
4. Mixed-In Prime – This has been achieved using the two methods described below (Mantilla and Button, 1994).
    a. During preparation of the last lift of the base (2 to 6 inches), mix in diluted emulsified asphalt instead of mixing water. After compaction to the required density, skeet the surface with diluted emulsion to enrich the surface with asphalt and, thus, provide a reasonably good bond with the next pavement layer.
    b. After the base density is achieved and the base is completed up to the blue-tops, scarify the top 1-3 inches and mix with diluted emulsified asphalt, and then recompact to the specified density. Skeet the surface with diluted emulsion to enrich the surface with asphalt and, thus, provide a reasonably good bond with the next pavement layer.

    Method a. is preferred because Method b. is more labor intensive and will break down the larger stones during the scarification recompaction processes. Method b. is usually utilized to treat a relatively thin layer.

There is some ambiguity in the way terms such as “Cut-in,” “Worked-in,” and “Mixed-in” are used to describe the prime coat. “Cut-in” or “Worked-in” prime essentially means the same thing in which the prime coat binder, diluted emulsified asphalt, is sprayed on the finished base and the base material windrow is worked back and forth to create a thin sand-asphalt layer that acts as the prime coat. A mixed-in prime is one where the top 2-3 inches of base is remixed with diluted emulsion and then recompacted. Cutting in or mixing in is, of course, used to achieve penetration of the prime, which cannot otherwise be achieved with regular mixing grade emulsified asphalts.

Gray (1982) found that the use of emulsified asphalt instead of cutback asphalt for a covered (inverted) prime saved significant money and yet exhibited good performance. Moreover, emulsified asphalt is more environmentally friendly than cutback asphalt. Appendix B presents a description of this method. This priming methodology is very similar to what is called an emulsion primerseal in Australia.

According to Lysenko (2008), the newer emulsion primerseals are attracting increased attention in Australia as a viable alternative to cutback primerseals as practitioners become more familiar with their benefits. These newer emulsion primerseals contain low levels of volatile hydrocarbons in the binders (Lysenko, 2002). Therefore, they achieve only modest levels of penetration. A primerseal is intended to be a short-term initial treatment prior to a final surfacing. In practice on lower volume roads, these surfacings can be left for up to 18 months before application of the final surfacing. The purpose of the delay between primerseal application and the final treatment is primarily to enable most of the cutter to escape and, thus, minimize the risk of flushing or bleeding of the final surface. An additional reason is to allow for the repair of weak areas in the pavement before the final surfacing is applied. Primerseals are usually placed in Australia as either a 0.25 or 0.50 treatment, depending on traffic density. Lysenko (2008) concluded that the successful application of emulsion primerseals at several locations should encourage a review of some long held conventions on the importance of primer binder penetration into tightly compacted pavements.

## PRIME COAT DESIGN

Historically, a prime coat has usually consisted of a spray-applied cutback bituminous material (e.g., MC-30) using a distributor truck for application. More recently, to enhance safety and reduce VOC production, emulsified asphalt specialty products (e.g., AEP, EAP, and PCE) have been successfully used. However, ordinary emulsified asphalt (e.g., SS-1, SS-1h, and MS-2) has also been mechanically mixed into the surface of base layers primarily because this is the most effective technique for minimizing VOCs. Again, these ordinary emulsified asphalts, merely sprayed onto the surface, will not adequately penetrate most compacted bases.

Basically, this subsection provides items that should be included in the thought process when a pavement designer or contractor is considering the application of a prime coat.

Prime coat design is a very simplistic but important process that should embrace several factors, including:

- location of the construction project (e.g., non-attainment area);
- material to be primed;
- base construction process (e.g., slush roll or blade and roll);
- thickness and composition of next pavement layer to be applied;
- experience, expertise, and equipment of available contractors;
- probability of inclement weather while the prime coat is exposed; and
- projected need to carry significant traffic or carry traffic for a prolonged period.

Senadheera and Vignarajah (2007) deduced that, in its simplest form, design of a prime coat consists of three fundamental elements:

1. Selection of an appropriate priming method,
2. Selection of a prime coat binder type, and

3. Selection of primer application rate.

Senadheera and Vignarajah (2007) further maintained that selection of the optimum prime coat type to use prior to application of a surface treatment depends on several items, such as:

- past experience,
- availability of a contractor pool with the required prime coat expertise,
- traffic control plan during construction, and
- base material.

Cutback asphalt primes should not be used on bituminous stabilized materials including full-depth reclamation projects or cold in-place recycled projects (ARRA, 2001). Solvents in typical prime materials (e.g., MC-30 and AEP) can soften the asphalt stabilized base, thereby weakening the pavement structure. These types of bases should be tacked using emulsified asphalt.

## SURFACE PREPARATION OF BASE

When a surface treatment placed on a flexible base is the final riding surface of the pavement, creating a smooth surface on the base is critical to the ultimate ride quality. Contractors across the state use various techniques to achieve a smooth final surface on the base. Unfortunately, some of the techniques used to create this smooth surface can result in a weak interface and can be detrimental to the performance of the surface treatment. A practice called “slush rolling” is often used to create a smooth surface. This practice incorporates excess water (i.e., above optimum moisture content for compaction) during rolling to pump excessive fines to the surface of the base which allows the blade operator to attain a very smooth surface. The thin layer of fines at the surface, however, can suppress penetration of the prime coat and create a weak interface, which can ultimately result in a delamination of the surface treatment.

Construction practices utilized to blade the flexible base to grade will depend on the characteristics of the granular base. A typical crushed limestone base has a tightly bonded, dense surface; whereas, a natural gravel or poorly graded crushed stone base may have a comparatively large void structure at the surface. A less tightly bound sandstone and some gravel bases are more susceptible to damage between construction sequences. No doubt then, different construction techniques are needed to achieve the finished surface of these various materials.

Before priming, the surface of the base should be thoroughly cleaned. In their laboratory study of torsional shear strength of primed interfaces, Mantilla and Button (1994) reported that primed specimens had much higher shear strengths than otherwise similar specimens when a small amount of dust was added to the surface before priming. Some believe that an asphalt prime coat will bond loose fine material to the surface of the base; this is not true! A compacted base, properly prepared for priming, must be clean and essentially free of any dust, loose particles, or foreign materials (NITRR, 1986). This can be accomplished by repeated passes of a mechanical broom, hand brooming, or blowing with high-pressure air.

## TIMING OF PRIMING

Senadheera and Vignarajah (2007) indicate that timing of the prime coat application is of great significance in achieving a good bond with the base. The moisture content in the base needs to be appropriate for the prime to sufficiently penetrate into the base. They mention that the 2004 TxDOT Standard Specification Item 247.4E stipulates, "Cure the finished section until the moisture content is at least 2 percentage points below optimum or as directed before applying the next successive course or prime coat."

Therefore, the base must be allowed to dry to some extent after finishing before the prime coat is applied. However, a base that is too dry can, particularly under traffic, generate a fine dust coating that inhibits the bonding of the prime coat to the base. This can result in freckling of the binder that leaves uncoated open spots on the base where surface treatment binder may not bond well (Figure 1). Mantilla and Button (1994) indicated that a light application of water spray onto an extremely dry base surface will aid in uniform distribution of the prime, making it more suitable for application of the prime coat.

**Figure 1**. **Freckling of Prime Coat Binder on a Dry Base (Senadheera andVignarajah, 2007).**

## PENETRATION OF PRIME INTO A BASE

In 1986, the South African guidelines (NITRR, 1986), recognizing the importance of penetration, stated that, "a prime must be capable of wetting and penetrating the dust film covering a granular base and coating the aggregate particles with a strongly adhering film of binder. It must be capable of penetrating the surface of the base to a limited extent. The depth of penetration is dependent on the density of the base: higher density typically yields lower penetration.

According to Senadheera and Vignarajah (2007), penetration of the prime coat into a base is very important to obtain the maximum benefit from the prime coat. The amount of penetration depends on a number of factors including the prime coating method, prime coat binder, base material, base finishing technique, and the permeability of the base course. Typical penetration depth of a sprayed cutback prime might range from 1/8 inch to 3/8 inch. Occasionally, penetration can exceed 1/2 inch. Figure 2 shows a schematic of prime coat penetration into the base layer. The inset photograph illustrates actual penetration of an MC-30 prime for a specimen prepared in a laboratory.

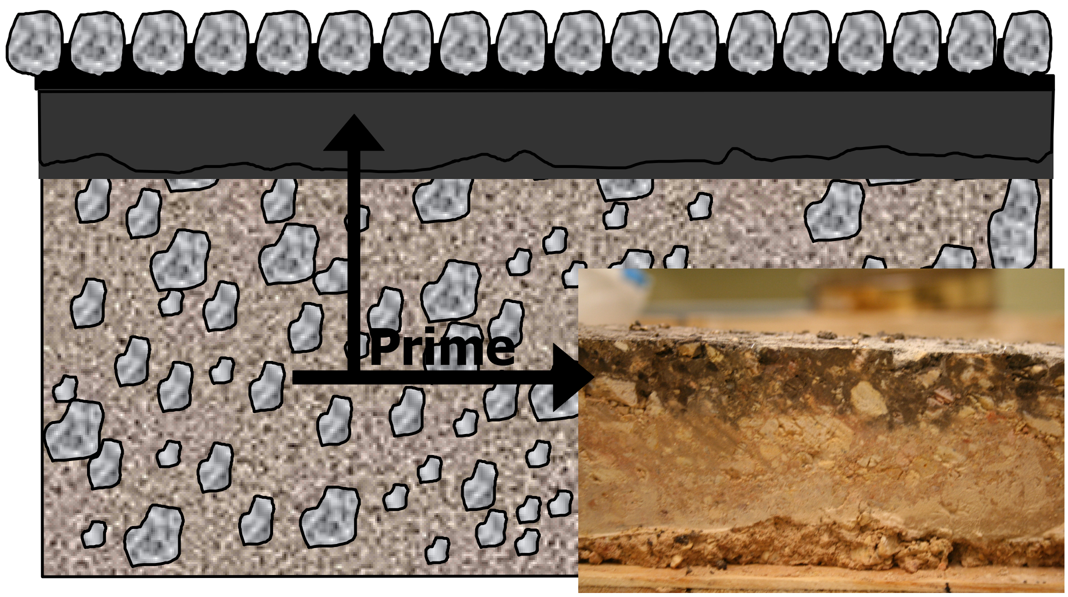


**Figure 2. Schematic Showing Prime Coat Penetration into Base with Photographic Inset Showing Actual Penetration in a Laboratory-Compacted Limestone Base (Senadheera and Vignarajah, 2007).**

Ordinary asphalt emulsions applied directly onto a compacted base are not suitable as prime coats, as they will not normally penetrate compacted dense-graded bases. Emulsified asphalt will break on the surface of the base and form a sticky film, which is usually removed by tires of subsequent construction traffic. Ubben and Floersch (1981) demonstrated that ordinary emulsified asphalt used for a prime coat would pick up on car tires even after a waiting period of 4 hours. They advised that regular emulsion should probably not be used as prime coat unless the underlying aggregate surface is slightly scarified to encourage penetration of the prime coat. (Of course, any aggregate particles disturbed by this scarification process must be recompacted prior to construction of the next pavement layer to avoid a weakened interface.)

Gray (1982) found that a prime coat using emulsified asphalt (CSS-1) did not penetrate the roadway surface. The CSS-1 stayed on top of roadway but was covered with crushed aggregate to accommodate ongoing construction and occasional local traffic. (This would be similar to a covered prime but without the penetration of the prime material.)

However, specialized emulsified asphalt products have been successfully used as prime coats, as they do offer some penetration. Further, slow setting mixing grade emulsified asphalt might be used as prime if it is mechanically mixed into the top couple of inches of the base to achieve suitable penetration.

## CURING OF PRIME COATS

Curing time should be no longer than necessary to permit evaporation of most of the carrier (i.e., cutter stock or water). Excessive curing time can promote contamination of the surface with dust and debris or damage by inclement weather. Proper curing time of prime coats depends on a number of factors: type of prime material, application rate, dilution rate, application method (spray-on or mix-in), weather, permeability of the base surface, and other factors. Curing of cutbacks may require several days; whereas, emulsified products may require only one day.

Emulsified asphalt primes require a relatively short curing time. Once the emulsion is broken and set, the base is ready to receive the next layer in the construction process. Recall that AEP, although an emulsion, contains solvent and should be given ample curing time.

NITRR (1986) advised that, if puddles of wet prime are still evident after the prime has been left to dry for as long as possible, such puddles should be covered with a layer of small stone (1/4-inch nominal single size), but not sand or crusher dust. Bleeding may occur if surfacing is placed over a wet prime.

Engineers are concerned with the use of cutback asphalts as prime for at least three reasons: safety (flammability), loss of VOCs into the air, and, in some instances, softening of the asphalt in an overlying pavement due to capturing of vapors from volatiles remaining in the base layer. Ishai and Livneh (1984) reported that, after one day of curing, MC-70 lost only 27 percent of its solvent (mainly kerosene), and MC-30 lost 15 percent. After two days, MC-70 and MC-30 lost 37 percent and 24 percent, respectively, and after seven days of exposure, only 58 percent and 40 percent, respectively. This indicates that significant volatiles may be available for absorption into a subsequently constructed asphalt pavement layer. The rate at which volatiles evaporate from an applied prime will depend on a number of factors, including temperature, wind velocity, permeability of base, grade of cutback, and application rate.

Specialized emulsified asphalt primes cure relatively quickly but do not completely solve the problem of VOC release into the atmosphere. These products contain some solvent; (this is what effects their penetration into the base).

## IMPORTANCE OF INTERFACIAL BOND BETWEEN PAVEMENT LAYERS

One writer (Chellgren, 2005) states, without proof, that, "There is a substantial amount of misinformation concerning the function and proper use of prime. Prime is not glue – causing the base to adhere to the pavement is not its purpose. Prime's purpose is to protect the base from rain and light traffic, when the paving will be delayed." He further states that a prime "has no structural value" and is applied "purely to provide convenience for the contractor," indicating that the protection offered by a prime coat allows the contractor to prepare several segments of base, which could all be paved at one time, thereby improving rideability.

However, most practitioners and researchers disagree with such broad, sweeping negative statements about prime coats. In fact, *all* others consulted in this literature review demonstrated, using field data, laboratory data, and/or mathematical models, significant benefits from an adequate bond between pavement layers provided by a suitable prime coat (or a tack coat, in some analytical cases). Experience has shown that the application of a prime coat reduces the risk of failure (NITRR, 1986), particularly for thin pavements.

Further, a number of highway pavement failures have been associated with interlayer bond problems (Kennedy and Lister, 1980; Peattie, 1980). Uzan et al. (1978) pointed out that crescent-shaped cracks may develop under vertical and horizontal loads in sections where the interface bond is weak due to poor construction. Several others (Canestrari et al., 2005; Sangiorgi et al., 2003; Romanoschi and Metcalf, 2003; Al Hakim et al., 2000; Hachiya and Sato, 1997; Lepert et al., 1992; SETRA, 1986; and Livneh and Schlarsky, 1962) indicate that loss of interfacial bond will lead to pavement distress.

Ameri-Gaznon and Little (1990) declared that interfacial bonding is the single most significant factor that affects octahedral shear stress distribution within an asphalt overlay and, further, that loss of bond allows the development of horizontal tensile stresses at the interface of the asphalt pavement and base, which substantially increases shear stresses in the surface layer, thus leading to increased propensity for rutting.

Ponniah et al. (2006) explained that good interlayer bonding is desirable to ensure that the entire pavement structure will act as a monolithic layer to provide the expected structural adequacy. Leng et al. (2008) unequivocally support this position indicating that the bond between an HMA overlay on concrete pavement is one of the most significant factors affecting overlay service life. They used accelerated pavement testing with different tack coat types and application rates as well as pavement texture to demonstrate the effects of interface bonding on pavement performance (i.e., rutting, slippage, and strain response).

Tschegg et al. (1995) affirmed that, to obtain appropriate loading capacity of the pavement and yielding longer lifetime of the road, appropriate bonding between the layers must be guaranteed. They proved this, using the old freshman engineering beam analogy, which states that two boards glued together are much stronger and stiffer than the same two boards when slippage is allowed between them. Additionally, Ziari and Khabiri (2007) concluded that, based on measured behavior of in-service pavements, the condition of the bonding between all pavement layers plays an important role in the performance of the road structure.

## PAVEMENT DISTRESS RELATED TO PRIME COATS

If a surface pavement is not glued to the base during construction, delamination occurs immediately; it is already present in the brand new pavement structure. Several researchers indicate that such a condition will result in various forms of pavement distress.

The Council for Scientific and Industrial Research (CSIR, 1967), in South Africa, deduced that the main purpose of a prime coat is to assist in achieving and maintaining a bond between the base and the new surfacing of a road. Ishai and Livneh (1984) concluded that the benefit/cost ratio of a prime coat, "with respect to the entire performance of the flexible pavement structure," is quite positive when a properly formulated prime is applied.

Romanoschi and Metcalf (2001) concluded from their research that the behavior of in-service pavements proves that the interface condition significantly affects the distribution of stresses and strains in flexible and semi-rigid pavement structures and, thus, their performance.

Jha (2005) blamed distress in relatively new pavements on poor prime coat construction practices. He defined distress by cracking, rutting, settlement, and loss of aggregate.

Further, West et al. (2005) suggested that specific pavement problems may be attributed to insufficient bond beneath HMA layers and that these include: compaction difficulties during construction including lateral slippage, premature fatigue cracking, top down cracking, and surface layer delamination.

Furthermore, Axup (2003) indicated that flushing in the wheel paths can have a number of causes. Those related to priming including excessive prime coat being incorporated into the seal coat by action of traffic or prime coat being covered before sufficient volatiles in primer binder have evaporated. Any flushing can ultimately result in reduction of friction values and, thus, become a hazard in wet weather.

## PERFORMANCE ISSUES RELATED TO SURFACE TREATMENTS

CSIR (1967) reported that the omission of the prime on a crusher-run partially decomposed dolerite road base had no effect on the performance of a two-layer surface treatment, but the performance of single layer surface treatment was adversely affected. They deduced that, in the special case of dense bases with low-permeability surfaces, which can be swept free of dust and where it is possible to construct the surfacing immediately after completion of the base, it may be satisfactory to omit the prime. If, however, the prime is omitted, an adjustment must be made to the rate of asphalt application of the surface treatment binder to allow for some absorption of binder by the base.

## TEST METHODS FOR EVALUATING PRIME COATS

These methods will be discussed briefly because laboratory tests were not a part of this study. They are included here as part of this comprehensive review and because the concepts were used in developing the field tests required by this research.

There are no standard, or even widely accepted, test methods for evaluating the quality of an applied prime coat in the field. However, a few laboratory test procedures have been developed for specific studies to evaluate penetration depth of a prime coat material or strength of the interfacial bond between the base and the pavement layer. Many pavement engineers believe a prime coat should reduce permeability of the surface of the base to near zero; therefore, a few have measured permeability of various prime coat treatments.

## Prime Coat Tests

### *Shear Tests*

In a project to identify methods to replace cutback asphalt primes with emulsified asphalt, Mantilla and Button (1994) developed two laboratory test methods to examine shear strength (torsional shear and direct shear) of a primed interface between a base and a pavement along with a simple procedure for gauging penetration depth of prime materials. The torsional shear tester utilized actual construction materials and layer sequences in a 6-inch diameter mold. The direct shear process utilized only the fine aggregate from the base material in a standard soil shear tester (2.8-inch diameter specimen). All prime materials yielded higher shear strengths over that of no prime at the lower normal stresses applied. The plane of failure in most of the torsional shear tests was near the bottom of the penetrated depth of the prime, indicating that the stratum of the base penetrated by the prime was stronger than the untreated underlying base material.

Ishai and Livneh (1984) measured direct shear strength of the primed interface of laboratory-prepared specimens (dolomitic aggregates in both base and HMA). This test procedure is described in detail by Uzan et al. (1978). Generally, the base layer was statically compacted in a 15 x 10-cm mold. The next day, prime coat was applied. One day later, HMA was compacted onto the sprayed surface. Then, 24 hours later, the direct shear test was performed. Under these conditions, MS-10 emulsion produced higher shear strengths than either MC-30 or MC-70.

### *Penetration Tests*

A prime penetration test was developed and described in detail by Mantilla and Button (1994). It is a laboratory procedure designed to estimate the penetration depth of a specific prime material into a particular type of aggregate to be used for base. The procedure uses moistened minus No. 4 sieve size aggregate that is compacted in a 2.9-inch diameter cylindrical mold (an asphalt tin) using a static load. Primer is applied at the specified application rate. One hour after application of prime, slice the specimen vertically, and measure penetration depth using a ruler or caliper. This procedure can be used to estimate the depth that a prime material can achieve into the granular base as well as the time required for it to fully penetrate. Further, it could be used to evaluate relative penetration depth of various primes into different base materials and to determine optimum application rates for various combinations of prime and base materials.

In Australia, Gaughan (1996) conducted a series of laboratory tests to investigate the relative penetration depth of cutback bitumen and emulsified asphalts into a range of bound base course materials used for the construction of pavements throughout New South Wales. Based on his work, he developed what he called a laboratory compatibility test for priming, which can be used to determine the best type of primer and the appropriate application rate to be utilized for a particular bound or unbound base course material.

One objective of a study by Ishai and Livneh (1984) was to determine if a prime coat contributes significantly to the functional and structural performance of the pavement. The authors measured penetrating ability of prime materials using statically compacted sands at optimum moisture content in 2-inch diameter cylindrical specimens. Researchers applied prime one day after compaction. Depth of penetration was measured at a vertical cut in the specimen one day after curing. Use of sand produced porous specimens and, consequently, yielded equivalent penetration depths for cutbacks and emulsions. This equivalency of penetration would not likely be the conclusion if limestone had been used.

*Permeability*

One of the primary purposes of a prime coat is to protect the base from inclement weather before application of the subsequent pavement layer. Therefore, an important function of the prime coat is to reduce permeability of the surface of the base, which is a particularly important attribute for those primes used as curing membranes. CSIR (1967) measured permeability of various primed and unprimed surfaces and subjectively evaluated their performance in resisting disintegration of the base. Generally, they determined that priming reduced the permeability of the base to water but did not completely seal the pores. The effect of priming on permeability depended mainly on size and distribution of the pores in the surface of the base and the extent to which the binder filled these pores. Permeability was, of course, influenced by the rate of application of the prime and its depth of penetration. They observed that, when moderate rain fell before paving, the prime coat waterproofed the base. Mantilla and Button (1994) observed in their field test near Abilene that, under flash flood conditions, none of several very different types of prime protected the base from severe erosion.

# CHAPTER 3.
# FINDINGS FROM A SURVEY OF TxDOT DISTRICTS

This chapter is based on findings from a phone survey of 20 of the 25 TxDOT districts that was conducted by the authors. All districts were called; many were called multiple times. The survey questions used to guide the phone survey are shown in Appendix A. Usually, the director of construction (DC) of the district was interviewed by a TTI researcher; however, in some instances, the DC delegated the interview to another person that he/she felt was more knowledgeable about prime coat materials and related activities in the district. The main goals of this survey were to determine how the districts typically construct pavement base layers, how they prime particular types of granular base in several different circumstances (e.g., traffic, construction materials, geographical location, climate, and highway type), which combinations of base materials and priming techniques are performing acceptably, and what combinations may be yielding undesirable performance.

## MATERIALS FOR BASE COURSE LAYERS

As shown in Table 1, the most commonly used flexible base (TxDOT Item 247) material is crushed limestone (used by 90 percent of the districts interviewed). A few districts use some locally available caliche (25 percent), river gravel (25 percent), and sandstone (15 percent). Very few districts use iron ore gravel (10 percent) or granite (10 percent). Sixty percent of the districts surveyed reported using cement-treated base, while only 10 percent reported using fly ash, and 15 percent reported using asphalt to stabilize base layers.

**Table 1. Types of Base Course Materials Used in TxDOT Districts.**

| Type of Base Material | Use by TxDOT, percent |
|---|---|
| Limestone | 90 |
| Caliche | 25 |
| River Gravel | 25 |
| Sandstone | 15 |
| Iron Ore Gravel | 10 |
| Granite | 10 |
| Cement-Treated Base | 60 |
| Fly Ash-Treated Base | 10 |
| Asphalt Stabilized Base | 15 |

## COMPACTING AND FINISHING BASE COURSE LAYERS

Seventy-five percent of the districts reported that their contractors use simple blading and rolling to finish the base layer. Fifty percent reported that they permit their contractors to use “slush” rolling, where excess water is applied during the latter portion of the compaction process to pump fines to the surface and, in so doing, achieve a very smooth surface. ***Slush rolling is not a recommended practice.*** Slush rolling, particularly of limestone, which contains large amounts of comparatively small-size fine material, can produce a surface with low permeability, thereby inhibiting penetration of spray-applied prime. Additionally, slush rolling can create a weakened plane of very fine material at the interface with the successive pavement layer. Although there is currently no known research to verify the following, it appears that this smooth, weakened interlayer could encourage slippage and/or delamination of the finished pavement surface.

Only five districts (25 percent) reported having used a base laydown machine, and all five of these districts indicated this occurrence was very rare. They further indicated that a base laydown machine produced a smooth layer with very little aggregate segregation and degradation when compared to typical base construction methods. A base laydown machine could be a valuable tool when placing base materials with low fines content that may be, or have been shown to be, subject to segregation.

For base compaction, the vast majority of districts (approximately 90 percent) allow the use of a sheepsfoot roller followed by a steel wheel finish roller. Three districts (Abilene, Pharr, and Yoakum) (14 percent) indicated that they preferred a padfoot roller, because it does not crush the larger stones as severely as does a sheepsfoot roller. Pharr indicated that crushing of larger stones was a particular problem as Pharr uses a significant amount of the relatively soft caliche for base material.

On some projects, Tyler uses steel wheel rollers only to reduce crushing of the softer sandstones they often use. However, to further reduce crushing of the larger stones, several districts (33 percent) prefer the use of a pneumatic breakdown roller followed by a steel wheel finish roller.

A couple of districts indicated that, with certain base materials, it is sometimes difficult to achieve adequate compaction when using a pneumatic roller followed by a steel wheel roller (although this is the preferred method to minimize crushing of larger stones). As a result, they are forced to revert to a sheepsfoot or padfoot roller. The Waco District indicated that compacting the base using this method when the base is too dry will still promote crushing of the larger stones. To achieve a tightly knitted base surface, the Bryan District, which uses mostly limestone, requires finish rolling using a pneumatic roller.

Sixty-five percent of the districts surveyed indicated that blowing dust is sometimes an issue during base construction. Most of these respondents reported that the contractor simply applies water as a dust palliative. The Austin, Bryan, and Odessa Districts sometimes require application of diluted emulsified asphalt as a dust palliative because this clearly offers longer term dust reduction than water alone. Those districts that prime by mixing diluted emulsified asphalt into the uppermost 2 or 3 inches of the base (Item 314) indicated that dusting is not normally an issue, at least not with that last lift.

Abilene suggested that, when using cement-treated or fly ash-treated base (Items 265 and 275), one should lower expectations regarding smoothness. Once cement-treated or fly ash-treated base is compacted, the contractor must leave it alone, because they cannot continue reworking the surface to attain a higher level of smoothness without severely compromising the strength of the base. However, when diluted mixing grade emulsified asphalt is mixed into the top couple of inches or so, the contractor has much longer to rework the surface to improve smoothness.

## MATERIALS UTILIZED FOR PRIME

Most districts (80 percent) stated that the prime material (Item 300), typically MC-30, was applied to the surface by spraying using an asphalt distributor truck. Thirty-five percent of the districts reported having mechanically mixed emulsified asphalt into the uppermost 2 to 3 inches of the compacted base.

Of the seven districts that mix emulsified asphalt into the uppermost base layer, most of them use SS-1 or CSS-1 for this purpose; however, on occasion, about half of them may use MS-2. The Odessa District stated that mixed-in emulsion was the primary method used for preparing and priming base layers.

Incidentally, TxDOT Project 1334 (Mantilla and Button, 1994) produced written guidelines for mechanically mixing diluted emulsified asphalt into the uppermost portion of a base layer, either by mixing with the last 2 inches (±) of base during the compaction process or by compacting, then scarifying the upper stratum, mixing with emulsion, and then recompacting (Appendix B). The latter method is not preferred because the recurrent processing (compaction, scarification, and recompaction) degrades the larger aggregate particles and, thus, may weaken the uppermost stratum of the base. Additionally, Project 1334 produced an instructional video on mechanically mixing emulsion into the upper portion of a base layer, which is available on a CD from the Texas Transportation Institute.

When asked about the materials used for prime in their districts, the respondents reported the following (Table 2). Note that the sum of the percentages exceeds 100 percent because most districts use multiple products for prime coats.

**Table 2. Types of Prime Coat Materials Used in TxDOT Districts.**

| Type of Prime | Amount of Use by TxDOT |
|---|---|
| MC-30 | 90 percent |
| AEP | 70 percent |
| RC-250 + Grade 5 stone[1] | 40 percent |
| SS-1 | 35 percent |
| MS-2 | 20 percent |
| PCE | 10 percent |
| CSS-1h | 5 percent |
| EAP&T | 5 percent |
| Emulsion + Grade 5 stone | 5 percent [2] |

[1] When the primed base must carry significant traffic or must carry traffic for a significant period of time.

[2] San Antonio District uses this method in non-attainment areas.

TxDOT's most common prime material is MC-30. All respondents that use MC-30 stated that it is used primarily because it provides the best penetration into the surface of a compacted base. The main disadvantage of MC-30 is that it usually requires at least 3 days to cure. Like all other prime coats applied onto the base surface, MC-30 is typically applied using an asphalt distributor truck.

Essentially all districts agreed that emulsified asphalt does not penetrate into a base and that, if used, it must be diluted and mechanically mixed into the upper portion of the base layer. When diluted emulsified asphalt is mixed into the surface of the base, it is often applied using a water truck instead of a distributor truck, since uniform application becomes less important. After final compaction of the uppermost base layer, when mixed with diluted emulsion, some districts apply additional diluted emulsion onto the finished surface to enrich the surface with asphalt, thus providing better protection of the base from weather and traffic and better adhesion to the subsequent pavement layer. Instead of mixing emulsion into the base, the Lufkin District uses multiple shots of diluted emulsion onto the surface of the prepared base.

The El Paso and Odessa Districts were the only districts that reported using mechanically mixed-in emulsified asphalt as prime most of the time. El Paso may mix emulsion into the top 6 inches; whereas, Odessa tries to mix into only the top 1 inch. Corpus Christi, when they use this method, mixes about 0.15 gal/sq yd/inch of residual asphalt into the top 2 inches of the base. The Corpus Christi specification requires not less than 2 percent residual asphalt in the total treated layer. General notes from the Paris District state, "The (emulsified) asphalt shall be diluted with base finish water and added incrementally and worked into the top 1/2 inch of flex base."

El Paso reported that they use mixed-in emulsion since they cannot use MC-30 because of restrictions on the resultant emission of VOCs. The few districts that mix in emulsion indicated that the cost is about the same as using MC-30 and, further, that the cost of priming (with anything) is very small compared to the overall cost of the project.

The San Antonio District sometimes mixes diluted emulsified asphalt into the upper 6 inches of a base primarily to improve its strength. That is, the main function of the emulsion is strength, not just a prime coat.

As indicated in Table 1, most districts (70 percent) have used AEP; however, several reported only occasional or even experimental use. Most of those districts that reported using AEP indicated that it is an emulsion and produces fewer VOCs than MC-30, and yet it provides fairly good penetration into the surface of the base. Although this is true, it should be pointed out that AEP is essentially emulsified cutback asphalt and does emit some VOCs. A couple of districts indicated that AEP does not penetrate as well as MC-30, which they view as a disadvantage. Typically, less of the residual cutback (and, thus, less VOCs) is applied when AEP is used instead of MC-30.

Because the majority of the bases in the Houston District are cement treated, they use mostly PCE for priming. The PCE serves primarily as a curing membrane for their cement-treated bases. They indicated that PCE does not provide a good barrier from surface water (e.g., rainfall) but appears to retard evaporation of water from below. They added that PCE is not sticky after three days or more and that they will often reapply PCE or apply a tack coat before placing the bond breaker asphalt concrete. The Houston District typically does not allow traffic on a compacted base.

The Houston District is not concerned with penetration of PCE (or any prime) into cement-treated bases, but are concerned that penetrating hydrocarbons will inhibit the cement hydration process and create a thin weakened layer. The engineer stated that he had seen prime penetrate a cement-treated base and yield a damaged layer that could literally be swept off.

A couple of districts have experimented with non-bituminous prime coat products from Prime Eco Group in Wharton, Texas. Their EC-30 is designed for untreated base; whereas, EC-20 is marketed for cement-treated base. These are water-based suspensions of a non-bituminous product. No district offered comments regarding performance of these newest products.

## PENETRATION OF PRIME INTO BASE SURFACE

Overall, TxDOT engineers indicated that they like to see about 1/4 to 3/4 inches of penetration of prime material, which is generally attained with MC-30. However, loose dust on the surface prior to priming will hold the primer on the surface, thus inhibiting penetration of the prime material. Slush rolling, particularly of stone which contains comparatively small fine material (e.g., limestone), can produce a surface with low permeability, thereby inhibiting penetration of spray-applied prime.

Very few districts actually measure penetration depth, and none specify a minimum penetration value. Penetration is normally observed by cutting a vertical slice into the primed base surface using a knife and simply measuring the depth of the dark color with a ruler. Because of the variability in penetration depth, due to the wide variability of particle sizes near the surface, one must make several measurements and compute an average depth to obtain a realistic value.

If the prime material does not completely penetrate (i.e., leaves puddles), before construction can proceed (or if limited highway traffic must be allowed on the primed base), blotter material is often distributed to soak up any excess prime or puddles. This blotter material must be swept off the base surface prior to paving.

Sixty percent of the districts allow the use of blotter material, while 40 percent do not. Waco allows blotter sand, but San Antonio does not; however, both encourage sweeping to spread any puddles of primer. A few districts added that they allow sanding only where public traffic must drive through the prime (e.g., intersections and driveways). Of those that allow blotter material, all permit the use of field sand. A few agencies outside of TxDOT encourage the use of crushed blotter material to avoid a weakened shear plane that might be caused by the usually rounded sand particles.

## TIMING OF PRIMING

Most TxDOT districts apply prime after the moisture content of the base is at least 2 percentage points below optimum, in accordance with the requirements in Item 247. However, several districts were unaware of this specification, although they did state that they desire some drying back, particularly of the surface of the compacted base layer.

The Yoakum District asserted that a very light application of water "to break the surface tension" just before applying cutback (MC-30 or RC-250) prime will provide better distribution, that is, prevent the formation of "perch eyes." Some have referred to this phenomenon as "freckling." Perch eyes or freckling (Figure 3) can be defined as 1/4 inch to 4-inch diameter holes in the cutback asphalt prime coat film that form when the material is suspended on a thin layer of dry dust such that it is momentarily unable to rapidly penetrate the surface of the base.

For those districts that use cement-treated bases, all agreed that priming (placement of a curing membrane) soon after finishing the base was important to retain the moisture for proper hydration of the cement.

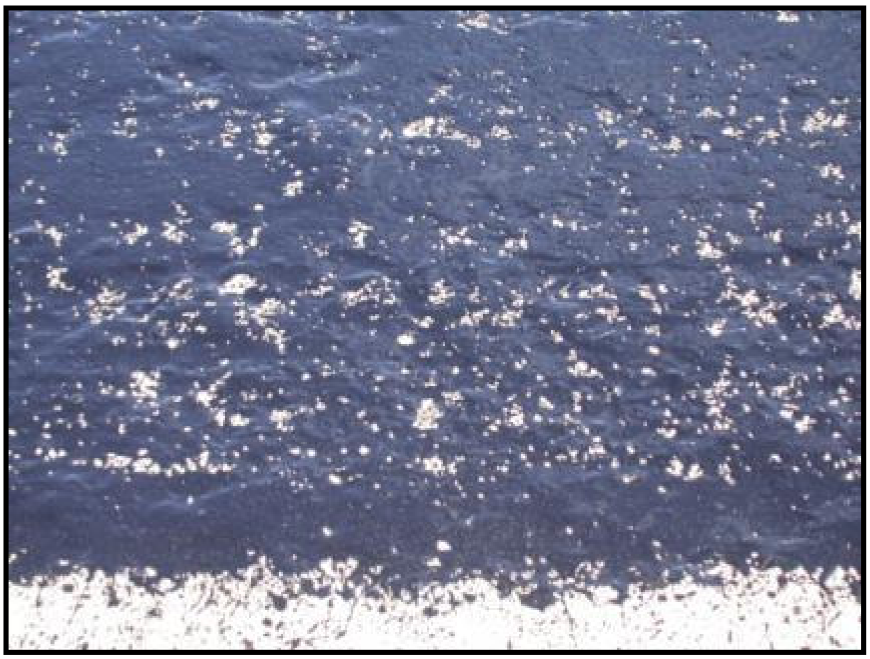

**Figure 3. Example of "Freckling" or "Perch Eyes" of Prime Coat on a Dry Base (Senadheera and Vignarajah, 2007).**

## PRIME COAT CURING REQUIREMENTS

Of the TxDOT districts that use cutback asphalt for prime, all of them agreed that a curing period was needed. This curing period is defined as time required for the prime coat to soak into the surface of the base and for the majority of the cutter stock (kerosene in MC or naphtha in RC products) to evaporate. Some districts had very specific requirements while others indicated that a subjective (i.e., visual) assessment for adequate curing was satisfactory.

Curing times reported for MC-30 ranged from one to 10 days. For RC-250, the Bryan and Yoakum Districts stated that they typically require about seven days for curing (note that these are usually fairly heavy application rates required to hold the Grade 5 stone). A couple of districts mentioned that curing time is shorter in hot weather and, of course, takes longer in cooler weather. Curing time for any product also depends on the application rate; a higher rate requires a longer curing time.

Only a couple of districts, and then only occasionally, apply regular emulsified asphalt (e.g., MS-2, SS-1, or SS-1h) on the surface of a base as prime, because it does not penetrate the surface and can create problems during subsequent progression of construction. However, several districts mix emulsion into the upper stratum of the base. Recall that emulsified prime coat products include AEP, EAP, and PCE. Of the districts that use an emulsion in some type of priming application, seven (35 percent) reported that they require a curing time, and five (25 percent) reported that no curing time is required. Only four (20 percent) districts suggested a curing time (ranging from 2 to 4 days) for mixed-in emulsified asphalt.

## PRIME COAT TESTS

None of the TxDOT districts physically measure prime coat quality after application or curing. Further, based on the worldwide literature review conducted as part of this project, there are no standardized tests whereby one can objectively measure prime coat quality. None of the districts specify or measure prime penetration depth, uniformity of application, permeability, color of surface, or stickiness. A few districts pointed out that they desire a uniform application, but that it is a judgment call. A couple of districts indicated that they desire a “nice black surface.” One construction engineer stated, “You have got to deal with the real world (e.g., equipment and personnel), so you let the contractor slide sometimes” to efficiently accomplish the mission at hand.

## ACCOMMODATION OF HIGHWAY TRAFFIC ON A PRIMED SURFACE

Sixty-five percent of the districts allow limited public highway traffic on a primed surface, usually after application of blotter material. Thirty-five percent of the districts reported that they do not permit highway traffic on a primed base. Essentially all districts that allow public traffic on a primed surface indicated that they do so only when absolutely necessary (e.g., at intersections and driveways). Abilene indicated they allow traffic only if the average daily traffic (ADT) is less than 200.

When it is preplanned that a primed base must carry significant highway traffic, or when it must carry traffic for a substantial period of time, several districts (40 percent) reported the use of “inverted prime” or “covered prime.” Inverted or covered prime was defined by them as application of RC-250 followed by Grade 5 stone, which essentially produces a fine or thin surface treatment. They reported that this treatment can often carry traffic throughout the winter months without significant damage to the surface of the base. The Brownwood District stated that they would like to use the inverted prime when appropriate but that, often, the few contractors available to them do not have that capability.

To accommodate traffic, the San Antonio District sometimes uses an inverted prime, but because they are in a non-attainment area, they use emulsified asphalt as the binder.

The Lufkin District indicated that when the situation calls for accommodating relatively high traffic or high-speed traffic, they increase the application rate of the RC-250 from about 0.17 gal/yd$^2$ to 0.20 gal/yd$^2$. Brownwood reported typical application rates ranging from 0.20

to 0.22 gal/yd$^2$. The Lubbock and Pharr Districts stated that, when the base must carry substantial traffic for a significant period, they apply a one-course surface treatment (an underseal), which is later followed by a two-course surface treatment or hot mix asphalt.

Five of the districts (25 percent) reported that they do nothing different when the primed base must carry limited highway traffic. About the same number indicated that they do not allow significant highway traffic on a compacted base.

## PAVEMENT PERFORMANCE ISSUES RELATED TO PRIME

Six districts (30 percent) reported that they had, at least once, observed slippage of the subsequent pavement layer at the primed interface. All agreed that these were very rare events. Corpus Christi blamed the slippage problem they recently experienced on improper surface preparation, in particular, excessive dust on the surface prior to priming. Houston reported an incidence of dust and grass blown onto the primed surface by high wind, which subsequently resulted in slippage of the final pavement. Laredo reported slippage on a pavement that they attributed to paving on an uncured prime coat.

The Abilene District observed slippage at or near the primed interface during construction of an HMA layer. They attributed the slippage to excessive fines on the AEP primed surface of a fly ash-treated base due to blading manipulations (after the fly ash had cured) to achieve a smooth surface. Then, the contractor placed a surface treatment, using CRS-1P, on the primed base. This surface treatment was under traffic for about six months with no observed distress. Then, a second course of the surface treatment was placed using CRS-2P.

Abilene engineers subsequently observed that the underseal “could be picked up like a carpet,” in some areas, particularly along the edges. Finally, the HMA surface was applied. While the contractor was compacting the HMA, the underseal slipped at the primed interface, primarily along the edges of the pavement and, in some locations, due to excessive slippage, rolled up the underseal. Abilene does not believe that the underseal is providing a good seal, and thus, they are concerned that it is leaking rainwater into the base. The pavement is now experiencing alligator cracking and some deterioration along the pavement edges that exhibited slippage.

The Bryan and San Antonio Districts have both, on occasion, observed intermittent pick-up of surface treatment down to the base. They were unable to isolate the cause of this uncommon incident. However, potential sources include a dusty surface before prime application or inadequate penetration of the prime material.

## BEST PRACTICES

### General

When the researchers asked the TxDOT district representatives which combinations of materials, finish, construction, and priming methods work best, they obtained a variety of comments. The responses clearly depend on the limitations of the specific region of the state (e.g., available construction materials, contractor capabilities, traffic levels (urban vs. rural), non-attainment concerns, and district construction philosophies). Some of the responses are summarized below.

**Pneumatic Roller**

The Corpus Christi and Ft. Worth Districts prefer limestone that is compacted using a pneumatic roller followed by a steel wheel roller without slush rolling. MC-30 is their preferred prime material. Pharr uses mostly caliche for construction of bases, but they prefer this same construction method.

**Contractor Expertise**

The Wichita Falls and Yoakum Districts almost always slush roll their limestone bases and prime using MC-30. On the other hand, the Brownwood District typically uses blading and rolling (without slush rolling) of limestone followed by spray application of MC-30. However, the Brownwood engineer pointed out that one should not specify a particular priming method. Rather allow the contractor to use his expertise, but require him to meet the requirements in Item 247.

Abilene District personnel stated that they prefer a limestone base compacted using a steel wheel roller followed by clipping using a maintainer and then primed with MC-30. They indicated that their contractors are generally good at this.

**Mixing in Emulsion**

Odessa prefers mixing diluted emulsified asphalt into the top 1 inch or so of their bases. Austin also prefers mixing emulsified asphalt into the top layer of its, typically, limestone bases. However, Austin stated that this process is difficult in the metro area because it takes more time than priming with MC-30 or AEP.

**Inverted Prime**

The San Antonio District stated that the inverted or covered prime (RC-250 + Grade 5 stone) works best for two reasons: (1) it can carry significant traffic for extended periods, and (2) it allows long areas to be primed, which subsequently allows long, continuous applications of surface treatment, thus reducing the number of transverse construction joints. This enhances pavement smoothness and ensuing pavement performance.

**PCE**

The Houston District uses a majority of concrete pavement, so their preferred construction practice is limestone plus cement, bladed and rolled, primed with PCE (typically primed a second time using PCE), followed by an asphalt concrete bond breaker, and then Portland cement concrete.

**Advice from Waco on Compaction of Relatively Soft Stone**

The Waco District offered the following rather extended advice. Contractors in the Waco District typically do not use sheepsfoot rollers on a deep lift of base because they are concerned that the high contact pressures will fracture the larger stones and, thus, decrease strength of the compacted base. More than 90 percent of the time, Waco uses limestone, which is fairly soft and subject to significant degradation during construction.

For base compaction, contractors frequently use a pneumatic roller followed by a steel wheeled roller. Sometimes contractors employ the steel-wheeled roller when the base is too dry and hard, and thus, the steel wheeled roller crushes the larger rocks at the surface of the base. In fact, softer stones can literally be crushed to powder and significantly alter the as-constructed gradation.

One contractor was allowed by the Waco District to use only a steel wheeled roller to compact a limestone base. The contractor compacted the base in 3-inch to 4-inch lifts that were above optimum moisture content using a steel wheeled roller. With the base material well above optimum, it was soft enough that the steel wheeled roller pressed the large rocks into the base, without breakage, leaving many large rocks near the surface of the base.

Because of the softness of the relatively wet base, the large rocks were not broken or crushed, as is often the case when the base layer is at or below optimum moisture content for compaction. They believe the presence of the large rocks near the surface provides a strong upper stratum in the base with good load spreading capacity, as is desired for optimum pavement performance.

Without the usual slush rolling, permeability of the surface of the limestone base was higher than usual. Therefore, the prime coat, typically MC-30 or AEP, was better able to penetrate the upper stratum of the base and provide a strong interface. The Waco District Director of Construction concluded that it was the best looking job that he had ever seen.

Incidentally, the authors believe that this Waco District process would accommodate mixing in of emulsified asphalt prime in the uppermost few inches of the base. The last lift to be compacted could be mixed with a dilute emulsion rather than mixing water, to increase the liquid content to the desired level. Then, after compaction, it could be sprayed with a light shot of diluted emulsion to enrich the surface and help protect the surface from erosion due to rainfall or light traffic.

# CHAPTER 4.

# DEVELOPMENT OF FIELD EXPERIMENT DESIGN

The research team used the information assembled during the first part of the study and the results of the survey of TxDOT districts to develop a testing plan and experiment design.

## ORIGINAL PLAN

The original concept was to establish a factorial design that included up to 24 sites of the most common combinations of base type, finishing method, construction technique, and prime coat material (Table 3). The designation of "Trafficked" and "Untrafficked" denotes whether the treatment was expected to be opened to traffic prior to placing the final surface.

At each test site, a 100-foot section of shoulder was to be laid out, followed by a 50-foot section that was to be left unprimed (leave out). There would be two of these sections per test site. Testing would include torque testing to determine the impact of the prime coat on the resistance to shear at the surface and falling weight deflectometer (FWD) testing to determine the impact of the prime coat on the strength of the pavement due to increased adhesion of the surface to the primed base. This plan was presented to and approved by the TxDOT project monitoring committee.

**Table 3. Original Partial Factorial Design.**

Untrafficked

| | | | Prime | | |
|---|---|---|---|---|---|
| **Base** | **Finish** | **Construction** | **AEP** | **MC-30** | **MS-2** |
| Stabilized | Blade and Roll | Spray Prime | 2 | 2 | |
| Limestone | Blade and Roll | Spray Prime | | 2 | |
| | Slush Roll | Spray Prime | | 3 | |
| Caliche | Blade and Roll | Spray Prime | | 1 | |
| Gravels | Blade and Roll | Work in/Cut in/Mix in | | | 1 |

Trafficked

| | | | Prime | | |
|---|---|---|---|---|---|
| **Base** | **Finish** | **Construction** | **RC-250** | **MC-30** | **MS-2** |
| Stabilized | Blade and Roll | Covered Prime | 1 | | |
| Limestone | Slush Roll | Covered Prime | 2 | | |
| | | Spray Prime | | 2 | |
| | Blade and Roll | Spray Prime | | 1 | |
| Caliche | Blade and Roll | Spray Prime | | 1 | |
| Gravels | Blade and Roll | Work in/Cut in/Mix in | | | 1 |

## FINAL PLAN

The original plan, including the distribution of test sections and testing plan, was modified during the project. Several districts resisted having a 50-foot area left unprimed because they felt that the performance of this area would be so poor that it would need to be reworked in a very short time, and they were unwilling to offer test sections. After losing these potential test sections, the untreated, leave out section was reduced to 3 feet (the width of a roll of roofing felt), and the FWD testing was replaced by pull-off testing (Figures 4, 5, and 6).

Districts were contacted many, many times in an attempt to fill the experiment design, but the reduced funding for new construction made finding specific sites difficult. Instead, any site where the district was willing to have a test section was chosen. On two occasions, the project team was unable to schedule trips to test sites, due to late notification of the work being performed, but in all other cases when work being conducted, the project team established a test site. Table 4 shows final factorial design.

**Figure 4. Leave Out Area.**

**Figure 5. Multiple Leave Out Areas.**

**Figure 6. Example of Unprimed Leave Out Area.**

**Table 4. Final Factorial.**

Untrafficked

| Base | Finish | Construction | Prime: CSS-1h | Prime: MC-30 | Prime: EC-30 | Prime: RC250 |
|---|---|---|---|---|---|---|
| Iron Ore Gravel | Blade and Roll | Spray Prime | | FM 134<br>FM 1841<br>SH 155<br>US 59 | | |
| Limestone | Blade and Roll | Spray Prime | | SH 6 | SH 31 | |
| | | Work in/Mix in | New (ODE) | | | |
| Stabilized | Blade and Roll | Work in/Mix in | | | | IH 45FR |

Trafficked

| Base | Finish | Construction | Prime: AEP | Prime: MC-30 |
|---|---|---|---|---|
| Gravel | Blade and Roll | Covered Prime | SH 6FR | |
| Limestone | Blade and Roll | Covered Prime | FM 1235<br>IH 20FR | FM 1235 |
| | | Work in/Mix in | US 283 | |

Due to construction contingencies, climatic factors, and contractor intervention, some tests were not conducted at some locations.

## FIELD TESTING PLAN

As mentioned earlier, the purposes and benefits of prime coats are to:

1. help seal the surface pores in the base, thus reducing the migration of moisture and absorption of the first application of surface treatment binder;
2. strengthen the granular base near its surface by binding the finer particles of aggregate;
3. help protect the base from inclement weather and limited vehicular traffic before the next pavement layer is constructed; and
4. promote adhesion between a granular base and a subsequently applied bituminous surface by precoating the surface of the base and by penetrating the voids near the surface.

Items 1 and 3 were not part of this study. Items 2 and 4 were addressed through the testing plan for cohesion and adhesion. For this study, these terms will be defined as:

***Adhesion*** is the tendency of certain dissimilar molecules to cling together due to attractive forces. In contrast, ***cohesion*** takes place between similar molecules.

**Penetration**

Penetration was measured at each site by using a chisel to remove a small portion of the primed surface and base and measuring the depth to where the prime coat penetrated.

The prime coat was removed by making a vertical cut into the prime using a hammer and chisel, then moving over 1 inch and making a diagonal cut toward the first cut, which popped out a piece of the prime surface. The measured penetration depth (in 1/16 of an inch) of the prime in the piece, or the depth as measured in the hole, whichever is deeper, was recorded. Figure 7 presents the procedure used to measure penetration, and Figures 8 and 9 along with Table 5 illustrate the readings.

Depth of penetration does not represent the quality of the prime coat. In areas where there is much loose material, the penetration will be higher. In areas where the surface of the base is impermeable, there will be little or no penetration. Penetration does indicate appropriate adjustments to the application rate.

- Locate three or more representative areas.
- After prime has cured sufficiently so that the surface is no longer tacky (at least one hour after prime coat application), make two 2 inch vertical slices into the base course using chisel and hammer, approximately 1 inch apart. A piece of base will usually debond. If no debonding occurs, retry with less separation.
- Clean area between the two cuts taking special care when removing large aggregates.
- Sweep cut area using a small whisk broom, sweeping from bottom to top and center to edge.
- Measure penetration depths at each location (brown color) using a ruler and compute average.

**Figure 7. Procedure for Determining Penetration.**

**Figure 8. Penetration Measurement, Showing Chisel, Hammer, and Scale.**

**Figure 9. Penetration of 1/16 of an Inch.**

**Table 5. Penetration Readings (1/16 of an Inch).**

| Treatment | Test 1 | Test 2 | Test 3 |
|---|---|---|---|
| New, NoTraf, Lime, Mix, CSS-1h | 3 | 1 | 1 |
| FM 134, NoTraf, Gr, Spray, MC-30 | 2 | 1 | 2 |
| FM 1841, NoTraf, Gr, Spray, MC-30 | 4 | 4 | 4 |
| SH 155, NoTraf, Gr, Spray, MC-30 | 2 | 4 | 1 |
| US 59, No Traf, Gr, Spray, MC-30 | 2 | 4 | 4 |
| SH 6, No Traf, Lime, Spray, MC-30 | 2 | 1 | 2 |
| SH 31, NoTraf, Lime, Spray, EC-30 | 2 | 1 | 1 |
| IH 45FR, No Traf, Stab, Mix, RC-250 | 1 | 1 | 1 |
| | | | |
| SH 6FR, Traf, Gr, Cover, AEP | 1 | 2 | 2 |
| FM 1235, Traf, Lime, Spray, AEP | 3 | 3 | 3 |
| IH 20FR, Traf, Lime, Cover, AEP | 3 | 2 | 3 |
| US 283, Traf, Like, Mix, AEP | 8 | 7 | 7 |
| FM 1235, Traf, Lime, Spray, MC-30 | 2 | 2 | 2 |
| Average | | 2.6 | |

## Cohesion

The application of the prime coat should improve the cohesive strength at the surface of the base and extend at least as deep as the prime coat penetration. To test this property, the project team designed and constructed a device (Figures 10 and 11) that would impart a horizontal torque to the surface, at different vertical compressive loads, and record the load required to cause shear failure (cohesive failure) at the surface. A surface with better cohesion should resist this shear better and result in higher values. The test is designed to be a measure of relative worth; a tool for ranking the performance, not an absolute engineering measurement. That is, at a site, the value for the primed area is compared to the value in the unprimed area. No work was done in this limited study to determine the mechanical properties of the test or determine engineering properties. This test was developed to determine whether the primed surface had properties that were different from the unprimed surface at that location. Comparisons between one test site and another are not valid due to surface texture and other differences. A procedure for the torque test was developed and is included in Appendix C.

The device slips into a 2-inch, square tube hitch receiver and uses the weight of the vehicle to provide the reaction force. A pressure regulator and a tank of nitrogen gas control and provide the vertical load (30, 40, and 65 pounds per square inch [psi]) while a torque multiplier and torque wrench are used to apply and measure the torque required to rotate the rubber-coated foot pad through an angle of 120 degrees. The torque multiplier (18:1) is needed to impart the necessary torque, especially at the higher contact pressure.

## Results of Cohesion Testing

At each site where it was possible to test, the cohesion test was performed three times at each of the three pressures, at two separate locations within the site, for a total of 36 torque tests per site. In some sites, fewer tests were performed due to construction or other problems (traffic control removed, contractor complaint, etc.). An average torque value for each pressure was calculated. A graph showing the results of all tests is shown in Figures 12, 13, and 14, and Table 6 has the average values for each site. Results from individual sites will be discussed later.

## Adhesion

The application of the prime coat should improve the adhesive strength between the surface of the base and the seal coat pavement by binding the fine, dusty particles and gluing the seal coat to the base. The prime coat should penetrate into the base, and this sticky asphaltic layer should adhere to the asphaltic seal coat binder.

To test adhesion, an adhesion tester (Dyna Proceq™ Pull-off Tester, Model Z16) was purchased (Figure 15). This model was chosen because another study (0-6271, "Full Depth Reclamation Performance Based Design, Construction, and Quality Control") was using this same device to test tack coats. Lessons learned and equipment purchased in one study were used in the other study. This device was used to test the adhesive strength of the bond between the seal coat and the underlying primed (and unprimed) base. A procedure for the pull-off test was developed and is included in Appendix C.

## Results of Adhesion Testing

After the seal coat had been applied at the site, and where it was possible to test, the pull-off test was performed at three locations that were primed and at three locations where there was no prime applied (leave out). The test measures the maximum force (in pounds) required to remove or dislodge the surface from the underlying base, which is then converted into psi. Table 7 contains the results.

**Figure 10. Cohesion Device.**


**Figure 11. Cohesion Device, Rear View.**

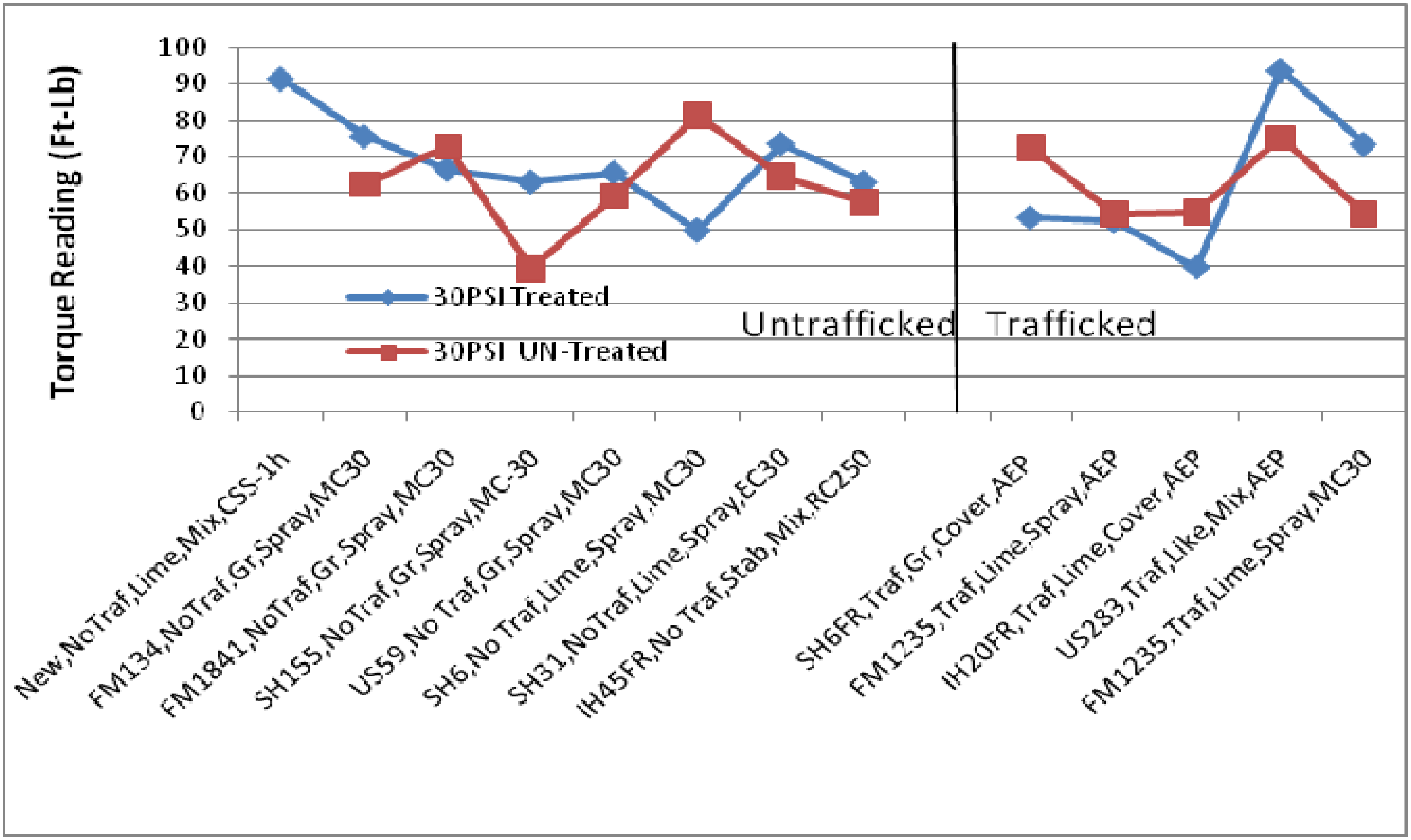


**Figure 12. Results of Torque Tests at 30 psi.**

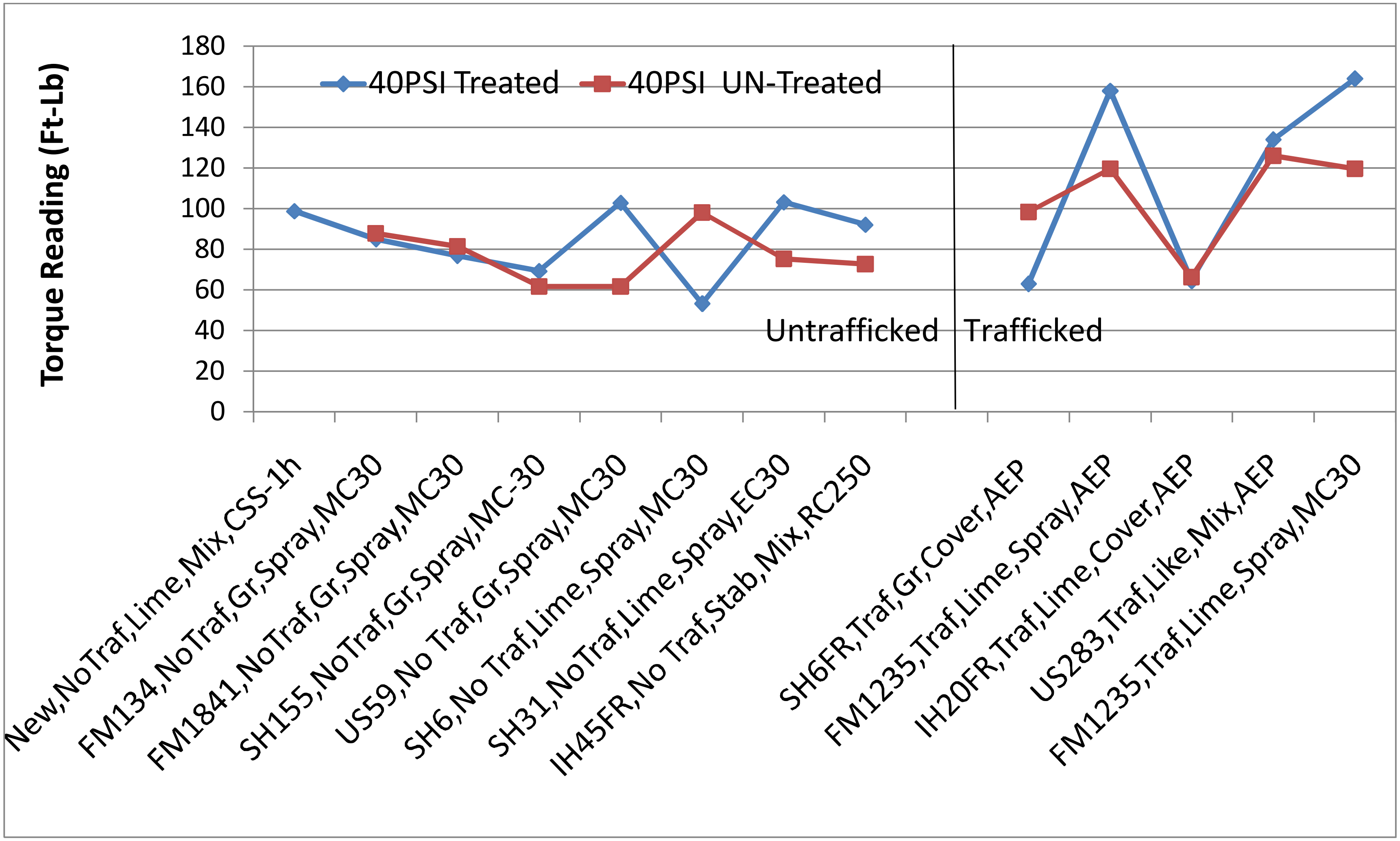


**Figure 13. Results of Torque Tests at 40 psi.**

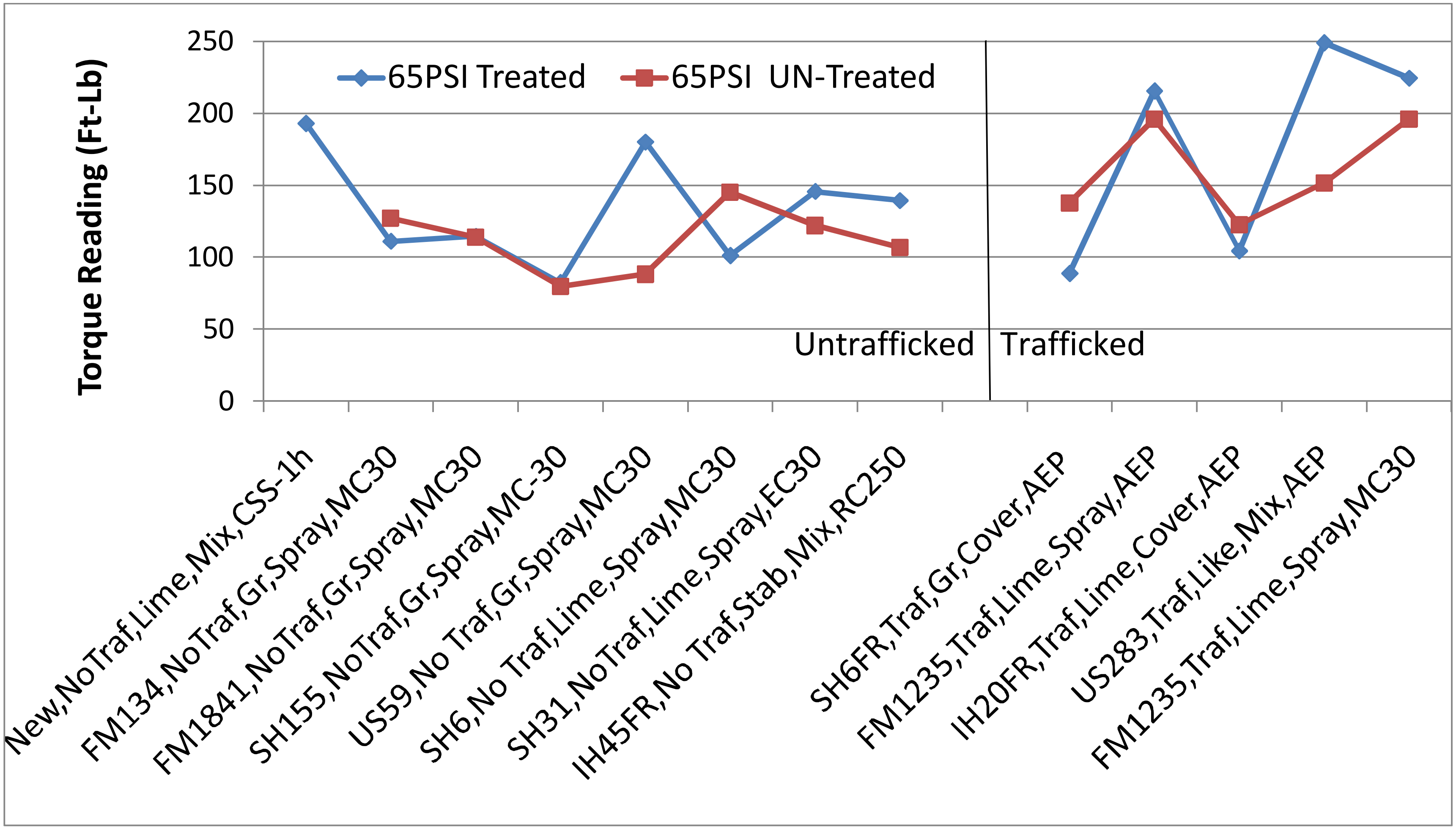


**Figure 14. Results of Torque Tests at 65 psi.**

## Table 6. Average Torque Reading.

| Treatment | 30 psi Treated | 30 psi Un-Treated | 40 psi Treated | 40 psi Un-Treated | 65 psi Treated | 65 psi Un-Treated |
|---|---|---|---|---|---|---|
| New, NoTraf, Lime, Mix, CSS-1h | 92 | | 99 | | 193 | |
| FM 134, NoTraf, Gr, Spray, MC-30 | 76 | 63 | 85 | 88 | 111 | 127 |
| FM 1841, NoTraf, Gr, Spray, MC-30 | 67 | 73 | 77 | 81 | 115 | 114 |
| SH 155, NoTraf, Gr, Spray, MC-30 | 63 | 40 | 69 | 62 | 82 | 80 |
| US 59, No Traf, Gr, Spray, MC-30 | 66 | 59 | 103 | 62 | 180 | 88 |
| SH 6, No Traf, Lime, Spray, MC-30 | 50 | 82 | 53 | 98 | 101 | 145 |
| SH 31, NoTraf, Lime, Spray, EC-30 | 74 | 65 | 103 | 75 | 146 | 122 |
| IH 45FR, No Traf, Stab, Mix, RC-250 | 63 | 58 | 92 | 73 | 139 | 107 |
| | | | | | | |
| SH 6FR, Traf, Gr, Cover, AEP | 53 | 73 | 63 | 98 | 89 | 138 |
| FM 1235, Traf, Lime, Spray, AEP | 53 | 55 | 158 | 120 | 216 | 196 |
| IH 20FR, Traf, Lime, Cover, AEP | 40 | 55 | 64 | 66 | 104 | 123 |
| US 283, Traf, Like, Mix, AEP | 94 | 75 | 134 | 126 | 249 | 152 |
| FM 1235, Traf, Lime, Spray, MC-30 | 74 | 55 | 164 | 120 | 225 | 196 |
| Average | 66.5 | 62.8 | 97.2 | 89.1 | 150.0 | 132.3 |

**Figure 15. Pull-off Tester and Application.**

**Table 7. Results of Adhesion Testing.**

| Treatment | Treat-1 | Treat-2 | Treat-3 | Untreat-1 | Untreat-2 | Untreat-3 |
|---|---|---|---|---|---|---|
| New, NoTraf, Lime, Mix, CSS-1h | 4 | 4 | 4 | Mix-in, no untreated area | | |
| FM 134, NoTraf, Gr, Spray, MC-30 | 0 | 2 | 0 | 0 | 0 | 0 |
| FM 1841, NoTraf, Gr, Spray, MC-30 | 0 | 0 | 2 | 2 | 2 | 4 |
| SH 155, NoTraf, Gr, Spray, MC-30 | 0 | 0 | 2 | 2 | 2 | 2 |
| US 59, No Traf, Gr, Spray, MC-30 | Overlaid | | | | | |
| SH 6, No Traf, Lime, Spray, MC-30 | Overlaid | | | | | |
| SH 31, NoTraf, Lime, Spray, EC-30 | Seal placed well after project over | | | | | |
| IH 45FR, No Traf, Stab, Mix, RC-250 | Overlaid | | | | | |
| | | | | | | |
| SH 6FR, Traf, Gr, Cover, AEP | 0 | 2 | 2 | 2 | 0 | 0 |
| FM 1235, Traf, Lime, Spray, AEP | 0 | 2 | | 2 | 2 | |
| IH 20FR, Traf, Lime, Cover, AEP | Contractor crew sealed "bare spots" | | | | | |
| US 283, Traf, Like, Mix, AEP | 2 | 4 | 2 | Mix-in, no untreated area | | |
| FM 1235, Traf, Lime, Spray, MC-30 | 5.4 | 5.7 | | 2 | 2 | |
| Average | 1.96 | | | 1.50 | | |

## Interpretation of Test Results

As can be seen in the preceding tables and graphs, there is some minor improvement in cohesion and adhesion, with the mix-in techniques performing best, but all of the results were much less than expected, especially for adhesion. This can be explained in one of several ways.

1. ***The prime coat improves adhesion and cohesion, but the tests do not measure the effect***. While it is possible that a lower contact pressure would better illustrate differences in the torque results, the range of values was chosen to span typical tire contact pressures. Results at lower pressures may exhibit greater differences, but the pavement will experience the contact pressures used in this study (due to car and truck tires), so that is the appropriate level for testing.
2. ***There is very little, if any, improvement in results***. The binding effect of the prime coat may lock up all of the fine materials, but unless the larger aggregate in the base are mobilized, these finer particles will contribute little to the strength. Likewise, if the prime does not penetrate due to the impermeability of the surface, larger aggregate will not be engaged.
3. ***Some treatments have an effect while others do not***. This will be discussed further when the individual results are discussed, but some treatments did perform better than others.
4. ***It takes much more time for the strength to develop***. It is certainly possible that the treatments need weeks or months to develop strength. This does not mean that they

are not cured, only that the asphalt may remain tender for an extended period of time and does not develop sufficient tensile strength rapidly enough to register with these tests, which were performed soon after construction. In addition, these treatments were placed in the summer while the temperature was high, which means the asphalt strength was low. The cohesion test had to be conducted fairly soon after construction because it had to be completed prior to the seal coat being placed.

The explanation that seems to make the most sense is Number 2. On almost every site, the surface was dusty, even after being swept (not all were swept, at least during the site visit by the researchers). The sites near Abilene showed the highest strength. Those sites were swept aggressively and had the most time between placement and testing (6 months). Figures 16-24 illustrate the excess fines at the surface and another case, which illustrates the relatively impermeable nature of that surface. Note in all pictures of the pull-off (adhesion) tests, the fine, dusty nature of the material at the surface. Researchers believe that this weak layer is responsible for the low test values.

The results of individual tests are presented in Appendix E, but Table 8 summarizes the results by prime coat type. The designations of average, lower, and better are based on the results shown in Tables 5, 6, and 7.

For penetration, EC 30 and RC 250 were considered lower because all tests were less than the average. For cohesion, the AEP sites were generally, but not exclusively, lower than the untreated results, while for adhesion, only the CSS Mix-in showed positive performance.

**Table 8. Summarized Results of Prime Coat Testing.**

| Prime | Penetration | Cohesion | Adhesion | Comments |
|---|---|---|---|---|
| CSS Mix-In | Average | Better | Better | Good results |
| MC-30 | Average | Average | Lower | Average |
| EC-30 | Lower | Better | - | Improved cohesion |
| RC-250 | Lower | Better | - | Improved cohesion |
| AEP | Average | Lower | Lower | Mix-in performed well |

**Figure 16. Bryan, SH 6, AEP. Good Looking Surface.**

**Figure 17. Atlanta, US 59, MC 30. Loose Fine Material.**

**Figure 18. Waco, US 84, Eco-Prime. Relatively Impermeable.**

**Figure 19. Atlanta, FM 134, MC 30. Dusty Skin at Surface.**


**Figure 20. Atlanta, FM 134, MC-30. Pull-off. Fines Only.**


**Figure 21. Atlanta, SH 155, MC-30. Bad Area.**

**Figure 22. Atlanta, SH 155, MC 30. Loose Material.**

**Figure 23. Abilene, FM 1235, AEP. Aggressive Brooming.**

**Figure 24. Abilene, FM 1235, AEP. Some Loose Material.**

# CHAPTER 5.
# CONCLUSIONS AND RECOMMENDATIONS

## CONCLUSIONS

Prime coats perform many functions in addition to providing adhesion and cohesion and are a valuable pavement construction technique that should be continued. As currently constructed, there seem to be too many fines and other impermeable materials at the surface to allow for good bonding of the surface seal coat to the top of the base. The suggested changes to Specification Item 310 were directed at the fines problem. Based on the results of testing, the best technique for promoting good bond is to mix the prime coat into the top inch or so of the base. If a spray technique is used, all treatments seemed to perform about the same in that all provided only little bonding. Ideally, this study would promote a much closer look into the base construction techniques that result in these excessive fines at the surface. The following presents a more complete review.

After merging the findings from a review of literature from worldwide sources, a survey of the vast majority of the districts in TxDOT, as well as laboratory and field experiments, the authors tender the following conclusions.

- There are four basic methods for priming a pavement base, and these methods are described in detail in the text of this report;
  - spray prime with or without blotting material,
  - inverted prime or covered crime,
  - mixed-in prime, and
  - worked-in (or cut-in) prime.
- The major purposes of prime coat are to:
  - protect the underlying base from wet weather and, in some cases, the action of traffic, by providing a temporary waterproofing layer;
  - reduce the drying rate of the compacted base;
  - promote bond of the base to the subsequent asphalt pavement layer;
  - seal the surface pores in the base to prevent absorption of the subsequent application of surface treatment binder (if the prime coat is omitted, an adjustment must be made to the rate of asphalt application of the surface treatment binder to allow for some absorption of the binder by the unprimed base); and
  - bind or stabilize the surface particles of the base.
- Generally, TxDOT is using the state-of-the-art technology with regard to prime coat products and application techniques. This is not to say that the state of the art in prime coat technology does not need to be improved or that all TxDOT districts are equally knowledgeable about prime coat technology.

- There are no conventional, widely accepted procedures to control the quality of prime coat application nor are there any American Association of State Highway Transportation Officials (AASHTO) standardized tests to evaluate or qualify an applied prime coat.
- Most researchers reported that a prime coat increased bond strength at the interface between a compacted base and an asphalt layer over that for similar layers with no prime coat. They further reported that this bond is important to ensure good pavement performance.
- If a surface pavement is not adhered to the base during construction, delamination does not occur with time; it is already present in the brand new pavement structure. Several researchers indicate such a condition will result in various forms of pavement distress (e.g., compaction difficulties during construction due to slippage, premature fatigue cracking, surface layer delamination, and rutting).
- Prime must adequately penetrate the compacted base to function properly. Penetration is normally achieved by cutback asphalts. Penetration can be guaranteed by mixing emulsified asphalt into the surface of the base.
- Medium cure cutbacks are normally used for prime. Cutback asphalts are solutions and, thus, penetrate reasonably well into a base. Ordinary emulsified asphalts are suspensions of asphalt in water, and as such, do not penetrate into a base.
- Ordinary emulsified asphalts generally require mechanical mixing into the uppermost stratum of a base to function properly. A final application of dilute emulsion onto the surface will assist adhesion to the subsequent pavement layer. When this priming process is considered in the total bid price for highway construction, the cost difference, when compared to spray-on cutback prime, is insignificant.
- Prime coats need to cure completely before application of the subsequent pavement layer. Curing time should be no longer than necessary. Excessive curing time can promote contamination of the surface with dust and debris or damage by inclement weather. Proper curing time of prime coats depends on a number of factors: type of prime material, application rate, dilution rate, application method (spray-on or mix-in), weather, permeability of the base surface, and other factors. Curing of cutbacks may require several days; whereas, emulsified products may require only a few hours.
- Excess prime that is not absorbed into the base after one day should be absorbed with blotter sand and then removed from the surface. Puddles should be swept using a broom to spread so that the excess primer can cure and not cause bleeding of the next bituminous layer.
- Some agencies delete a prime coat during cold weather, because it may be more harmful to pave over uncured prime than over unprimed base. Prime coats are occasionally deleted when no wet weather is anticipated and the compacted base can be covered within seven days. Without proof, some have stated that prime may be eliminated if the subsequent HMA layer is greater than 4 inches thick (Erdmenger, 1969; TAI, 1987; USACE, 2001; TAI, 2001).

- Laboratory shear tests and tensile (pull-off) test on primed interfaces often yield opposite results. This is probably because shear and tensile tests measure fundamentally different test values and material properties. Further, higher tack rates can lubricate the interface and, thereby, reduce shear strength between the two rough surfaces; whereas, higher tack rates provide more adhesion to increase tensile strength between the same two surfaces. It appears that both shear and tensile strength are important factors; but they are optimized at different tack rates. That is, an optimum amount of prime provides adequate tensile strength without being detrimental to shear strength.
- Cutback prime should not be applied to cement or fly ash stabilized base or subgrade at the typical rates to achieve a high penetration depth. At least one district is concerned that penetrating kerosene or naphtha from cutback prime will inhibit the cement hydration process and create a thin, weakened layer. In fact, one engineer stated that he had observed prime to penetrate a cement-treated base and yield a damaged layer that could literally be swept off the surface.
- A prime coat is not designed to bind loose dust left on the surface of a compacted and cured base. Prior to priming, all dust must be removed from the surface of the base.
- Engineers are concerned with the use of cutback asphalts as prime for at least three reasons:
  - Safety – flammability,
  - air quality – evaporation of VOCs, and
  - pavement performance – potential softening of the asphalt in an overlying pavement due to capturing of vapors from volatiles that may remain in the base layer.
- Mixed-in ordinary mixing-grade emulsified asphalt can eliminate these three concerns.
- Specialized emulsified asphalt primes cure relatively quickly but do not completely solve the problem of VOC release into the atmosphere. These products contain some solvent. It is this solvent that facilitates their penetration into the base.
- When there is a high probability of runoff entering a waterway or aquifer, cutback prime should be replaced with ordinary emulsified asphalt or omitted, if performance will not be negatively impacted.
- Slush rolling incorporates excess water (i.e., above optimum moisture content for compaction) during rolling to pump fines to the surface of the base, which allows the blade operator to attain a very smooth surface. The thin layer of fines at the surface, however, can suppress penetration of the prime coat and create a weak interface, which can ultimately result in a delamination of the surface treatment.
- Cross and Shrestha (2005) developed comprehensive "Guidelines for Using Prime and Tack Coats," which are available on the Internet at: http://ttap.colostate.edu/Library/FHWA/FHWA-TD-05-002.pdf.

## RECOMMENDATIONS

Guidelines for Selection, Application, and Evaluation of Prime Coats were developed as part of this study and are included in Appendix C of this report. These guidelines contain comprehensive recommendations for improving the quality of prime coats. The guide addresses all elements of base priming including:

- base surface preparation,
- prime coat design,
- alternative priming methods,
- materials selection criteria,
- proper application methods and quantities,
- curing procedures,
- construction control and quality assurance, and
- safety precautions.

The authors recommend that this guideline be published as a separate document (in the form of a handbook) and made available for use by contractors and TxDOT personnel responsible for specifying, designing, applying, and/or quality control/assurance of prime coats.

A statewide workshop on prime coats should be conducted to ensure that all TxDOT districts are well informed on the state-of-the-art technology available for prime coats, including discussions on the appearance of the final surface prior to priming and a review of the requirements for brooming. A less expensive way of disseminating the information would be for TxDOT to conduct regional workshops. A far less expensive and more comprehensive way of distributing the information to the TxDOT district personnel is for Project 0-5635 to produce an instructional video and send it to the districts and post it to the TxDOT website. Appendix D includes a PowerPoint® presentation on the guidelines, including video clips compiled during placement of a prime coat.

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# APPENDIX A.
# QUESTIONNAIRE USED IN CONDUCTING PHONE SURVEY

## Base/Prime Construction Coat Questionnaire

### TxDOT Project 0-5635

Name ____________________ Title ____________________ District ____________

*Purpose*: Capture knowledge, prepare list of techniques, lessons learned

For this research project, a prime coat is defined as the application of a binder material onto the surface, or mixed into the uppermost portion of a compacted granular base, as a preliminary treatment before the subsequent application of a bituminous surface treatment.

1. Determine the various types of materials used for base construction by this district (PUT ON FORM) for:
   a. Unstabilized – aggregates (limestone, caliche, iron ore, crushed, etc.)
   b. Stabilized – e.g., cement, lime, RAP, etc.
2. Discuss different methods of compacting base layers, particularly, methods for finishing the surface (PUT ON FORM, USING COMBINATIONS).
   a. Sheepsfoot roller, finish roller
   b. Slush rolling
   c. Application of excess water to achieve a smooth surface
   d. Blade and roll
   e. Trimming or blading
   f. Is dusting of the base during construction an issue? How do you address?
3. Discuss different types of materials used for prime coats along with their advantages and disadvantages (perceived or actual) (PUT ON FORM, USING COMBINATIONS). Specifically, which kinds of each and are there availability issues and air quality limitations in your regions?
   a. Cutbacks
   b. Emulsions
   c. Specialty prime products (e.g., AEP, EAP, PCE)
   d. Non-asphalt materials

4. Discuss issues related to penetration of emulsified prime materials into base surface and how they are addressed.

5. Discuss alternative priming methods used by the districts represented.

   a. Spray on compacted surface with distributor or water truck

   b. Mix emulsified asphalt into surface of base – how mixed, how deep

   c. Did you know that guidelines and a video exist for this?

   d. Others

6. Discuss TxDOT requirements for acceptable application of prime coat and how they are measured.

   a. Apply while base is at optimum moisture content

   b. Cure stabilized base before priming – e.g., dry curing of base

   c. Smoothness of base surface

   d. Uniformity of application

   e. Color of surface

   f. Stickiness

7. TxDOTs definition of a good or acceptable prime coat and how measured. How does TxDOT know when the contractor is doing a GOOD job? How do we know when they are doing a BAD job?

   a. Depth of prime penetration

   b. Permeability of primed surface

   c. Stickiness of primed surface after curing; immediately prior to placing surface

Do you require curing of prime coat before application of subsequent pavement layer?

a. Cutback

b. Emulsion

8. Do you allow traffic on a primed base?

   a. Heavy loads on base without protection of pavement can crack the base in the wheel paths, and these cracks can reflect through the subsequent pavement.

   b. Traffic, particularly during wet weather, can abrade the primed layer

9. Do you allow blotter sand to be placed on primed surface?

   a. Should not be done unless absolutely necessary; reduces adhesion between base and subsequent pavement.

   b. Can create a slip plane even worse than slush rolling

   c. Should NOT use rounded sands (crushed materials, etc.)

10. Have you experienced slippage of a pavement at the primed base interface? (This question does not address slippage between tacked HMA layers.)

11. Which combinations of materials, finish, construction, and prime methods work best? Which are not working?

12. Any current projects (2008, 2009) where TTI could establish a test section? Need to have some areas left unprimed. Could be a shoulder if surface will be same design and construct.

    a. With whom do we talk

    b. Which methods are/will be used

Fill out during or immediately after the interview.
Circle specific base type.
Draw a line to the finish method or methods for that specific base type.
Draw a line to the construction method for that specific base type and finish method.
Draw a line to the prime type for that specific base type, finish method, and construction.

**UNTRAFFICKED – Material/Construction/Combinations**

| Base | Finish | Construction | Prime |
|---|---|---|---|
| Limestone | Slush Roll | Spray Prime (w/wo Blotter) | MC-30 |
| Caliche | Blade and Roll | Worked in/Cut in | MS-2 |
| Iron Ore Gravel | Trimming | Covered Prime | AEP |
| Gravel | Base Lay Down Machine | Mixed-in Prime | EAP&T |
| Fly-ash Stabilized | | | PCE |
| Cement Treated | | | HFRS2 |
| Asphalt Stabilized | | | |
| Granite | | | |
| Sandstone | | | |
| Other | Other | Other | Other |

**TRAFFICKED –Material/Construction/Combinations**

| Base | Finish | Construction | Prime |
|---|---|---|---|
| Limestone | Slush Roll | Spray Prime (w/wo Blotter) | MC-30 |
| Caliche | Blade and Roll | Worked in/Cut in | MS-2 |
| Iron Ore Gravel | Trimming | Covered Prime | AEP |
| Gravel | Base Lay Down Machine | Mixed-in Prime | EAP&T |
| Fly-ash Stabilized | | | PCE |
| Cement Treated | | | HFRS2 |
| Asphalt Stabilized | | | |
| Granite | | | |
| Sandstone | | | |
| Other | Other | Other | Other |

# APPENDIX B.

# PRIMING USING CONVENTIONAL EMULSIFIED ASPHALT

**Method A. Mix and Compact**

When using ordinary mixing grade emulsified asphalt for prime, it is usually beneficial to mechanically mix the prime with the uppermost 1 to 2 inches of base to achieve a desirable penetration depth. The more effective of two alternative methods for applying emulsified asphalt prime coats is described as follows:

1. Prepare and compact the granular base, and blade to grade minus the depth of material to be treated with prime. One should not create a smooth surface at this point, which could result in a weak interface between this lift and the next.
2. Windrow the material to be primed onto the compacted base. The quantity of material should be that required to produce 1 to 2 inches of compacted base.
3. Spray the windrow with the predetermined quality of dilute emulsified asphalt, and blade mix.
4. Add more dilute emulsion until the mixture reaches optimum fluids content for compaction, and blade mix.
5. As a general guide, the total undiluted asphalt emulsion in a treated 1.5-inch compacted layer of base should be approximately 0.30 gal/yd$^2$. About 0.05 gal/yd$^2$ of that amount should be held back and applied to the surface of the base as it is being finished. The optimum emulsion application rate will depend on the gradation and absorbency of the aggregate.
6. Blade mix until thoroughly blended.
7. Spread treated material, and compact to grade.
8. It may be necessary to periodically spray (skeet) the compacted surface with a light coat of diluted emulsion to minimize damage by traffic and/or just prior to placement of the next placement layer to provide a clean, tacky surface.

This method minimizes effort and, thus, maximizes efficiency and should be used for priming whenever emulsified asphalt is required. A method similar to this has been used in the Odessa District.

**Method B. Compact-Scarify-Mix-Compact**

Another method similar to this requires scarification of the base after it has been compacted to grade, followed by incorporation of the emulsified asphalt prime. This method has been used occasionally in the Austin District. It is described in the following sequence.

1. Complete compaction of the flexible base to grade, set blue tops, and ensure that proper density has been achieved.
2. Before the base dries and hardens, scarify or blade off the top 1 1/2 inches, more or less. Normally, the blade of a motor grader is used for this step.
3. Windrow the loose material, and apply a predetermined quantity of dilute asphalt emulsion, and blade mix.

4. Add more diluted emulsion until the mixture reaches optimum fluids content for compaction, and blade mix.
5. As a general guide, the total undiluted asphalt emulsion in a treated 1.5-inch compacted layer of base should be approximately 0.30 gal/yd$^2$. About 0.05 gal/yd$^2$ of that amount should be held back and applied to the surface of the base as it is being finished. The optimum emulsion application rate will depend on the gradation and absorbency of the base aggregate.
6. Blade mix until thoroughly blended.
7. Spread the blended mixture, and compact to grade while quite wet. Use a vibratory steel wheel roller to push the larger stones down and pump fines and some emulsion to the surface.
8. Once the roadway has dried somewhat (usually 1 - 2 days) so that it is (1) hard enough that no further compaction can occur, and (2) soft enough that it can be shaved using a blade without excessive damage to the underlying material, it is ready to be finished.
9. Apply a light shot of less concentrated (than before) solution of emulsion in water. Then use the blade to cut the surface to a depth approximately as deep as any depressions that may exist. This will create a rather small, dry roll of fines. This roll is never sprayed.
10. Spray the roadway with another light application of dilute emulsion, and immediately drift the dry roll across the surface depositing the fines in any depressions. Repeat this operation until the desired surface texture is obtained.
11. Then skeet the roadway periodically with dilute emulsion to obtain the proper amount of oil to form a “membrane” on the surface to promote bonding to the subsequent pavement layer.

If the unpaved base must be exposed or is required to carry traffic for an extended period, the base can be periodically skeeted with diluted emulsion to keep the surface tough and water resistant.

Note that blading off the top portion of the fully compacted base and subsequent reworking and compacting breaks up many of the larger aggregate. This procedure creates a weakened layer right where strength is needed most—at the top of the base layer. Researchers recommend, therefore, that the emulsion be added during the building of the base. That is, use Method A, whenever possible.

Benefits of the mix-in priming method over the spray-on process include:

- can typically carry traffic longer (several weeks),
- provides better protection against rainfall,
- is less dependent on weather conditions,
- less time is required for curing (before placement of next lift), and
- adds strength to the pavement structure.

Although the above mixing-in procedures appear to be comparatively expensive processes, requiring of this method of priming has historically had negligible effects on the total bid price for highway construction. Depending on the application, construction sequence, and timing, it may be more cost effective to mix emulsion into the upper stratum of the base than to just spray prime the surface.

**Method C. Inverted or Covered Prime**

A third method of using conventional emulsified asphalt for prime involves a process similar to application of a surface treatment. It is sometimes referred to as inverted prime or covered prime. Undiluted emulsified asphalt is sprayed onto the compacted base using a distributor truck; then, uniformly graded stone is immediately spread to provide a driving surface for temporary traffic and construction vehicles.

Typically, undiluted HFRS-2 emulsion is applied at a rate of 0.30 to 0.40 gal/yd$^2$, depending on the time of year (less in the spring if traffic must be carried during hot weather to avoid flushing). Grade 5 stone is spread at a rate of about 1 yd$^3$/100 yd$^2$. After the emulsion breaks, about 1 hour, a pneumatic roller is used to seat the stone. This surface can be opened to traffic in about 4 hours. It can carry passenger vehicle traffic for a few months, but heavy truck traffic may damage the surface.

The engineer should take into consideration that the emulsified asphalt will not likely penetrate the compacted base, particularly a slush-rolled, dense-graded limestone. This could create a weakened interface subject to slippage and/or delamination.

Using emulsified asphalt for this process instead of cutback asphalt reduces the probability of flushing of the final surface treatment during hot weather, because there is no evaporation of cutter stock up through the overlying pavement surface.

# APPENDIX C.
# GUIDELINES FOR SELECTION, APPLICATION, AND EVALUATION OF PRIME COATS

# INTRODUCTION

This guideline has been prepared for contractor and/or TxDOT personnel who are responsible for designing or constructing prime coats and for inspectors who are responsible for ensuring that applied prime coats meet the requirements set forth by TxDOT.

Engineers have often speculated whether prime coats are a cost-effective element of pavement construction, because some pavements constructed without a prime coat have provided satisfactory performance (Cross et al., 2005). However, there have also been failures due to the omission of the prime coat. Undoubtedly, the application of a prime coat reduces the risk of premature failure resulting from imperfections that may occur in the base, which are very costly to repair (NITRR, 1986).

This guideline addresses the selection, application, and evaluation of prime coats that are applied onto compacted base layers prior to construction of the next pavement layer. The main purposes of this guideline are to assist the Texas Department of Transportation (TxDOT) with:

- training and/or providing vital information to those responsible for priming base layers,
- selection of alternative priming products and processes that have demonstrated acceptable performance,
- optimized preparation of the base layer to receive a prime coat,
- proper application of the prime on the prepared base, and
- evaluation of the applied prime before construction of the subsequent pavement layer.

These recommendations are based on an extensive review of pertinent literature, findings in TxDOT Research Project 0-5635 “Develop Guidelines for Effective Prime Coats,” and the experience of the research team.

### Definition of a Prime Coat

The priming process is briefly described in Item 310 of the TxDOT Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges.

A prime coat is defined as the application of a binder material onto the surface, or mixed into the uppermost portion of a compacted granular base, as a preliminary treatment before the application of a subsequent asphalt paving layer (e.g., surface treatment, asphalt stabilized base, or asphalt concrete pavement). The bituminous surface treatment may be the final pavement surface, or it may be a bituminous underseal placed before construction of a hot mix asphalt (HMA) concrete pavement surface. It is because of the availability of new non-asphalt prime materials that primes are not defined herein as bituminous materials.

**Note:** For clarity, a *tack coat* is defined as the material applied to a pavement surface to promote adhesion between the existing pavement and a new asphalt pavement layer (overlay). A tack coat may be applied to asphalt concrete, Portland cement concrete, or a primed surface. Emulsified asphalts are, by far, the most used product for tack coats, and they are normally applied immediately before placing a hot mix asphalt layer.

### Functions of a Prime Coat

The main functions of a prime are to penetrate the base layer on which it is applied while leaving a small residual amount of binder on the surface to:

- penetrate and seal the surface pores in the base, thus reducing the migration of moisture and absorption of the first application of surface treatment binder;
- protect the base from rainfall while allowing some migration of water in the vapor phase out of the base;
- bind the finer particles on the uppermost zone of the base to accommodate light traffic, including construction vehicles, for a short period until the new surfacing can be placed; and
- promote adhesion between a granular base and a subsequently applied bituminous surface by precoating the surface of the base and by penetrating the voids near the surface.

**Note:** Typical prime coats are not suitable to be applied to cement-stabilized materials as curing membranes to prevent the loss of moisture and carbonation from taking place in the layer. Prime, cure, erosion control (PCE), normal emulsified asphalt, or other products are normally used as curing membranes.

## TYPES OF PRIME MATERIAL

Types and grades of typical prime coat materials are described in Item 300 of the TxDOT Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges.

### Cutback Asphalts

The most widely used cutback asphalt prime is MC-30. RC-250 is used by some districts to produce a covered prime or inverted prime, which is similar to a surface treatment using Grade 5 stone.

MC-30 has been reported to occasionally resist penetration in dense crushed stone bases and natural gravel bases with higher clay contents. Penetration becomes particularly difficult when slush rolling is employed. MC-30 can require up to one week or longer to dry or cure under certain conditions. In these cases, the prime application rate should be lowered.

### Emulsified Asphalts

Although AEP is, by definition, an emulsion, the asphalt is mixed with a significant amount of cutter stock before it is emulsified. PCE is primarily a curing seal for cement-treated bases and is not considered to be a traditional prime coat. EAP&T is an emulsified asphalt that is available in Texas, but it is seldom used as a prime coat.

When using ordinary mixing grade emulsified asphalt (e.g., SS-1) for prime, it is most beneficial to dilute the emulsion with water and mechanically mix the prime with the uppermost 1 to 2 inches of base to achieve a desirable penetration depth. Bonding strength is enhanced by applying a light shot of diluted emulsion onto the finished surface.

### Proprietary Products

If primes that do not comply with TxDOT specifications are to be used, the supplier should provide specifications against which his product can be tested for compliance. These products must be approved in advance by the Engineer.

## REQUIREMENTS OF A PRIME COAT

Low-viscosity cutback asphalt (e.g., MC-30 and RC-250), asphalt emulsion prime (e.g., AEP), or inverted bitumen emulsion (rarely used) generally meet the requirements of a prime. All of these contain volatile hydrocarbon solvents and should be considered as cutbacks.

Ordinary oil-in-water type asphalt emulsions, such as SS-1 and spray grades, are not suitable as primes, as they do not penetrate dense bases. Figure C-1 illustrates that regular emulsified asphalt does not normally penetrate the surface of a compacted base. Asphalt droplets in regular emulsion coalesce on the surface to form a skin after the water has been absorbed or evaporated. This sticky skin is usually picked up by vehicle tires. Penetration of regular emulsified asphalt can be achieved by mechanically mixing the emulsion into the 1 or 2 inches of the base just prior to compaction.

After a prime has been sprayed, it penetrates into the base layer and starts to cure through the loss of volatiles by evaporation and absorption. The prime should be formulated in such a way that, once it is sprayed, it dries within a reasonable period to allow for the construction of the next layer to transpire without pick-up by the tires of construction vehicles. It should not be necessary to heat the prime material in order to reduce the viscosity and, thus, achieve adequate penetration. In other words, all primes should be able to penetrate at ambient temperature (SABITA, 2006).

Figure C-2 shows significantly more penetration by a cutback asphalt emulsion prime coat. Cutback asphalt is a pure solution, and as the solvent penetrates the base, it carries asphalt with it. AEP provides penetration because it contains solvent. In an inverted emulsion, the asphalt is the continuous phase and water is the discontinuous phase. Inverted emulsions offer relatively low water contents, but they also contain cutter stock and should be considered cutbacks. The greatest penetration is normally obtained by MC-30 because it is the lowest viscosity cutback available.

The amount of penetration depends on a number of factors including the prime coating method, prime coat binder, base material, base finishing technique, and the permeability of the base surface. Typical penetration depth of a sprayed cutback prime might range from 1/8 inch to 3/8 inch. Occasionally, penetration can exceed 1/2 inch.

If the prime is omitted, construction of the surface treatment or seal coat should proceed without delay, and the first spray application should be increased by + 0.15 l/m² to allow for some absorption of the binder into the base.

**Figure C-1. No Penetration with Normal Emulsified Asphalt (a suspension of asphalt in water) (After SABITA, 2006).**

**Figure C-2. Penetrating Effect of Inverted Asphalt Emulsion Prime (a suspension of water in asphalt) (After SABITA, 2006).**

## PRIME COAT APPLICATION METHODS

Senadheera and Vignarajah (2007) described four types of prime coat. These include:

1. Spray Prime with or without Blotting Material – This is typically MC-30 or AEP cutback sprayed onto a compacted base using an asphalt distributor at an application rate of about 0.20 gallons per square yard depending on conditions. If the project is constructed under traffic, a blotting material such as sand or small crushed stone is often applied to eliminate splash onto vehicles and then removed.
2. Inverted Prime or Covered Prime – This is similar to a one-course surface treatment where 0.17 to 0.20 gal/yd$^2$ of RC-250 is applied onto the finished base and then covered by spreading Grade 5 stone. This technique is particularly useful when the primed surface must accommodate significant traffic or must carry traffic for a prolonged period (e.g., through the winter months).
3. Mixed-In Prime – This has been achieved using the two methods described below (Mantilla and Button, 1994).

    a. During preparation of the last lift of the base (2 to 6 inches), mix in diluted emulsified asphalt instead of mixing water. After compaction to the required density, skeet the surface with diluted emulsion to enrich the surface with asphalt, thus providing a reasonably good bond with the next pavement layer.
    b. After the base density is achieved and the base is completed up to the blue-tops, scarify the top 1-3 inches and mix with diluted emulsified asphalt, and then recompact to the specified density. Skeet the surface with diluted emulsion to enrich the surface with asphalt, thus providing a reasonably good bond with the next pavement layer.

    Method a. is preferred because Method b. is more labor intensive and will break down the larger stones during the scarification recompaction processes. Method b. is usually utilized to treat a relatively thin layer.

4. Worked-in (or cut-in) Prime – Diluted emulsified asphalt (e.g., SS-1, CSS-1h, or MS-2) is sprayed on the finished base, which is then covered with a thin coating of base material fines, working the windrow from side to side using a motor grader. This process is usually repeated 2-3 times to obtain an asphalt-sand layer that is approximately 1/8-inch thick with a residual emulsion application rate of about 0.20 gallons per square yard.

## PRIME COAT DESIGN

Basically, prime coat design involves selection of an appropriate priming process, binder type, and application rate. It is a simplistic but important process that should embrace several factors, including:

- location of the construction project (e.g., non-attainment area);
- material to be primed;
- base construction process (e.g., slush roll or blade and roll);

- thickness and composition of next pavement layer to be applied;
- experience, expertise, and equipment of available contractors;
- probability of inclement weather while the prime coat is exposed; and
- projected need to carry significant traffic or carry traffic for a prolonged period.

Some agencies delete a prime coat during cold weather because it may be more harmful to pave over uncured prime than over unprimed base. Prime coats are occasionally deleted when no wet weather is anticipated and the compacted base can be covered within seven days. Without proof, some have stated that prime may be eliminated if the subsequent HMA layer is greater than 4 inches thick.

Cutback asphalt primes should not be used on bituminous stabilized materials including full-depth reclamation projects or cold in-place recycled projects (ARRA, 2001). Solvents in typical prime materials (e.g., MC-30 and AEP) can soften the asphalt stabilized base, thereby weakening the pavement structure. These types of bases should be tacked using emulsified asphalt.

There is usually no need to prime a prepared subgrade.

**PRIME SELECTION CRITERIA**

The main factors that influence the selection of the optimum priming process are the type and the absorptive properties of the base as well as the environmental and functional conditions of the base. Table C-1 provides guidance in selecting the optimum priming process for certain situations.

Key for Table 1:
1 = primary recommendation,
2 = secondary recommendation, and
— = not suitable.

**Table C-1. Guide for Determining Optimum Priming Process.**

| Type of Base | Priming Process | | | | |
|---|---|---|---|---|---|
| | MC-30 | AEP | Covered Prime [1] | Mixed-In Emulsion | PCE |
| Crushed Stone | 1 | 1 | 2 | 1 | -- |
| Natural Gravel | 1 | 1 | 2 | 1 | -- |
| Caliche | 1 | 1 | 1 | 1 | -- |
| Cement or Lime Stabilized | -- | -- | -- | -- | 1 |
| Slush Rolled Limestone | 1 | 2 | -- | -- | -- |
| Asphalt Stabilized [2] | -- | -- | -- | -- | -- |
| Functional and Environmental Conditions | | | | | |
| Must Carry Limited Traffic | -- | -- | 1 | 2 | -- |
| High Humidity Air | 1 | 1 | 2 | 1 | -- |
| Damp Surface | -- | 2 | -- | 1 | -- |
| Surface Temperature > 70°F | 1 | 1 | 1 | 1 | -- |
| Surface Temperature < 70°F | 2 | 2 | 2 | 1 | -- |
| Properties of Base Surface | | | | | |
| Low Porosity | 2 | 2 | -- | 1 | -- |
| High Porosity | 1 | 1 | 2 | 1 | -- |
| Low Moisture Content | 1 | 1 | 2 | 1 | -- |
| High Moisture Content | -- | 2 | -- | 1 | -- |
| Open Graded [3] | 1 | 1 | -- | -- | -- |

[1] RC-250 + Grade 5 stone.
[2] Apply a tack coat using regular emulsified asphalt (e.g., SS-1).
[3] Consider using two or more light applications, allowing surface to dry after each.

## CONSTRUCTION CONSIDERATIONS

### Preparation of the Base

Priming should be performed only after the base has dried sufficiently (typically 2 percentage points below optimum for compaction) to preclude the entrapment of excess moisture, which may lead to an undesirable buildup of moisture underneath the newly placed surfacing and possibly lead to premature distress. The base should be cleaned of all loose material, ideally, until the larger aggregate particles are exposed.

The surface of the base should be moistened by a light sprinkling of water prior to priming to reduce the surface tension and to avoid the formation of "perch eyes" or "freckling" on the primed surface (See Figure C-3). Care should be taken not to apply excess water and, thus, saturate the layer, as voids filled with water cannot be filled with prime.

**Figure C-3. An Example of "Freckling" or "Perch Eyes" of Prime Coat on a Dry Base Surface (after Senadheera and Vignarajah, 2007).**

Certain "optimum" conditions that a base should have before a sprayed-on prime coat is applied are (Senadheera and Vignarajah, 2007; Vignarajah and Senadheera, 2007):

- A Reasonably Smooth Surface – However, it should not be overly smooth as is often achieved using slush rolling, because this can produce a low-porosity surface and inhibit penetration of prime, thus yielding a weakened primed interface with a poor bond to the next pavement layer.
- Reasonable Porosity (permeability) – This is best achieved by simply blading and rolling the base at or slightly above optimum moisture content. The required pore size is governed by the prime coat material and the wettability of the compacted base.
- No Loose Dust on the Surface – Brooming must be performed carefully to avoid disturbing the larger aggregate particles at the surface of the compacted base. If the base structure is too fragile for aggressive brooming (as with some sandstones that lack fine binder material), compressed air can be used to cleanse the surface.
- Adequate Structural Strength – The base should be adequately but only partially cured such that strength is sufficient to support construction traffic and occasional highway traffic. A treated/stabilized base should be completely cured before application of cutback asphalt that may inhibit the stabilizer curing process. It should be allowed to dry to 2 percentage points below optimum to enhance penetration of the prime material, in accordance with Item 247.4.E.

**Application Rates**

The selected application rate should be such that the base will absorb the applied prime and leave behind a thin, quick-drying film on the surface. The application rate will vary according to the type of base and its absorptive properties, and these rates should be adjusted to take into consideration the net residual binder of each product.

The shot rate or application rate to achieve the specified residual asphalt content can be determined using the following formula: (USACE, 2001)

$$AR = RAR/RAC$$

where,

AR = application or shot rate of undiluted prime,
RAR = specified residual application rate, and
RAC = residual asphalt content of prime.

Typical application rates are 0.20 to 0.50 gal/yd$^2$ for sprayed-on cutbacks and 0.1 to 0.3 gal/yd$^2$/inch of depth for mixed-in emulsions. Appropriate 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. Excess prime should be removed with blotter sand.

As a rule of thumb, a typical application rate should render a net *residual* binder of about 0.15 gal/yd$^2$ to 0.20 gal/yd$^2$ for MC-30 or AEP. The following adjustments to the net residual binder are recommended: (SABITA, 2006)

- If the base is coarse or open, increase the application rate by 15 percent.
- If the base is fine and dense, decrease the application rate by 15 percent.

When using a covered prime to accommodate relatively high traffic or high-speed traffic or for trafficking through the winter months, increase the application rate of the RC-250 from about 0.17 gal/yd$^2$ to 0.20 gal/yd$^2$.

When using sprayed prime, to ensure that the correct application rate is selected, researchers recommend that a simple paint test be conducted on the prepared base (SABITA, 2006). This is best achieved by marking out areas of one square yard and applying the candidate prime and spreading with a brush at different application rates to determine the ideal application rate.

For mixed-in emulsion, the total undiluted asphalt emulsion per inch of compacted base should be approximately 0.20 gal/yd$^2$. About 0.05 gal/yd$^2$ should be applied to the surface of the base as it is being finished. The optimum emulsion application rate will depend on the gradation and absorbency of the compacted base.

**Spraying of Prime**
Prime should not be sprayed if the expected minimum air temperature for the ensuing seven days is below 50°F, or when rain is imminent. Spraying should only be executed when the air temperature is 60°F and above, or above 50°F and rising, in accordance with Item 310.4.A. The actual spray rate should not deviate by more than 0.013 gal/yd$^2$ from the target rate.

Proper asphalt distributor operation procedures will prevent streaking, attain proper application rates, and achieve uniform coverage. 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, as shown in Figure C-4.

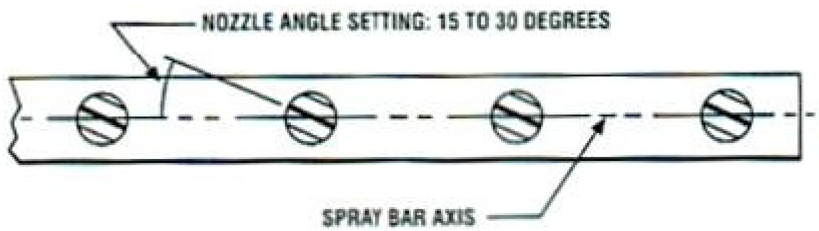



**Figure C-4. Schematic Showing Proper Setting of Spray-Bar Nozzles (TAI, 1987).**

Nozzles are normally set at 30 degrees. Height of the spray bar should be set to allow for an exact single, double, or triple overlap. A double overlap is recommended for most prime applications. For uniform coverage, proper spray bar height must be maintained during application. This requires that the spray bar height be adjustable to correct for the rising of the truck as the load decreases. Figure C-5 illustrates the effect of incorrect spray bar height as well as the proper spray bar heights for double and triple coverage.

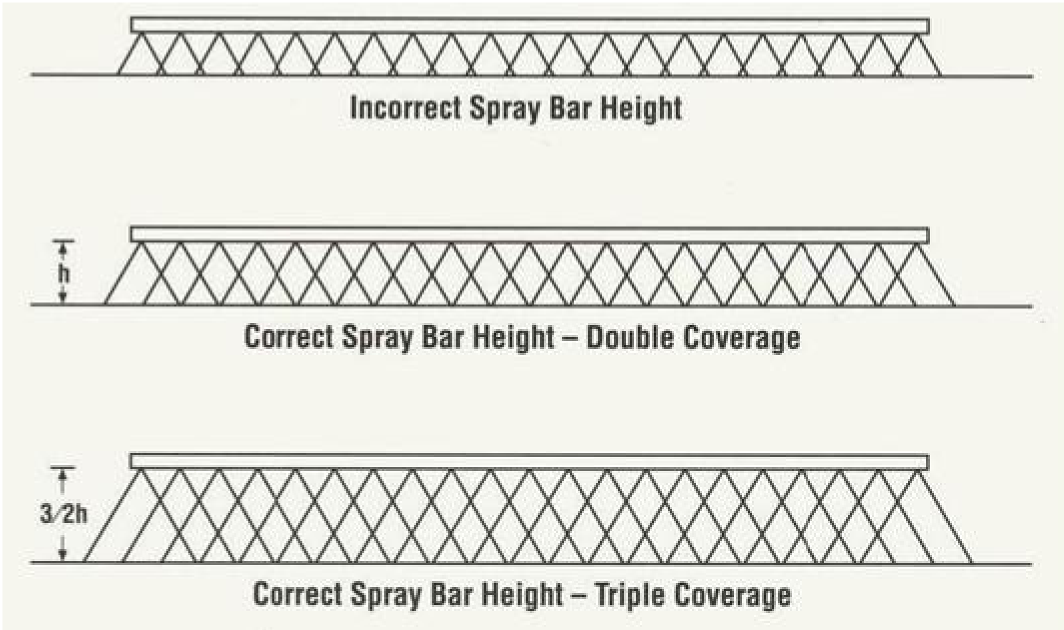



**Figure C-5. Schematic Showing Spray Bar Height for Ideal Coverage.**

**Spraying Temperatures**

The proper viscosity of liquid primes for optimal application is achieved by heating cutbacks and occasionally emulsions or by diluting emulsions with water. Table C-2 provides typical recommended spray temperatures for various primes.

**Table C-2. Recommended Spray Temperature Ranges for Prime Coats.**

| Type and Grade of Prime | Spray Temperature Range, °F |
|---|---|
| MC-30 | 85 - 150 |
| RC -250 | 125 - 180 |
| MC-250 | 125 - 210 |
| AEP | 120 - 180 |
| EAP&T | 60 - 100 |
| SS-1, SS-1H, CSS-1, CSS-1H | 70 - 160 |
| MS-1, MS-2, MS-2H, CMS-2, CMS-2H | 100 - 160 |
| PCE | 60 - 160 |

**Safety Precautions**
Use caution when handling cutback prime. RC-250 contains naphtha and/or gasoline; the flash point may be as low as 80°F. MC-30 contains kerosene and/or diesel as the cutter; the flash point may be as low as 100°F.

Use particular caution when heating cutback prime prior to application, as the spray temperature could be above the flash point. Prime is heated only to ensure that it flares properly when discharged through the nozzles on the spray bar of the distributor. Heating of prime should only be performed as soon as is practicable before spraying to minimize loss of the volatile fractions. Cutback and emulsified primes are pumpable at ambient temperature and, thus, do not need to be heated during loading, transport, off-loading, or storage.

**Curing of Prime Coat**
A prime coat should be allowed to dry before opening to traffic or proceeding with construction of the next layer. Curing time should, however, be no longer than necessary to permit evaporation of most of the carrier (i.e., cutter stock or water). Excessive curing time can promote contamination of the surface with dust and debris or damage by inclement weather. Proper curing time of prime coats depends on a number of factors: type of prime material, application rate, dilution rate, application method (spray-on or mix-in), temperature, humidity, wind velocity, permeability of the base surface, and other factors.

Curing of cutbacks may require several days; whereas, emulsified products may require only 24 hours or less. Recall that AEP, although an emulsion, contains solvent and should be given ample time to cure. Insufficient curing can allow significant volatiles to be absorbed into a subsequently constructed asphalt pavement layer, thereby softening it and reducing its effectiveness.

Excessive prime (e.g., puddles) on the surface should be blinded with crusher dust *and removed*. Primer cannot bind loose aggregate/dust on the surface of a base. Leaving this blinding material may create a weak shear plane beneath the subsequent pavement layer.

**Bases That Resist Penetration of the Prime**
Slush rolling is one of the chief causes of poor prime penetration. This process pumps fines to the surface of the base and, admittedly, does produce a very smooth base surface. However, the concentration of very fine aggregate at the surface creates a thin layer with very low permeability, which inhibits penetration of the prime and may produce a weakened interlayer.

A related issue is a base material that contains a significant amount of very fine material. The fine material may be natural aggregate or stabilizer (e.g., lime, cement, or fly ash) or a combination of the two. Experience in Texas has shown that base materials containing more than 5 percent minus No. 325 particle sizes can resist penetration and produce poor adhesion to the subsequent pavement layer (Alexander, 2009).

**Priming Bases That Contain Soluble Salts** (SABITA, 2006)
Adhesion of bituminous materials to pavement layers containing soluble salts can be problematic. Experience has shown that the base should be primed immediately after completion and surfaced within 24 hours using hot asphalt. The base should not be dampened before priming, as this can cause the dissolved salts to migrate to the surface and recrystallize during curing of the prime.

## Proposed Modification to

## ITEM 310

### PRIME COAT

**300.1. Description.** Prepare and treat existing or newly constructed surface with a bituminous material. Apply blotter material as required.

**300.2. Materials.**

**A. Bituminous.** Use material of the type and grade shown on the plans in accordance with Item 300, "Asphalts, Oils, and Emulsions."

**B. Blotter.** Unless otherwise shown on the plans or approved, use either base course sweepings obtained from cleaning the base or native sand as blotter materials.

**300.3. Equipment.** Provide applicable equipment in accordance with Article 316.3, "Equipment."

**300.4. Construction.**

**A. General.** Apply the mixture when the air temperature is 60°F and above, or above 50°F and rising. Measure the air temperature in the shade away from artificial heat. The Engineer will determine when weather conditions are suitable for application.

Do not permit traffic, hauling, or placement of subsequent courses over freshly constructed prime coats. Maintain the primed surface until placement of subsequent courses or acceptance of the work.

**B. Surface Preparation.** Prepare the surface by sweeping or other approved methods. ***The surface must be relatively free of loose dust and fine material prior to application of the prime coat.*** When directed, before applying bituminous material, lightly sprinkle the surface with water to control dust and ensure absorption.

**C. Application.**

1. **Bituminous.** The Engineer will select the application temperature within the limits recommended in Item 300, "Asphalts, Oils, and Emulsions." Apply material within 15°F of the selected temperature.

   Distribute the material smoothly and evenly at the rate selected by the Engineer. When directed, roll the freshly applied prime coat with a pneumatic-tire roller to ensure penetration.

2. **Blotter.** Spread blotter material before allowing traffic to use a primed surface. When "Prime Coat and Blotter" is shown on the plans as a bid item, apply blotter material to primed surface at the rate shown in the plans or as directed. When "Prime Coat" is shown on the plans as a bid item, apply blotter to spot locations or as directed to accommodate traffic movement through the work area. Remove blotter material before placing the surface. Dispose of blotter material according to applicable state and federal requirements.

3. ***Torque testing, if conducted, in a cured area should exceed the results from an untested area by more than 10%.***

**300.5. Measurement.** This Item will be measured by the gallon of bituminous material placed and accepted.

**300.6. Payment.** The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Prime Coat" or "Prime Coat and Blotter" of the type and grade of bituminous material specified. This price is full compensation for cleaning and sprinkling the area to be primed; materials, including blotter material; and rolling, equipment, labor, tools, and incidentals.

## EVALUATION OF PRIMED SURFACE

### Penetration Test Procedure

Penetration of the prime coat should be measured periodically by using a chisel to remove a small portion of the primed surface and base and measuring the depth to where the prime coat penetrated.

The prime coat is removed by making a vertical cut into the prime using a hammer and chisel, then moving over approximately one inch and making a vertical cut toward the first cut (15 degrees from vertical, with the top angled away from the first cut). This will normally cause a piece of primed material to pop out a piece of the prime surface. The measured penetration depth (in 1/16 of an inch) of the prime in the piece, or the depth as measured in the hole, whichever is deeper, is recorded. Figure C-3 presents the procedure used to measure penetration, while Figures C-4 and C-5 illustrate the procedure.

Depth of penetration does not represent the quality of the prime coat. In areas where there is much loose material, the penetration will be higher. In areas where the surface of the base is impermeable, there will be little or no penetration. Penetration does indicate appropriate adjustments to the application rate.

- Locate three or more representative areas.
- After prime has cured sufficiently so that the surface is no longer tacky (at least one hour after prime coat application), make two 2-inch long vertical slices into the base course using chisel and hammer, approximately one inch apart. A piece of base will usually debond. If no debonding occurs, retry with less separation.
- Clean area between the two cuts taking special care when removing large aggregates.
- Sweep cut area using a small whisk broom, sweeping from bottom to top and center to edge.
- Measure penetration depths at each location (brown color) using a ruler and compute average.

**Figure C-3. Procedure for Determining Penetration.**

Figure C-4. Penetration Measurement, Showing Chisel, Hammer, and Scale.

Figure C-5. Penetration of 1/16 of an Inch.

**Cohesion Test Procedure**

The application of the prime coat should improve the cohesive strength at the surface of the base and extend at least as deep as the prime coat penetration. To test this property (Figure C-6), the project team designed and constructed a device (Figures C-7 and C-8) that would impart a horizontal torque to the surface, at different vertical compressive loads, and record the load required to cause shear failure (cohesive failure) at the surface. A surface with better cohesion should resist this shear better and result in higher values. The test is designed to be a measure of relative worth; a tool for ranking the performance, not an absolute measurement. That is, at a site, the value for the primed area is compared to the value in the unprimed area, but no work was done in this limited study to determine the mechanical properties of the test or determine engineering properties. This test was developed to determine whether the primed surface had properties that were different from the unprimed surface.

The testing frame is inserted into a standard 2-inch, square tube hitch receiver and uses the weight of the vehicle to provide the reaction force. A pressure regulator and a tank of nitrogen gas control and provide the vertical load (30, 40, and 65 pounds per square inch [psi]) while a torque multiplier and torque wrench are used to apply and measure the torque required to rotate the rubber-coated foot pad through an angle of 120 degrees. The torque multiplier (18:1) is needed to impart the necessary torque, especially at the higher contact pressure.

- Locate three or more representative areas.
- After prime has cured sufficiently so that the surface is no longer tacky (at least four hours after prime coat application), insert and assemble device including foot pad, pressure regulator, torque multiplier, and torque wrench into square tube receiver.
- Lower foot pad and establish first testing pressure (30, 40, or 65 psi).
- Rotate testing device through 120 degrees in one second using torque wrench and torque multiplier.
- Record torque, raise and clean foot, and move to next location.
- Continue until three tests at three pressures for treated and untreated locations have been tested and recorded.

**Figure C-6. Procedure for Determining Penetration.**

**Figure C-7. Cohesion Device.**


**Figure C-8. Cohesion Device, Rear View.**

**Adhesion Test Procedure**

This draft field procedure has been developed for use with the Dyna Proceq™ Pull-off Tester, Z16, when used on new chip seal pavements to test the adhesion strength in direct tension on field specimens. The test should not be performed less than two hours after the seal coat was placed. Longer durations, up to 24 hours, are better.

1. Select areas to be tested. Areas should be typical of the pavement to be tested (for the prime coat testing study, areas were selected in primed and un-primed areas). Remove loose material from test area.

2. Select six (6) clean test disks.

3. Prepare two-part epoxy according to manufacturers recommendations (the prime coat study used J-B Weld, Underwater Weld).

4. Depending on the surface texture, more or less epoxy will be needed to fill the surface voids and ensure a good bond.

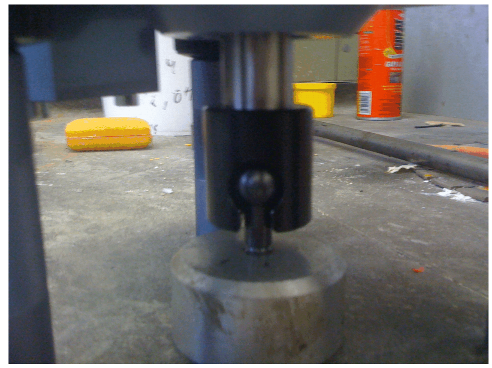
5. After mixing thoroughly, apply the epoxy to the bottom of the test disk and press into the pavement. Excess epoxy should be cleaned off with a tongue depressor or other disposable flat tool. Note time the disk was applied.

6. Repeat procedure on remaining disks.

7. Let disks cure for 30 minutes. To ensure that the test is directed at the interface and not the relatively soft fresh chip seal, one cup of ice should be placed on and just around the disk.

8. Once ice has melted, screw in small, black, test bolt with rounded head. Turn on and attach Proceq Pull-off tester, being careful not to dislodge test disk, and level test head using leg screws. The center load screw can be raised manually to engage the device.

9. Using the large black adjustment screw, bring the device in contact with the test bolt.



10. Turn crank handle until bond is broken (load returns to zero).

11. Record the maximum value.

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# APPENDIX D.
# PRESENTATION MATERIALS FOR GUIDELINES FOR SELECTION, APPLICATION, AND EVALUATION OF PRIME COATS

## GUIDELINES FOR SELECTION, APPLICATION, AND EVALUATION OF PRIME COATS

Study 0-5635, Develop Guidelines for Effective Prime Coats

## Purpose of Presentation

- Training and/or providing vital information to those responsible for priming base layers

## Purpose of Presentation

- Training and/or providing vital information to those responsible for priming base layers
- Selection of alternative priming products and processes that have demonstrated acceptable performance

## Purpose of Presentation

- Optimized preparation of the base layer to receive a prime coat

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- Optimized preparation of the base layer to receive a prime coat
- Proper application of the prime on the prepared base,

## Purpose of Presentation

- Optimized preparation of the base layer to receive a prime coat
- Proper application of the prime on the prepared base,
- Evaluation of the applied prime before construction of the subsequent pavement layer

## Prime Coat Definition

– A prime coat is defined as the application of a binder material onto the surface, or mixed into the uppermost portion of a compacted granular base, as a preliminary treatment before the application of a subsequent asphalt paving. The bituminous surface treatment may be the final pavement surface, or it may be a bituminous underseal placed before construction of a hot mix asphalt (HMA) concrete pavement surface. It is because of the availability of new non-asphalt prime materials that primes are not defined herein as bituminous materials.

## Item 310, TxDOT Specs

- PRIME COAT
  - Description. Prepare and treat existing or newly constructed surface with a bituminous material. Apply blotter material as required.
    - Materials
      - Bituminous. Use material of the type and grade shown on the plans in accordance with Item 300, "Asphalts, Oils, and Emulsions."
      - Blotter. Unless otherwise shown on the plans or approved, use either base course sweepings obtained from cleaning the base or native sand as blotter materials.

## Item 310, TxDOT Specs

- PRIME COAT
  - Equipment. Provide applicable equipment in accordance with Article 316.3, "Equipment."
  - Construction
    - General. Apply the mixture when the air temperature is 60°F and above, or above 50°F and rising. Measure the air temperature in the shade away from artificial heat. The Engineer will determine when weather conditions are suitable for application.

## Item 310, TxDOT Specs

- PRIME COAT
  - Do not permit traffic, hauling, or placement of subsequent courses over freshly constructed prime coats. Maintain the primed surface until placement of subsequent courses or acceptance of the work.

## Item 310, TxDOT Specs

- PRIME COAT
  - Surface Preparation. Prepare the surface by sweeping or other approved methods. When directed, before applying bituminous material, lightly sprinkle the surface with water to control dust and ensure absorption.
    - Application.
      - Bituminous. The Engineer will select the application temperature within the limits recommended in Item 300, "Asphalts, Oils, and Emulsions." Apply material within 15°F of the selected temperature.

## Item 310, TxDOT Specs

- PRIME COAT
  - Distribute the material smoothly and evenly at the rate selected by the Engineer. When directed, roll the freshly applied prime coat with a pneumatic-tire roller to ensure penetration.
    - Blotter. Spread blotter material before allowing traffic to use a primed surface. When "Prime Coat and Blotter" is shown on the plans as a bid item, apply blotter material to primed surface at the rate shown in the plans or as directed. When "Prime Coat" is shown on the plans as a bid item, apply blotter to spot locations or as directed to accommodate traffic movement through the work area. Remove blotter material before placing the surface. Dispose of blotter material according to applicable state and federal requirements.

## Item 310, TxDOT Specs

- PRIME COAT
  - Measurement. This Item will be measured by the gallon of bituminous material placed and accepted.
  - Payment. The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Prime Coat" or "Prime Coat and Blotter" of the type and grade of bituminous material specified. This price is full compensation for cleaning and sprinkling the area to be primed; materials, including blotter material; and rolling, equipment, labor, tools, and incidentals.

## Functions of a Prime Coat

- The main functions of a prime are to penetrate the base layer on which it is applied while leaving a small residual amount of binder on the surface to achieve the following:
  - Penetrate and seal the surface pores in the base, thus reducing the migration of moisture and absorption of the first application of surface treatment binder;
  - Protect the base from rainfall while allowing some migration of water in the vapor phase out of the base;

## Functions of a Prime Coat

- Bind finer particles on uppermost zone of base to accommodate light traffic (including construction vehicles) until new surfacing can be placed
- Promote adhesion between granular base and surface course by precoating surface of base and penetrating voids near the surface.

## Requirements of a Prime Coat

- Penetration

Good Surface, Good Penetration

Good Surface, Poor Penetration

## Requirements of a Prime Coat

- Penetration
  - Quickly
  - Amount of penetration depends on:
    - prime coating method,
    - prime coat binder,
    - base material,
    - base finishing technique, and
    - permeability of the base surface.
  - Typical penetration is 1/8 to 3/8 inch

## Penetration (Movie)

## Types of Prime Materials

- Types and grades of prime coat materials described in Item 300 of TxDOT Standard Specifications
- **Cutback Asphalts**
  - Most widely used cutback asphalt prime is MC-30.
  - RC-250 used by some districts to produce a covered prime or inverted prime
    - **Similar to a surface treatment that uses Grade 5 stone.**

## Types of Prime Materials

- Cutback Asphalts
  - Most widely used cutback asphalt prime is MC-30.
  - RC-250 used by some districts to produce a covered prime or inverted prime
    - Similar to a surface treatment that uses Grade 5 stone.
  - Penetration a problem when slush rolling employed
  - With low permeability and humid conditions, MC-30 can require one week or longer to dry or cure.
    - **In these cases, application rate should be reduced.**

## Types of Prime Materials

- **Emulsified Asphalts (SS-1, RC-250)**
  - Usually emulsion is diluted with water
  - Can be sprayed on or mixed-in with blade and rollers
    - AE-P is emulsion where asphalt is mixed with a cutter stock before being emulsified.

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    - PCE is primarily a curing seal for cement-treated bases. Not considered a traditional prime coat.

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  - Can be sprayed on or mixed-in with blade and rollers
    - AE-P is emulsion where asphalt is mixed with a cutter stock before being emulsified.
    - PCE is primarily a curing seal for cement-treated bases. Not considered a traditional prime coat.
    - EAP&T is a type of emulsified asphalt that is available in Texas, but seldom used as a prime coat.

## Types of Prime Materials

- **Proprietary Products**
  - Too many to list
  - Many new, non-asphaltic products
  - If proposed prime coat does not comply with TxDOT specifications, supplier should provide specifications against which his product can be tested for compliance.
  - These products must be approved in advance by the Engineer.

## Prime Coat Application Methods

- Spray Prime with or without Blotting Material
- Inverted Prime or Covered Prime
- Mixed-In
- Worked-in (or cut-in)

## Prime Coat Application Methods

- Spray Prime with or without Blotting Material
  - Typically MC-30 or AEP cutback
  - Sprayed on compacted base using asphalt distributor
  - Application rate ≈ 0.20 gallons per square yard
    - Depends on conditions
  - If prime will have traffic, blotting material (sand or small crushed stone) applied.

## Prime Coat Application Methods

- Inverted Prime or Covered Prime
  - Similar to a 1-course surface treatment
  - Typically RC-250
  - Sprayed onto finished base using asphalt distributor and covered by spreading Grade 5 stone
  - Application rate 0.17 to 0.20 gal/yd$^2$.
  - Particularly useful when primed surface must accommodate significant traffic or must carry traffic for a prolonged period (e.g., through the winter months).

## Prime Coat Application Methods

- Mixed-In Prime – Two methods
  - A.) During final lift of base (2 – 6"), mix in diluted emulsified asphalt instead of mixing water. After compaction to required density, skeet the surface with diluted emulsion to enrich the surface with asphalt to provide good bond with surface layer

## Prime Coat Application Methods

- B.) After base is completed up to the blue-tops and base density is achieved, scarify top 1-3", mix with diluted emulsified asphalt, then re-compact to the specified density. Skeet the surface with diluted emulsion to enrich the surface with asphalt and thus providing a reasonably good bond with the next pavement layer.

## Prime Coat Application Methods

- Method A preferred because Method B is more labor intensive
- May crush larger stones during the scarification recompaction processes
- Method B usually used to treat relatively thin layer

## Prime Coat Application Methods

- Worked-in (or cut-in) Prime
  - Diluted emulsified asphalt (SS-1, CSS-1h, MS-2) sprayed on finished base, covered with thin coating of fines
  - Windrow worked from side to side using a motor grader
  - Repeated 2-3 times to obtain an asphalt-sand layer approximately 1/8 inch thick with residual emulsion application rate of ≈ 0.20 gallons per square yard.

## Prime Coat Design

- Involves selection of an appropriate priming process, binder type, and application rate. Depends on:
  - Location of the construction project (non-attainment area)
  - Material to be primed
  - Base construction process (slush roll or blade and roll)
  - Thickness and composition of next pavement layer to be applied

## Prime Coat Design

- Involves selection of an appropriate priming process, binder type, and application rate. Depends on:
  - Experience, expertise, and equipment of available contractors
  - Probability of inclement weather while the prime coat is exposed
  - Projected need to carry significant traffic or carry traffic for a prolonged period

## Prime Coat Design

- Some agencies eliminate prime coat during cold weather
  - May be more harmful to pave over uncured prime than over unprimed base
  - Occasionally deleted when no wet weather is anticipated and base can be covered within seven days
  - Without proof, some have stated that prime may be eliminated if the subsequent HMA layer is greater than 4 inches thick

## Prime Coat Design

- Cutback asphalt primes should **not** be used on bituminous stabilized materials
- Solvents in typical prime materials can soften asphalt stabilized base and weaken pavement structure
- These types of bases should be **tacked** using emulsified asphalt
- Usually no need to prime a prepared subgrade

## Prime Selection Criteria

- Main factors that influence the selection of the optimum priming process are:
  - Type of base
  - Absorptive properties of the base
  - Environmental conditions
  - Functional conditions of the base

| Construction Situation | Priming Process | | | | |
|---|---|---|---|---|---|
| | MC-30 | AEP | Covered Prime [1] | Mixed-In Emulsion | PCR |
| Type of Base | | | | | |
| Crushed Stone | Primary | Primary | Secondary | Primary | — |
| Natural Gravel | Primary | Primary | Secondary | Primary | — |
| Caliche | Primary | Primary | Primary | Primary | — |
| Cement or Lime Stabilized | — | — | — | - | Primary |
| Slush Rolled Limestone | Primary | Secondary | — | - | — |
| Asphalt Stabilized [2] | — | — | — | - | — |
| Functional and Environmental | | | | | |
| Must carry limited traffic | — | — | Primary | Secondary | — |
| High Humidity Air | Primary | Primary | Secondary | Primary | — |
| Damp Surface | — | Secondary | — | Primary | — |
| Surface Temperature > 70°F | Primary | Primary | Primary | Primary | — |
| Surface Temperature < 70°F | Secondary | Secondary | Secondary | Primary | — |
| Properties of Base Surface | | | | | |
| Low Porosity | Secondary | Secondary | — | Primary | — |
| High Porosity | Primary | Primary | Secondary | Primary | — |
| Low Moisture Content | Primary | Primary | Secondary | Primary | — |
| High Moisture Content | — | Secondary | — | Primary | — |
| Open Graded [3] | Primary | Primary | — | - | — |

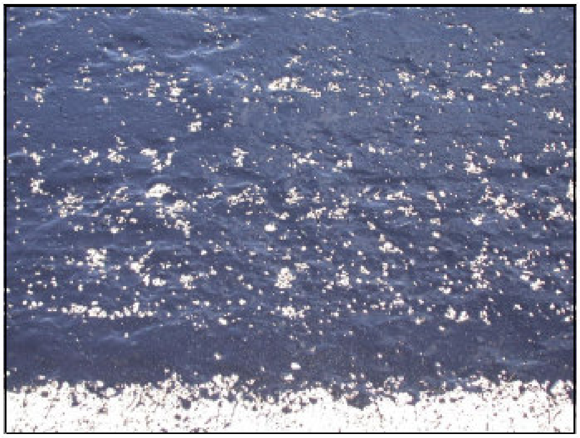
[1] RC-250 + Grade 5 stone.
[2] Apply a tack coat using regular emulsified asphalt (e.g., SS-1).
[3] Consider using two or more light applications, allowing surface to dry after each, to minimize draindown.

## Construction Considerations

- **Preparation of the Base**
  - Prime **only** after the base has dried sufficiently
    - Typically 2 percentage points below optimum for compaction
    - Item 247.4.E
    - Prevents trapping excess moisture in base
    - The base should be cleaned of all loose material, ideally, until the larger aggregate particles are exposed

## Construction Considerations

- Surface of the base should be moistened by a light sprinkling of water prior to priming
  - Reduce the surface tension
  - Avoid the formation of "perch eyes" or "freckling"
  - Avoid applying excess water
  - Voids filled with water cannot be filled with prime



## Construction Considerations

- Need Reasonably Smooth Surface
  - Not overly smooth (slush rolled)
  - Can produce a low-porosity surface
  - Inhibits penetration of prime
  - Makes weakened interface (poor bond to next layer)
- Reasonable Porosity (permeability)
  - Best achieved by blading and rolling base
  - At or slightly above optimum moisture content

Finished and cured surface should be capable of absorbing a small amount of water within a few minutes (Movie)

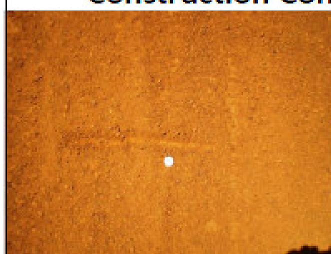
## Construction Considerations

- No Loose Dust on the Surface – Brooming must be performed carefully to avoid disturbing the larger aggregate particles at the surface of the compacted base. If the base structure is too fragile for aggressive brooming (as with some sandstones that lack fine binder material), compressed air can be used to cleanse the surface.

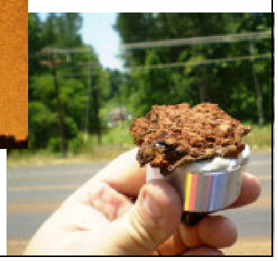
All loose material must be removed from the surface by blading (Movie)

Brooming (Movie)

## Construction Considerations



Too much loose material



## Construction Considerations

- Adequate Structural Strength
  - Base should be adequately, but only partially cured such that strength is sufficient to support construction traffic and occasional highway traffic
  - Treated/stabilized base should be completely cured before application of cutback asphalt
    - May inhibit the stabilizer curing process
  - Should be allowed to dry to 2 percentage points below optimum to enhance penetration of the prime material (Item 247.4.E)

Surface should be relatively dry and hard enough to resist scarring when using a sharp hand tool (Movie)

## Application Rate

- Rate should be so that base will absorb prime
- Leave behind thin, quick-drying film on surface
- Varies according to type of base and absorptive properties

## Application Rate

- Should be adjusted to take into consideration the net residual binder of each product.
- Formula for application rate (USACE, 2001)
  - AR = RAR / RAC

    where,
    - AR = application or shot rate of undiluted prime
    - RAR = specified residual application rate
    - RAC = residual asphalt content of prime

## Application Rate

- Typical rate
  - Cutbacks = 0.20 to 0.50 gal/yd²
  - Mixed -in emulsion = 0.1 to 0.3 gal/yd²/inch of depth
- No more prime than can be absorbed by the granular base in 24 hours. Excess prime should be removed with blotter sand.

## Application Rate

- Rule of thumb – typical application rate is a net *residual* binder of about 0.15 gal/yd² to 0.20 gal/yd² for MC-30 or AEP.

## Application Rate

- Recommended adjustments to net residual binder content (SABITA, 2006)
  - If base is coarse or open, increase the application rate by 15%
  - If base is fine and dense, decrease the application rate by 15%

## Application Rate

- Covered prime
  - increase the application rate of the RC-250 from about 0.17 gal/yd² to 0.20 gal/yd²
- Sprayed prime
  - Correct application rate can be based on simple paint test (SABITA, 2006)
    - Mark areas of one square yard
    - Apply prime with a brush at different application rates
    - Determine the ideal application rate

## Application Rate

- Mixed-in Emulsion
  - Total undiluted asphalt emulsion per inch of compacted base should be approximately 0.20 gal/yd²
  - About 0.05 gal/yd² should be applied to the surface of the base as it is being finished
  - Optimum emulsion application rate depends on gradation and absorbency of the compacted base

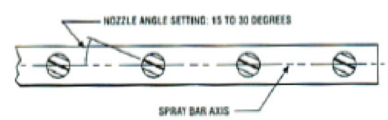
## Spraying of Prime

- Prime should **not** be sprayed if expected minimum air temperature for the next 7 days is below 50°F
- When rain is imminent
- Spray when air temperature is 60°F and above
- Above 50°F and rising
- Actual spray rate should not deviate by more than 0.013 gal/yd² from the target rate.

## Spraying of Prime

- Proper asphalt distributor procedures required to:
  - Prevent streaking,
  - Attain proper application rates, and
  - Achieve uniform coverage
- To prevent spray of liquid asphalt from interfering with adjacent spray nozzles, nozzles should be set at angle of 15 to 30 degrees to horizontal axis of the spray bar

## Spraying of Prime




- Proper Setting of Spray-Bar Nozzles (TAI, 1987).

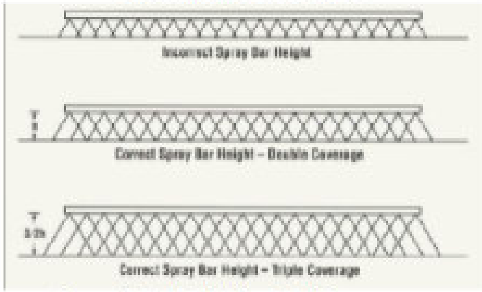
## Spraying of Prime

- Nozzles set at 30 degrees (normally)
- Spray bar height should be set to allow for an exact single, double, or triple overlap
- Double overlap recommended for most prime applications

## Spraying of Prime

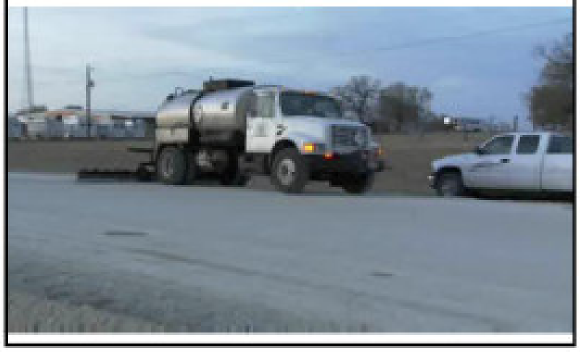
- For uniform coverage, proper spray bar height must be maintained during application
- Spray bar height must be adjustable to correct for the rising of the truck as the load decreases

## Spraying of Prime




Spray Bar Height for Ideal Coverage

Spraying of prime should include all measures to achieve a uniform application at appropriate rate (Movie)



## Spray Temperatures

- The proper viscosity of liquid primes for optimal application is achieved by heating cutbacks and occasionally emulsions or by diluting emulsions with water

| Type and Grade of Prime | Spray Temperature Range, °F |
|---|---|
| MC-30 | 85 - 150 |
| RC-250 | 125 - 180 |
| MC-250 | 125-210 |
| AE-P | 120 - 180 |
| EAP&T | 60 - 100 |
| SS-1, SS-1H, CSS-1, CSS-1H | 70 - 160 |
| MS-1, MS-2, MS-2H, CMS-2, CMS-2H | 100 - 160 |
| PCE | 60 - 160 |

## Safety Precautions

- Use caution when handling cutback prime.

## Safety Precautions

- Use caution when handling cutback prime.
- RC-250 contains naphtha and/or gasoline
  - Flash point may be as low as 80°F.
- MC-30 contains kerosene and/or diesel as the cutter
  - Flash point may be as low as 100°F.

## Safety Precautions

- Use caution when heating cutback prime prior to application
  - Spray temperature could be above the flash point
  - Prime heated **only to ensure that it flares properly when discharged** through nozzles on spray bar of the distributor.
  - Should be performed just before spraying
    - Minimize loss of the volatile fractions.

## Safety Precautions

- Cutback and emulsified primes are pumpable at ambient temperature
  - Do not need to be heated during loading, transport, off-loading, or storage.

## Curing of Prime Coat

- Prime coat should be allowed to dry before opening to traffic or proceeding with construction of the next layer
- Curing time should be no longer than necessary to permit evaporation of most of the carrier
- Excessive curing time can promote contamination of the surface with dust and debris or damage by inclement weather

## Curing of Prime Coat

- Proper curing time of prime coats depends on a number of factors
  - Type of prime material,
  - Application rate,
  - Dilution rate,
  - Application method (spray-on or mix-in),
  - Temperature,
  - Humidity,
  - Wind velocity,
  - Permeability of the base surface,
  - and other factors.

## Curing of Prime Coat

- Curing of cutbacks may require several days
- Emulsified products may require 24 hours or less
- AEP is an emulsion but contains solvent
  - Should be given ample time to cure

## Curing of Prime Coat

- Insufficient curing can allow significant volatiles to be absorbed into a subsequently constructed asphalt pavement layer
- Softens asphalt layer and reduce effectiveness
- Excessive prime (puddles) on the surface should be blinded with crusher dust *and then removed*

## Curing of Prime Coat

- Primer cannot bind loose aggregate or dust on the surface of a base
- Leaving blinding material may create weak shear plane beneath surface pavement layer

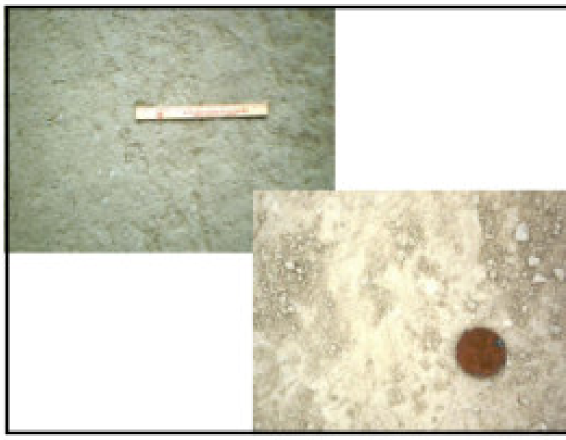
Blinding can be accomplished by hand or by using an aggregate spreader (Movie)

## Bases That Resist Penetration by Prime

- Slush rolling one of the chief causes of poor prime penetration
- Pumps fines to the surface of the base
- Does produce a very smooth base surface
- Concentration of very fine aggregate at the surface creates a thin layer with very low permeability which inhibits penetration of the prime and may produce a weakened interlayer

## Bases That Resist Penetration by Prime

- Base material that contains a significant amount of very fine material will behave same as slush rolled
- Base materials containing more than 5% minus No. 325 can resist penetration and produce poor adhesion to the subsequent pavement layer



## Priming Bases That Contain Soluble Salts

- Adhesion of prime coats bases with soluble salts can be a problem
- These bases should be primed immediately after completion
- Surfaced within 24 hours using hot asphalt
- Should **<u>not</u>** be dampened before priming

## HAPPY PRIMING!!!

## For More Information

- Project 0-5635, "Effective Prime Coats for Compacted Pavement Bases"
- Project 0-5619, "Design and Construction Guide for Surface Treatments over Base Courses"
- SemMaterials, "Penetration of Prime in Regard to Gradation of Flexible Base Materials"
- SABITA, "Interim Guidelines for Primes and Stone Precoating Fluids"

# APPENDIX E.
# RESULTS OF FIELD TESTING

| New Alignment, Odessa | | | |
|---|---|---|---|
| Mix-in | CSS-1H | 0.11gal/sy | Limestone |
| Location 1 | 30 psi | 40 psi | 65 psi |
| Test 1 | 81 | 122 | 164 |
| Test 2 | 88 | 103 | 194 |
| Test 3 | 100 | 82 | 200 |
| Average | 89.7 | 102.3 | 186.0 |
| Sdev | 9.6 | 20.0 | 19.3 |
| Range-High | 108.9 | 142.3 | 224.6 |
| Range-Low | 70.4 | 62.3 | 147.4 |
| | | | |
| | Treated | | |
| Location 2 | | | |
| Test 1 | 95 | 90 | 220 |
| Test 2 | 100 | 99 | 215 |
| Test 3 | 85 | 96 | 165 |
| Average | 93.3 | 95.0 | 200.0 |
| Sdev | 7.6 | 4.6 | 30.4 |
| Range-High | 108.6 | 104.2 | 260.8 |
| Range-Low | 78.1 | 85.8 | 139.2 |
| | 91.5 | 98.7 | 193.0 |
| | Untreated | | |
| Location 1 | | | |
| Test 1 | | | |
| Test 2 | | | |
| Test 3 | | | |
| Average | | | |
| Sdev | | | |
| Range-High | | | |
| Range-Low | | | |
| | | | |
| | Untreated | | |
| Location 2 | | | |
| Test 1 | | | |
| Test 2 | | | |
| Test 3 | | | |
| Average | | | |
| Sdev | | | |
| Range-High | | | |
| Range-Low | | | |

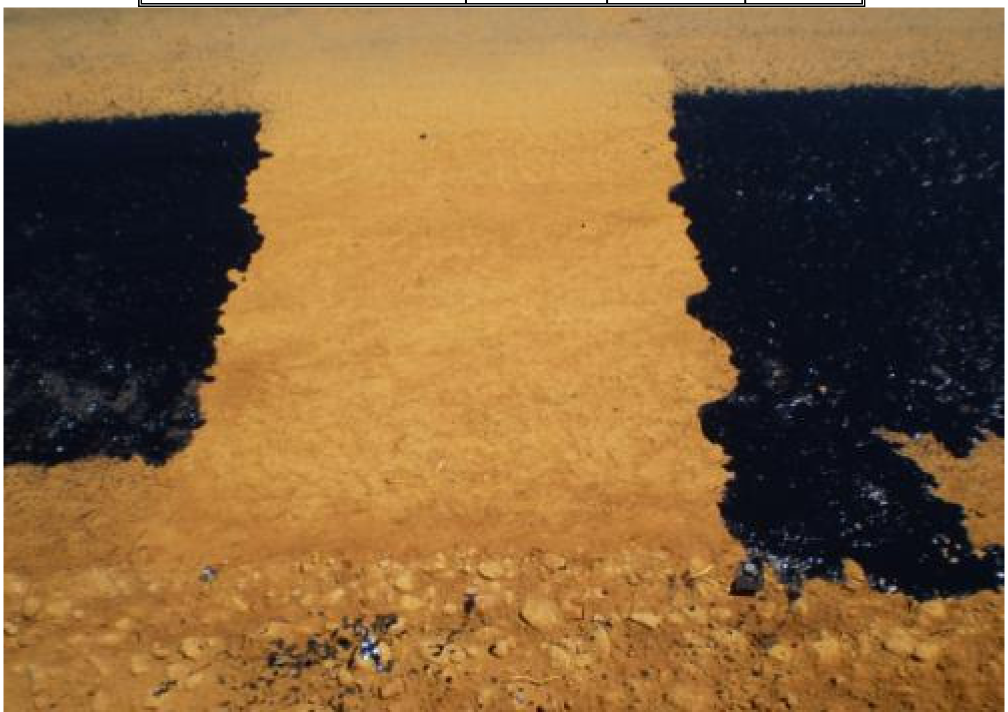
| PENETRATION | 3/16 | 1/16 | 1/16 |
|---|---|---|---|
| | | | |
| Pull Off | New Alignment, Odessa | | |
| Treated | 12 | 12 | 12 |
| Untreated | x | x | x |
| Comment | Mix-in, no untreated sections | | |

| FM 134, Near Karnack | | | |
|---|---|---|---|
| | MC-30 | 0.22gal/sy | Iron Ore |
| Location 1 | 30 psi | 40 psi | 65 psi |
| Test 1 | 74 | 84 | 109 |
| Test 2 | 70 | 80 | 110 |
| Test 3 | 82 | 85 | 112 |
| Average | 75.3 | 83.0 | 110.3 |
| Sdev | 6.1 | 2.6 | 1.5 |
| Range-High | 87.6 | 88.3 | 113.4 |
| Range-Low | 63.1 | 77.7 | 107.3 |
| | Treated | | |
| Location 2 | 30 psi | 40 psi | 65 psi |
| Test 1 | 77 | 85 | 106 |
| Test 2 | 75 | 92 | 108 |
| Test 3 | 76 | 84 | 121 |
| Average | 76.0 | 87.0 | 111.7 |
| Sdev | 1.0 | 4.4 | 8.1 |
| Range-High | 78.0 | 95.7 | 128.0 |
| Range-Low | 74.0 | 78.3 | 95.4 |
| | 75.7 | 85.0 | 111.0 |
| | Untreated | | |
| Location 1 | 30 psi | 40 psi | 65 psi |
| Test 1 | 64 | 80 | 120 |
| Test 2 | 59 | 74 | |
| Test 3 | 53 | 76 | |
| Average | 58.7 | 76.7 | 120.0 |
| Sdev | 5.5 | 3.1 | |
| Range-High | 69.7 | 82.8 | |
| Range-Low | 47.7 | 70.6 | |
| | Untreated | | |
| Location 2 | 30 psi | 40 psi | 65 psi |
| Test 1 | 74 | 94 | 142 |
| Test 2 | 72 | 100 | 123 |
| Test 3 | 53 | 103 | 137 |
| Average | 66.3 | 99.0 | 134.0 |
| Sdev | 11.6 | 4.6 | 9.8 |
| Range-High | 89.5 | 108.2 | 153.7 |
| Range-Low | 43.2 | 89.8 | 114.3 |
| | 62.5 | 87.8 | 127.0 |

| PENETRATION | 1/8 | 1/16 | 1/8 |
|---|---|---|---|
| | | | |
| Pull Off | FM 134, Near Karnack | | |
| Treated | 0 | 6 | 0 |
| Untreated | 0 | 0 | 0 |

| FM 1841, Atlanta, Cass Co | | | |
|---|---|---|---|
| | MC-30 | 0.23gal/sy | Iron Ore |
| Location 1 | 30 psi | 40 psi | 65 psi |
| Test 1 | 70 | 70 | 115 |
| Test 2 | 68 | 76 | 108 |
| Test 3 | 68 | 79 | 111 |
| Average | 68.7 | 75.0 | 111.3 |
| Sdev | 1.2 | 4.6 | 3.5 |
| Range-High | 71.0 | 84.2 | 118.4 |
| Range-Low | 66.4 | 65.8 | 104.3 |
| | Treated | | |
| Location 2 | 30 psi | 40 psi | 65 psi |
| Test 1 | 63 | 68 | 109 |
| Test 2 | 57 | 79 | 102 |
| Test 3 | 74 | 89 | 142 |
| Average | 64.7 | 78.7 | 117.7 |
| Sdev | 8.6 | 10.5 | 21.4 |
| Range-High | 81.9 | 99.7 | 160.4 |
| Range-Low | 47.4 | 57.7 | 74.9 |
| | 66.7 | 76.8 | 114.5 |
| | Untreated | | |
| Location 1 | 30 psi | 40 psi | 65 psi |
| Test 1 | 70 | 86 | 113 |
| Test 2 | 75 | 82 | 114 |
| Test 3 | 73 | 76 | 115 |
| Average | 72.7 | 81.3 | 114.0 |
| Sdev | 2.5 | 5.0 | 1.0 |
| Range-High | 77.7 | 91.4 | 116.0 |
| Range-Low | 67.6 | 71.3 | 112.0 |
| | Untreated | | |
| Location 2 | 30 psi | 40 psi | 65 psi |
| Test 1 | 71 | | |
| Test 2 | 75 | | |
| Test 3 | | | |
| Average | 73.0 | | |
| Sdev | 2.8 | | |
| Range-High | 78.7 | | |
| Range-Low | 67.3 | | |
| | 72.8 | 81.3 | 114.0 |

| PENETRATION | 1/4 | 1/4 | 1/4 |
|---|---|---|---|
| | | | |
| Pull Off | FM 1841, Atlanta, Cass Co | | |
| Treated | 0 | 0 | 6 |
| Untreated | 6 | 6 | 12 |



| SH 155, Atlanta, Big Sandy | | | |
|---|---|---|---|
| | MC-30 | 0.25gal/sy | Iron Ore |
| Location 1 | 30 psi | 40 psi | 65 psi |
| Test 1 | 57 | 72 | 86 |
| Test 2 | 59 | 77 | 80 |
| Test 3 | 68 | 74 | 95 |
| Average | 61.3 | 74.3 | 87.0 |
| Sdev | 5.9 | 2.5 | 7.5 |
| Range-High | 73.1 | 79.4 | 102.1 |
| Range-Low | 49.6 | 69.3 | 71.9 |
| | Treated | | |
| Location 2 | 30 psi | 40 psi | 65 psi |
| Test 1 | 56 | 66 | 80 |
| Test 2 | 62 | 62 | 72 |
| Test 3 | 77 | 64 | 81 |
| Average | 65.0 | 64.0 | 77.7 |
| Sdev | 10.8 | 2.0 | 4.9 |
| Range-High | 86.6 | 68.0 | 87.5 |
| Range-Low | 43.4 | 60.0 | 67.8 |
| | 63.2 | 69.2 | 82.3 |
| | Untreated | | |
| Location 1 | 30 psi | 40 psi | 65 psi |
| Test 1 | 39 | 72 | 91 |
| Test 2 | 36 | 66 | 74 |
| Test 3 | 27 | 57 | 86 |
| Average | 34.0 | 65.0 | 83.7 |
| Sdev | 6.2 | 7.5 | 8.7 |
| Range-High | 46.5 | 80.1 | 101.1 |
| Range-Low | 21.5 | 49.9 | 66.2 |
| | Untreated | | |
| Location 2 | 30 psi | 40 psi | 65 psi |
| Test 1 | 49 | 52 | 75 |
| Test 2 | 42 | 56 | 77 |
| Test 3 | 44 | 67 | 75 |
| Average | 45.0 | 58.3 | 75.7 |
| Sdev | 3.6 | 7.8 | 1.2 |
| Range-High | 52.2 | 73.9 | 78.0 |
| Range-Low | 37.8 | 42.8 | 73.4 |
| | 39.5 | 61.7 | 79.7 |

| PENETRATION | 1/8 | 1/4 | 1/16 |
|---|---|---|---|
| | | | |
| Pull Off | SH 155, Atlanta, Big Sandy | | |
| Treated | 0 | 0 | 6 |
| Untreated | 6 | 6 | 6 |

| US 59, Atlanta, South of Linden | | | |
|---|---|---|---|
| | MC-30 | 0.17gal/sy | Iron Ore |
| Location 1 | 30 psi | 40 psi | 65 psi |
| Test 1 | 82 | 105 | 147 |
| Test 2 | 76 | 91 | 210 |
| Test 3 | 57 | 105 | 183 |
| Average | 71.7 | 100.3 | 180.0 |
| Sdev | 13.1 | 8.1 | 31.6 |
| Range-High | 97.8 | 116.5 | 243.2 |
| Range-Low | 45.6 | 84.2 | 116.8 |
| | Treated | | |
| Location 2 | 30 psi | 40 psi | 65 psi |
| Test 1 | 54 | 137 | |
| Test 2 | 68 | 104 | |
| Test 3 | 57 | 75 | |
| Average | 59.7 | 105.3 | |
| Sdev | 7.4 | 31.0 | |
| Range-High | 74.4 | 167.4 | |
| Range-Low | 44.9 | 43.3 | |
| | 65.7 | 102.8 | 180.0 |
| | Untreated | | |
| Location 1 | 30 psi | 40 psi | 65 psi |
| Test 1 | 57 | 54 | 100 |
| Test 2 | 62 | 50 | 94 |
| Test 3 | 61 | 51 | 77 |
| Average | 60.0 | 51.7 | 90.3 |
| Sdev | 2.6 | 2.1 | 11.9 |
| Range-High | 65.3 | 55.8 | 114.2 |
| Range-Low | 54.7 | 47.5 | 66.5 |
| | Untreated | | |
| Location 2 | 30 psi | 40 psi | 65 psi |
| Test 1 | 57 | 76 | 112 |
| Test 2 | 61 | 67 | 74 |
| Test 3 | 58 | 71 | 72 |
| Average | 58.7 | 71.3 | 86.0 |
| Sdev | 2.1 | 4.5 | 22.5 |
| Range-High | 62.8 | 80.4 | 131.1 |
| Range-Low | 54.5 | 62.3 | 40.9 |
| | 59.3 | 61.5 | 88.2 |

| PENETRATION | 1/8 | 1/4 | 1/4 |
|---|---|---|---|
| | | | |
| Pull Off | US9, Atlanta, South of Linden | | |
| Treated | x | x | x |
| Untreated | x | x | x |
| Comment | overlaid with no warning | | |

| SH 6, Waco, South of Marlin | | | |
|---|---|---|---|
| | MC-30 | 0.20gal/sy | Limestone |
| Location 1 | 30 psi | 40 psi | 65 psi |
| Test 1 | 32 | 50 | 112 |
| Test 2 | 48 | 41 | 110 |
| Test 3 | 43 | 50 | 85 |
| Average | 41.0 | 47.0 | 102.3 |
| Sdev | 8.2 | 5.2 | 15.0 |
| Range-High | 57.4 | 57.4 | 132.4 |
| Range-Low | 24.6 | 36.6 | 72.2 |
| | Treated | | |
| Location 2 | 30 psi | 40 psi | 65 psi |
| Test 1 | 64 | 66 | 100 |
| Test 2 | 65 | 53 | |
| Test 3 | 47 | | |
| Average | 58.7 | 59.5 | 100.0 |
| Sdev | 10.1 | 9.2 | |
| Range-High | 78.9 | 77.9 | |
| Range-Low | 38.4 | 41.1 | |
| | 49.8 | 53.3 | 101.2 |
| | Untreated | | |
| Location 1 | 30 psi | 40 psi | 65 psi |
| Test 1 | 75 | 112 | 150 |
| Test 2 | 80 | 97 | 146 |
| Test 3 | 84 | 87 | |
| Average | 79.7 | 98.7 | 148.0 |
| Sdev | 4.5 | 12.6 | 2.8 |
| Range-High | 88.7 | 123.8 | 153.7 |
| Range-Low | 70.6 | 73.5 | 142.3 |
| | Untreated | | |
| Location 2 | 30 psi | 40 psi | 65 psi |
| Test 1 | 83 | 84 | 157 |
| Test 2 | 85 | 107 | 125 |
| Test 3 | 82 | 101 | 144 |
| Average | 83.3 | 97.3 | 142.0 |
| Sdev | 1.5 | 11.9 | 16.1 |
| Range-High | 86.4 | 121.2 | 174.2 |
| Range-Low | 80.3 | 73.5 | 109.8 |
| | 81.5 | 98.0 | 145.0 |

| PENETRATION | 2/16 | 1/16 | 2/16 |
|---|---|---|---|
| | | | |
| Pull Off | SH 6, Waco, South of Marlin | | |
| Treated | x | x | x |
| Untreated | x | x | x |
| Comment | overlaid with no warning | | |

| SH 31, @US 84, Waco | | | |
|---|---|---|---|
| | EC-30 Prime | 0.20gal/sy | Limestone |
| Location 1 | 30 psi | 40 psi | 65 psi |
| Test 1 | 70 | 80 | 135 |
| Test 2 | 72 | 96 | 124 |
| Test 3 | 75 | 105 | 165 |
| Average | 72.3 | 93.7 | 141.3 |
| Sdev | 2.5 | 12.7 | 21.2 |
| Range-High | 77.4 | 119.0 | 183.8 |
| Range-Low | 67.3 | 68.3 | 98.9 |
| | Treated | | |
| Location 2 | 30 psi | 40 psi | 65 psi |
| Test 1 | 75 | 107 | 200 |
| Test 2 | 73 | 123 | 135 |
| Test 3 | 77 | 108 | 115 |
| Average | 75.0 | 112.7 | 150.0 |
| Sdev | 2.0 | 9.0 | 44.4 |
| Range-High | 79.0 | 130.6 | 238.9 |
| Range-Low | 71.0 | 94.7 | 61.1 |
| | 73.7 | 103.2 | 145.7 |
| | Untreated | | |
| Location 1 | 30 psi | 40 psi | 65 psi |
| Test 1 | 62 | 60 | 110 |
| Test 2 | 50 | 64 | 155 |
| Test 3 | 65 | 59 | 107 |
| Average | 59.0 | 61.0 | 124.0 |
| Sdev | 7.9 | 2.6 | 26.9 |
| Range-High | 74.9 | 66.3 | 177.8 |
| Range-Low | 43.1 | 55.7 | 70.2 |
| | Untreated | | |
| Location 2 | 30 psi | 40 psi | 65 psi |
| Test 1 | 63 | 90 | 145 |
| Test 2 | 73 | 85 | 124 |
| Test 3 | 75 | 93 | 91 |
| Average | 70.3 | 89.3 | 120.0 |
| Sdev | 6.4 | 4.0 | 27.2 |
| Range-High | 83.2 | 97.4 | 174.4 |
| Range-Low | 57.5 | 81.3 | 65.6 |
| | 64.7 | 75.2 | 122.0 |

| PENETRATION | 2/16 | 1/16 | 1/16 |
|---|---|---|---|
| | | | |
| Pull Off | SH 31, @US 84, Waco | | |
| Treated | x | x | x |
| Untreated | x | x | x |
| Comment | After Project Over | | |

| IH 45 NBFR, Wilson Road | | | |
|---|---|---|---|
| | Treated | | |
| Location 1 | 30 psi | 40 psi | 65 psi |
| Test 1 | 60 | 91 | 160 |
| Test 2 | 74 | 92 | 137 |
| Test 3 | 63 | 94 | 146 |
| Average | 65.7 | 92.3 | 147.7 |
| Sdev | 7.4 | 1.5 | 11.6 |
| Range-High | 80.4 | 95.4 | 170.8 |
| Range-Low | 50.9 | 89.3 | 124.5 |
| | Treated | | |
| Location 2 | 30 psi | 40 psi | 65 psi |
| Test 1 | 60 | 96 | 158 |
| Test 2 | 56 | 92 | 127 |
| Test 3 | 65 | 87 | 108 |
| Average | 60.3 | 91.7 | 131.0 |
| Sdev | 4.5 | 4.5 | 25.2 |
| Range-High | 69.4 | 100.7 | 181.5 |
| Range-Low | 51.3 | 82.6 | 80.5 |
| | 63.0 | 92.0 | 139.3 |
| | Untreated | | |
| Location 1 | 30 psi | 40 psi | 65 psi |
| Test 1 | 54 | 85 | 100 |
| Test 2 | 64 | 83 | 105 |
| Test 3 | 55 | 50 | 115 |
| Average | 57.7 | 72.7 | 106.7 |
| Sdev | 5.5 | 19.7 | 7.6 |
| Range-High | 68.7 | 112.0 | 121.9 |
| Range-Low | 46.7 | 33.4 | 91.4 |
| | Untreated | | |
| Location 2 | 30 psi | 40 psi | 65 psi |
| Test 1 | | | |
| Test 2 | | | |
| Test 3 | | | |
| Average | | | |
| Sdev | | | |
| Range-High | | | |
| Range-Low | | | |

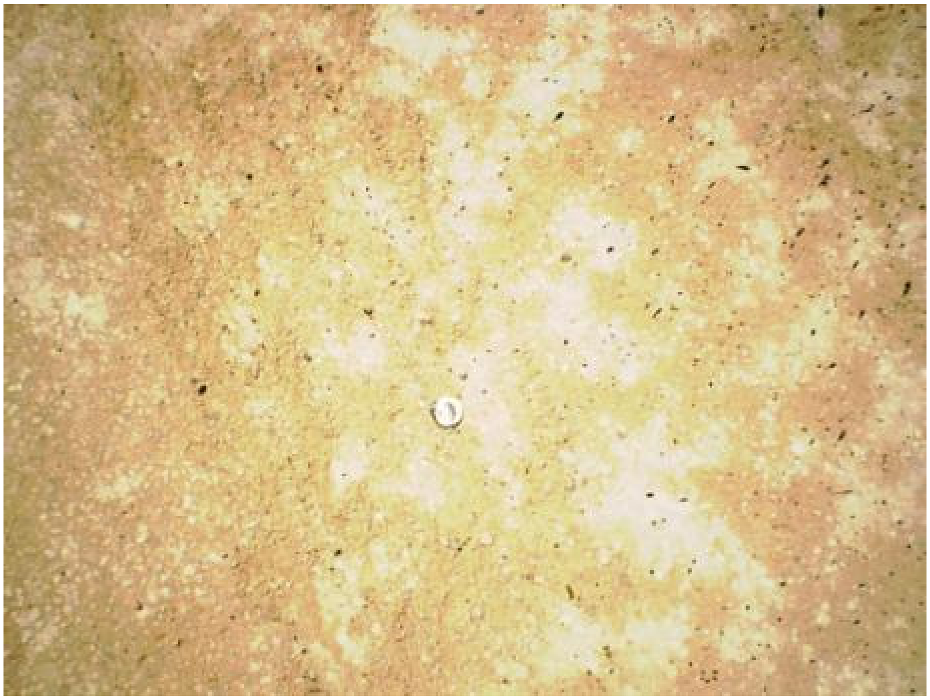
| **PENETRATION** | **1/16** | **1/16** | **1/16** |
|---|---|---|---|
| | | | |
| Pull Off | IH 45 NBFR, Wilson Road | | |
| Treated | x | x | x |
| Untreated | x | x | x |

| SH 6 Frontage Road, Bryan | | | |
|---|---|---|---|
| | AEP | AEP | AEP |
| Location 1 | 30 psi | 40 psi | 65 psi |
| Test 1 | 58 | 59 | 75 |
| Test 2 | 50 | 59 | 100 |
| Test 3 | 52 | 71 | 91 |
| Average | 53.3 | 63.0 | 88.7 |
| Sdev | 4.2 | 6.9 | 12.7 |
| Range-High | 61.7 | 76.9 | 114.0 |
| Range-Low | 45.0 | 49.1 | 63.3 |
| | Treated | | |
| Location 2 | 30 psi | 40 psi | 65 psi |
| Test 1 | | | |
| Test 2 | | | |
| Test 3 | | | |
| Average | | | |
| Sdev | | | |
| Range-High | | | |
| Range-Low | | | |
| Type Average | | | |
| | Untreated | | |
| Location 1 | 30 psi | 40 psi | 65 psi |
| Test 1 | 78 | 115 | 143 |
| Test 2 | 77 | 95 | 145 |
| Test 3 | 74 | 77 | 141 |
| Average | 76.3 | 95.7 | 143.0 |
| Sdev | 2.1 | 19.0 | 2.0 |
| Range-High | 80.5 | 133.7 | 147.0 |
| Range-Low | 72.2 | 57.6 | 139.0 |
| | Untreated | | |
| Location 2 | 30 psi | 40 psi | 65 psi |
| Test 1 | 55 | 96 | 135 |
| Test 2 | 77 | 100 | 125 |
| Test 3 | 75 | 107 | 136 |
| Average | 69.0 | 101.0 | 132.0 |
| Sdev | 12.2 | 5.6 | 6.1 |
| Range-High | 93.3 | 112.1 | 144.2 |
| Range-Low | 44.7 | 89.9 | 119.8 |
| Type Average | 72.7 | 98.3 | 137.5 |

| **PENETRATION** | **1/16** | **1/8** | **1/8** |
|---|---|---|---|
| | | | |
| Pull Off | SH 6 Frontage Road, Bryan | | |
| Treated | 0 | 6 | 6 |
| Untreated | 6 | 0 | 0 |

| FM 1235, Abilene, 1.2 mi SE of US 277, MC-30 and AEP | | | |
|---|---|---|---|
| | MC-30 | | |
| Location 1 | 20 psi | 50 psi | 80 psi |
| Test 1 | 73 | 164 | 225 |
| Test 2 | 74 | 164 | 224 |
| Test 3 | | | |
| Average | 73.5 | 164.0 | 224.5 |
| Sdev | 0.7 | 0.0 | 0.7 |
| Range-High | 74.9 | 164.0 | 225.9 |
| Range-Low | 72.1 | 164.0 | 223.1 |
| | | | |
| | AEP | | |
| Location 2 | 20 psi | 50 psi | 80 psi |
| Test 1 | 57 | 185 | 223 |
| Test 2 | 48 | 131 | 208 |
| Test 3 | | | |
| Average | 52.5 | 158.0 | 215.5 |
| Sdev | 6.4 | 38.2 | 10.6 |
| Range-High | 65.2 | 234.4 | 236.7 |
| Range-Low | 39.8 | 81.6 | 194.3 |
| | | | |
| | Untreated | | |
| Location 1 | 20 psi | 50 psi | 80 psi |
| Test 1 | 57 | 117 | 225 |
| Test 2 | 52 | 122 | 167 |
| Test 3 | | | |
| Average | 54.5 | 119.5 | 196.0 |
| Sdev | 3.5 | 3.5 | 41.0 |
| Range-High | 61.6 | 126.6 | 278.0 |
| Range-Low | 47.4 | 112.4 | 114.0 |
| | Untreated | | |
| Location 2 | 20 psi | 50 psi | 80 psi |
| Test 1 | | | |
| Test 2 | | | |
| Test 3 | | | |
| Average | | | |
| Sdev | | | |
| Range-High | | | |
| Range-Low | | | |

| PENETRATION | AEP 3/16, 3/16, 3/16 | MC-30 2/16, 2/16, 2/16 | |
|---|---|---|---|
| | | | |
| Pull Off | FM 1235, Abilene, 1.2 mi SE of US 277, MC-30 and AEP | | |
| MC30 | 17 | 18 | |
| Untreated | 6 | 6 | |
| AEP | 0 | 6 | |



| IH 20FR, Brownwood, Strawn | | | |
|---|---|---|---|
| | AEP | 0.30gal/sy | Limestone |
| Location 1 | 30 psi | 40 psi | 65 psi |
| Test 1 | 37 | 65 | 137 |
| Test 2 | 38 | 57 | 81 |
| Test 3 | 44 | 71 | 95 |
| Average | 39.7 | 64.3 | 104.3 |
| Sdev | 3.8 | 7.0 | 29.1 |
| Range-High | 47.2 | 78.4 | 162.6 |
| Range-Low | 32.1 | 50.3 | 46.0 |
| | Treated | | |
| Location 2 | 30 psi | 40 psi | 65 psi |
| Test 1 | tearing up surface insp said "off" | | |
| Test 2 | | | |
| Test 3 | | | |
| Average | | | |
| Sdev | | | |
| Range-High | | | |
| Range-Low | | | |
| | Untreated | | |
| Location 1 | 30 psi | 40 psi | 65 psi |
| Test 1 | 50 | 52 | 186 |
| Test 2 | 51 | 64 | 127 |
| Test 3 | 59 | 60 | 96 |
| Average | 53.3 | 58.7 | 136.3 |
| Sdev | 4.9 | 6.1 | 45.7 |
| Range-High | 63.2 | 70.9 | 227.8 |
| Range-Low | 43.5 | 46.4 | 44.9 |
| | Untreated | | |
| Location 2 | 30 psi | 40 psi | 65 psi |
| Test 1 | 60 | 84 | 99 |
| Test 2 | 51 | 66 | 128 |
| Test 3 | 58 | 71 | 100 |
| Average | 56.3 | 73.7 | 109.0 |
| Sdev | 4.7 | 9.3 | 16.5 |
| Range-High | 65.8 | 92.2 | 141.9 |
| Range-Low | 46.9 | 55.1 | 76.1 |
| | 54.8 | 66.2 | 122.7 |

| **PENETRATION** | **3/16** | **2/16** | **3/16** |
|---|---|---|---|
| | | | |
| Pull Off | IH 20FR, Brownwood, Strawn | | |
| Treated | x | x | x |
| Untreated | x | x | x |
| Comment | contractor crew sealed bare spots | | |

| US 283, Brownwood, N of Coleman | | | |
|---|---|---|---|
| Mix in | AEP | 0.40gal/sy | Limestone |
| Location 1 | 30 psi | 40 psi | 65 psi |
| Test 1 | 91 | 174 | too hard |
| Test 2 | 93 | 116 | too hard |
| Test 3 | 88 | 118 | too hard |
| Average | 90.7 | 136.0 | |
| Sdev | 2.5 | 32.9 | |
| Range-High | 95.7 | 201.8 | |
| Range-Low | 85.6 | 70.2 | |
| | Treated | | |
| Location 2 | 30 psi | 40 psi | 65 psi |
| Test 1 | 93 | 121 | too hard |
| Test 2 | 100 | 127 | too hard |
| Test 3 | 98 | 148 | too hard |
| Average | 97.0 | 132.0 | |
| Sdev | 3.6 | 14.2 | |
| Range-High | 104.2 | 160.4 | |
| Range-Low | 89.8 | 103.6 | |
| | 93.8 | 134.0 | |
| | Untreated | | |
| Location 1 | 30 psi | 40 psi | 65 psi |
| Test 1 | 80 | 120 | 110 |
| Test 2 | 77 | 165 | 165 |
| Test 3 | 68 | 124 | 180 |
| Average | 75.0 | 136.3 | 151.7 |
| Sdev | 6.2 | 24.9 | 36.9 |
| Range-High | 87.5 | 186.1 | 225.4 |
| Range-Low | 62.5 | 86.5 | 78.0 |
| | Untreated | | |
| Location 2 | 30 psi | 40 psi | 65 psi |
| Test 1 | 79 | 107 | traffic control lost |
| Test 2 | 63 | 130 | |
| Test 3 | 84 | 110 | |
| Average | 75.3 | 115.7 | |
| Sdev | 11.0 | 12.5 | |
| Range-High | 97.3 | 140.7 | |
| Range-Low | 53.4 | 90.7 | |
| | 75.2 | 126.0 | 151.7 |

| **PENETRATION** | **8/16** | **7/16** | **7/16** |
| --- | --- | --- | --- |
| | | | |
| Pull Off | US 283, Brownwood, N of Coleman | | |
| Treated | 6 | 12 | 6 |
| Untreated | x | x | x |
| Comment | mix in, no untreated | | |